The Nature of Scientific Laws

by

Yang Zhao

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Department of Philosophy

University of Alberta

Abstract

My thesis is about the nature of natural laws. My view of scientific laws, as you have seen, is very different from the traditional theories of laws. My methods in this paper are very similar in style to Russell's discussions of laws and science since we both pay attention to actual scientific practices and we both carry out a detailed analysis of scientific knowledge as the basis of further investigations.

My investigations in this paper start from the most elementary or basic components of scientific knowledge, that is, scientific quantities. More specifically, I worked on physical quantities because physics is the origin and representative of modern science. The most important point I made about quantities is that they are fundamentally different from qualities, internal or relational. Unlike quality, which is a "static" concept, a quantity captures some aspect of physical changes. Correspondingly, scientific laws, which are composed by quantities, depend on physical changes such as motions as well. The basis of laws is not any individuals, but rather an event or a

fact as a whole. As a result, the whole metaphysical picture underlying laws of nature is different. The world of objects with their properties is replaced by the world of motions with quantities. I am not denying the validity of the original world picture. It is just that this is not the world conceived by science.

This new understanding of laws also leads to new explications of causation and idealization as given in the last chapter of the paper. As I have argued in the paper, singular causal facts depend substantially on non-causal scientific laws. However, it is not that we directly have a law which connects the cause with the effect. Rather, scientific laws only feature indirectly here. If the quantities that originally describe different facts are finally combined and subsumed by a single law, then we can say these two facts have a causal relation.

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Introduction

The topic of my thesis is the nature of natural laws. That is, I aim to solve the question what the metaphysical basis of natural laws is. Although my discussion is primarily concerned with physical laws, it also works for any law that can be given in the form of mathematical equations.

There have been many different theories featuring in this debate, such as the Humean theory, the essentialist theory and the dispositionalist theory. Recent discussions in this area focus more on the methodological or epistemological side of this issue. However, I do not think that the metaphysical question of what a law of nature is can be indirectly answered or simply replaced by other questions. Therefore, my project is not an epistemological one of how we conceive of natural laws or a methodological one about how we actually carry out scientific practice. An understanding of the nature of natural laws is exactly what I aim to achieve in this discussion.

What I aim to argue for in this thesis is that scientific laws depict mathematical structures of facts. As equations, they are mathematical in nature. However, they also reflect structures of actual facts in the empirical world. My arguments mainly depend on a detailed analysis of the content of natural laws, especially quantities involved in laws, and the scientific practice of measurement. Specifically, in the first chapter, I will give a brief introduction to the main kinds of theories of laws. In the next chapter, I will show some theoretical problems with the traditional views of laws, especially the universalist and dispositionalist theories; that is, the problems they have just considering the theories themselves. Then in the third chapter, I will investigate the nature of quantities involved in scientific laws and argue that they are essentially different from qualities. In the fourth chapter, I will be ready to explicate laws themselves. The main idea is that like quantities, laws are ontologically based on physical facts as well. Finally, I will clarify my position by further specifying some features of laws understood as such. I will also discuss problems related to causal explanation and idealizations of laws.

Chapter 1. Introducing traditional theories of laws

Traditionally, there are mainly three kinds of competing theories of scientific laws, namely universalist theories, dispositionalist theories and Humean theories. Each kind has been developed into many versions, which I could not cover completely in this thesis. In what follows, I will only give a brief statement of the thrust of these three kinds of theories.

First, I introduce the universalist theory, proposed by Armstrong, Fred Dretske and Michal Tooley. It takes a law to be a necessary relation between properties or universals. Laws are “universals themselves possessing or being related by higherorder universals"[1]. Specifically, "Suppose it to be a law that Fs are Gs. F-ness and G-ness are taken to be universals. A certain relation, a relation of non-logical or contingent necessitation, holds between F-ness and G-ness. This state of affairs may be symbolized as 'N(F,G)'"[2] Here, symbols such as F and G stand for universals, which are exactly speaking properties. Note here that the necessity universalists accord to laws is physical necessity. In other words, universalists believe that laws could have been different from what they actually are now. A more precise formulation of a (deterministic) law, as given by Armstrong himself, is that "something's being F and having R to a further thing of the sort G causes the further thing to become H"[3]. Correspondingly, an example of a law that he used for illustration is "guillotining causes the guillotined to be immediately decapitated"[4].

Then there is the dispositionalist theory of laws. Many people including Nancy Cartwright and Alexander Bird have defended such a view. Simply put, such theories base natural laws on dispositional properties. Borrowing Schrenk's words, "when an object has such a dispositional property, it reacts with a certain manifestation when triggered, i.e., when being in certain stimulus conditions"[5]. This strategy looks more promising than the essentialist theory in that it seems to be able to apply to fundamental physical laws. For example, in explaining the second law of motion, i.e.,

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1 See Bird (2007), p 2.
2 See Armstrong (1983), p 85.
3 See Armstrong (1997), p 225.
4 ibid. p 227.
5 See Schrenk (2016), p 224.

“in an inertial reference frame, the vector sum of the forces *F* on an object is equal to the mass *m* of that object multiplied by the acceleration *a* of the object”[6], dispositionalists would treat the forces as having the disposition of bringing about such and such acceleration for a given mass. So it is a law that the force is equal to the mass multiplied by the acceleration because this is necessitated by the dispositional property of the force.

Finally there are the Humean or regularity theories. Included in this category are theories such as those of Frank Ramsey, David Lewis and John Earman. “According to Lewis’s regularity theory, ultimately all there is in the world are individual things possessing the properties (among which I include relations) that they do. Laws are not anything extra in addition to the things possessing their properties. Rather the laws are just certain regular patterns of things possessing properties”[7]. At the same time, law statements are to be distinguished from mere regularities. Many strategies have been taken by the Humean to achieve this goal. For example, “Laws are regularities that fit into or may be derived from the optimal systematization of the facts concerning individual things.”[8] This theory is thus also called the Best System Account[9]. For example, that objects expand when heated is a law because it is always the case that objects expand when heated and also because this fact “belongs to a systematic and

[6] See https://en.wikipedia.org/wiki/Newton%27s_laws_of_motion.
[7] See Bird (2007), p 1.
[8] ibid.
[9] See Markus (2016), p 136.

organized set of regularities (which we dignify as the laws of nature)"[10]. For people holding this view, law statements are simply universally quantified statements of the form $\forall x\ (Fx \rightarrow Gx)$, where F and G stand for properties of objects. For example, F might stand for being a metal and G stands for having a specific melting point.

The divergence between Humean theories and the first two kinds is a metaphysical one, that is, the ontological basis of natural laws. While the universalist and the dispositionalist theories take laws to be "themselves a certain kind of *sui generis* fact"[11], Humean theorists give no special ontological status to natural laws over and above regularities that happen to obtain in the actual world. According to them, laws of nature are just generalized from and supervene on the totality of local matters of particular fact. As Ayer's comments nicely concludes, for Humean theories, "the distinction between accidentally true sentences and lawlike statements becomes a more pragmatic issue: we might want to call those universal statements that we find more useful for predictions, explanations, counterfactual reasoning, etc. laws. Objectively, however, these laws are really not separated from the accidents by any profound ontological gap"[12].

However, there is one commonality to all these theories of laws that needs special attention, that is, fundamentally it is properties of objects that feature in the

[10] See Armstrong (1997), p 223.
[11] See Bird (2007), p 2.
[12] See Ayer (1963), p 230.

ontological story of laws. This is obvious in universalist and dispositionalist theories which base laws on properties of objects. This is also the case in Humean theories. Although apparently they are talking about particular facts, these facts are still facts about objects possessing their properties. Similarly, although Armstrong characterizes universals in laws as state-of-affairs types, they are still essentially properties.

As a result, we can see that all these three kinds of theories take laws to be about properties of things. It is one of their fundamental presuppositions that "laws concern the properties of things"[13]. For example, as analyzed by Bird, "the law of gravity tells us how the force on an object depends on its mass and the mass of other objects as well as their separations; Kirchhoff's laws tell us how the current, electromotive force, and impedance in electrical circuits are related, where those quantities are properties of the circuit or its parts; the laws of thermodynamics relate the thermal properties, such as heat, entropy, and temperature of substances and systems."[14] This supposition about the form and content of laws is the basis of all their further discussions, which disagree on the nature of properties. However, despite its importance, this supposition has never been questioned or seriously examined. It is exactly my goal of this paper to cast doubt on this presupposition. I want to demonstrate that laws are not about properties of objects, but motions of objects.

[13] See Bird (2007), p 1.
[14] Ibid.

The Humean attempt of trying to connect laws with particular matters of facts, I think, is worth pursuing because it respects our actual discovery of scientific laws and is also ontologically more economic compared with the other two approaches. However, I contend that Humeans have focused on the wrong kinds of facts and employed the wrong strategies for connecting laws with particular facts. They have not shown clearly how these two are actually related. This not only constitutes a defeat of these theories themselves, it also makes such theories unable to explain features we normally attribute to laws such as necessity, universality and causal explanation. This is exactly my goal in this thesis, to specify the relation between natural laws and physical facts, showing how natural laws are extracted from particular facts and how they have the features that we expect.

Among the various more complicated and mature versions of theories of laws developed from refining the three "naive" theories sketched above, two of them are of particular interest to me, which are Nancy Cartwright's and Russell's views of laws.

Cartwright made many interesting distinctions in her discussions of laws, such as fundamental laws versus phenomenal laws, which is of special importance. Phenomenal laws merely describe what happens while fundamental laws are basic equations that explain. Typical examples of fundamental laws are abstract equations of physics. In Section IV.2. below about the form of laws, I will discuss this distinction and show why it is problematic. Theoretical laws are abstract capacity claims. “The great explanatory and predictive powers of our theories lies in their fundamental laws. Nevertheless the *content* of our scientific knowledge is expressed in the phenomenological laws”[15]. Her main idea is that “the theoretical laws of physics are false and inaccurate in contrast to the phenomenological ones”[16]. “The fundamental laws of physics do not describe true facts about reality”[17].

This view of laws is intimately related with her standpoint on scientific explanation. As contended by her, “the manifest explanatory power of fundamental laws does not argue for their truth. In fact the way they are used in explanation argues for their falsehood. We explain by *ceteris paribus* laws, by composition of causes, and by approximations that improve on what the fundamental laws dictate. In all of these cases the fundamental laws patently do not get the facts right”[18]. I hold exactly the opposite view. I will argue that fundamental laws of science are true and correspondingly, I will propose a new understanding of scientific explanation in Chapter V.

One great contribution of Russell’s discussion to our understanding of natural laws are his speculations on the notion of cause and his insight that laws are in the form of differential equations. His arguments against causation have been nicely summarized

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15 See Cartwright (1983), p 101.
16 See Nugayev (1991), p 79.
17 Ibid. p 54.
18 See Cartwright (1983), p 3.

by Corry as “the asymmetry argument” and “the intervention argument”[19]. The asymmetry argument, as explicated by Corry, is as follows. “Causal laws describe relations of determination between cause and effect (or alternatively they describe probability-raising relations). Furthermore, the cause-effect relation is essentially asymmetric—being a cause is quite different from being an effect. The fundamental equations of physics, on the other hand, are (almost) completely time symmetric:
if the state of a system at time t determines the future states of the system according to these equations, then it will equally determine the past states of the system. Thus, we must conclude that the causal relation is not one of the determination relations described by the equations of physics.”[20] This argument thus calls into doubt laws conceived as having the form “A causes B”. The intervention argument also questions the plausibility of conceiving causal laws as stating “that when one type of event occurs, some other particular type of event will occur”[21]. Simply put, it points out a dilemma about laws. On the one hand, “if a law is to be informative or useful, then the events mentioned by the law must be the kind of things that can be repeated”[22], which contradicts the fact that “the state of our entire universe at any time has not and will not be repeated”[23]. On the other hand, “if we do not include a very large amount of information about the state of the universe in our statement of a causal law, then it is

[19] See Corry (2006), p 263.
[20] See Corry (2006), p 263.
[21] Ibid. p 264.
[22] Ibid.
[23] Ibid.

always possible that the cause described by a causal law could occur, but something else could intervene to prevent the effect from happening"[24].

Of equal importance is his detailed investigation of scientific concepts such as force, energy, etc. and scientific laws including the law of inertia and the relativity theory. It is from these examinations, i.e., "causal laws of physics should be stated in terms of acceleration"[25] and "acceleration being the second differential of the position with respect to time"[26], that Russell reaches the conclusion that "causal laws of dynamics must be differential equations of the second order"[27].

My own explication of scientific laws shares the same spirit with Russell's. I agree with his doubts about the traditional concept of cause. My discussions in this paper also involve much consideration of actual scientific practice and laws. So this paper can be seen as a supplement and enhancement to Russell's discussion, by giving a substantial theory of the ontological basis of scientific laws. My arguments provide detailed proofs of why scientific laws are in the form of differential equations. A new understanding of causation is proposed as well.

[24] Ibid.
[25] See Russell (2009), p 20.
[26] Ibid. p 21.
[27] Ibid.

Chapter II. Problems with traditional theories of laws themselves

In this chapter, I will point out some inherent problems of the traditional theories of laws. I will put the universalist theory and the dispositionalist theory of natural laws in the same category in so far as they both take some features of properties of objects to be the underpinnings of natural laws. Indeed, they are both objectionable in so far as they resort to properties to explain why a certain natural law holds at all. As a result, in what follows, I will examine these two theories at the same time.

First is the universalist theory, represented by Armstrong. It takes a law to be a necessary relation between properties or universals. For example, "Suppose it to be a law that Fs are Gs. F-ness and G-ness are taken to be universals. A certain relation, a relation of non-logical or contingent necessitation, holds between F-ness and G-ness. This state of affairs may be symbolized as 'N(F,G)'". Take the law of thermal expansion as an example. Universalists would say that "whenever a rod is heated, it expands" is a law because there is a necessary relation between the universal/property being heated and the universal/property undergoing expansion. This seems, prima facie, a tenable explanation of laws and nicely distinguishes law statements from mere generalizations. However, the strength of such an explanation is revealed to be illusory once we take a closer look at it.

First there is an objection to this theory in its abstract form. As has been pointed out by Nancy Cartwright, generally laws have "*ceteris paribus* modifiers". Only when the if-clause is added to the original statement is it a complete expression of the law. So instead of "Fs are Gs", we should say "*ceteris paribus*, Fs are Gs". One implication of this is that the F and the G are not just related with each other and isolated from all other properties. Other properties or universals are related to the F or the G and they also have an influence on the relation between the F and the G. This fact, then, has to be included into the content of the law, besides the explicitly stated F-G relation. To account for this, the universalists have two possible strategies. They could either add a negative relation, such as an excluding relation, between other properties/universals and the F and G. Or, they can treat it to be a relation between negative entities, i.e., non-existent properties/universals and the F and G. Either way, however, the resultant interpretation of laws would be undesirably complex and essentialists would also have insurmountable difficulty explaining what negative relations or negative entities actually are. For example, consider Snell's law: "the ratio of the sines of the angles of incidence and refraction is equivalent to the ratio of phase velocities in the two media"[28]. Then in this case, F would be the ratio of the sines of the angles of incidence and refraction and G be the ratio of phase velocities in the two media. However, this relation of equality between F and G is subject to special conditions, namely, the media needs to be isotropic. This factor is what is hidden in the *ceteris paribus* modifier. As a result, the two ratios here are not related in isolation. Properties

[28] See https://en.wikipedia.org/wiki/Snell%27s_law

of the media, being isotropic or anisotropic, also have an influence on their relation. Therefore, it is not just the relation between the ratios that makes Snell's law true. We have to also take into account the property of the media. So it is the relation among these three factors that underlies this law. Even if we could be sure that no other factors are relevant here, we would face the problem of accounting for this other factor as sketched above.

In addition, this strategy would render their interpretation of laws superfluous. Presumably, in a natural system, no one property which is claimed to exist exists in isolation, without relating to other properties in the same system. This means that the same kind of entities would need to be alluded to in explaining different laws. For example, pressure, temperature and volume are all related with each other in a physical system of gas. A change in any one of them would lead to changes in the other two. If as universalists, we take them to be three properties of a physical system, temperature being designated by G, pressure F and volume H, then the relation among them can be symbolized as R (F, G, H). Now it is a law that gases expand when heated at constant pressure, and it is also a law that increases in temperature result in increases in pressure when the volume is fixed. These are two different laws. However, they are both based on R (F, G, H). It is only that in the first law, F is chosen to be the in the *ceteris paribus* conditioner while in the second law, H is in the *ceteris paribus* modifier. There seems to be no other way for universalists to explain why some properties are explicitly mentioned in a law while some are only put in the *ceteris paribus* modifier than alluding to some pragmatic or practical reasons. In other words, there seems to be some arbitrariness in what properties we choose to state explicitly in a law. This, however, betrays the whole universalist project which values most the necessity of laws. This further means that the universalists' claim that laws are about relations between properties or universals become useless or unhelpful since such talk is not even adequate to identify actual laws. Different laws may be based on the same properties.

Furthermore, these theories are actually circular or at best trivial. The problem is that the only way for the universalists to judge whether two properties are necessarily related or not is to see whether they are involved in a law. There is no non-empirical or a priori way to discover the "non-logical or contingent necessitation" relation as depicted by them. Then such a characterization by universalists either is dependent on law determination in the first place and is thus a circular explanation or is only a paraphrase of "being a law" which is however not yet proved.

Indeed, it is hard to see how to prove the contingent necessary relation between properties as required by universalists. On the one hand, the element of "necessitation" does not seem to be able to be inferred empirically (because it goes beyond empirical facts and Humean regularities). On the other hand, such a contingent relation is only discoverable empirically. This is the dilemma that the universalist theories face. The dispositionalist theory, I think, can in some sense be seen as an attempt based on the universalist theory to solve this dilemma. Its strategy is to reduce a two-place relation to a one-place relation, i.e., a property. In this way, we no longer need to be concerned about building a relation between two different properties that are external to one another. We only need one property which is responsible for connecting these two properties. In other words, the relation between two different properties is now further grounded on one single property. More specifically, borrowing Schrenk's words, "when an object has such a dispositional property, it reacts with a certain manifestation when triggered, i.e., when being in certain stimulus conditions"[29]. So take again the above thermal expansion law as an example. Now, dispositionalists would say that objects have a dispositional property, that is, expanding whenever being heated. This appears to be better than the universalist theory in that we can now account for the "necessitation" element involved in laws. This necessity results from the very definition or nature of a property.

However, dispositionalist theories pay for this improvement by suffering more problems. First, in order to explain the law "Fs are Gs" in this way, either F stands for the body that has the dispositional property at issue and G is whatever it brings about, or F stands for the "stimulus conditions" in Schrenk's definition and G the corresponding "manifestation". Either way, this explanation involves or presupposes causal relations with the object or its dispositional property as the cause and the

[29] See Schrenk (2016), p 224.

manifested phenomena as the effect. Then it can only deal with causal laws. However, there are also non-causal laws besides the causal ones. Typical examples are kinematic laws of physics such as Kepler's laws of planetary motion. In addition, such an explanation is undesirable because it explains more than what needs to be explained. By this I mean especially causality. Causality is not the content of laws. It is not implied by the law itself. This has long been pointed out and stressed by Hume and his followers. A law, by itself, is about the succession of two events and does not provide enough information for us to pin down the cause. As a result, this explanation utilizes information which is beyond the cognitive scope of a law. This is permissible only if the dispositionalists give at the same time a substantial theory of causality which is independent of what is given by laws. In other words, the causal relation has to be taken to be ontologically substantial and more than merely a stipulation or definition based on law statements. However, I find this almost impossible because our causal knowledge indeed depends on our knowledge of laws.

This leads to the same circularity problem as suffered by the essentialists, that is, the causal relation that dispositionalists make use of depends in the first place on the law. We have to determine the law before knowing what causal relation is involved. Then the explanation relies on the explanandum. Again, it becomes a circular explanation or an unjustified rephrase of lawhood.

Chapter III. Quantity and measurement

From the above introduction of the universalist and the dispositionalist theory, we can infer one important contention of their views about the concepts involved in laws. Both these theories take quantities, such as force or mass, either as a property or something that has a certain property. It is tempting to take physical quantities such as length, force, weight as denoting properties of objects. This is why the concept "qualitative intensity" was invented, which takes quantities to be "qualities that were amenable to quantitative treatment"[30]. For example, velocity is treated by Nicole Oresme as a quality which has different intensities. This is intuitively appealing because these concepts are expressed as nouns and nominalization is the standard way of denoting properties. Properties also come first to our mind when talking about what is shared by many objects. More fundamentally, perhaps, this is because objects with their properties is a very basic mode, or the mode we are most familiar with, of our perceiving and understanding the world. So quantities are also thought to be constructed by means of properties.

In this chapter, I set out to investigate the nature of quantities involved in laws and show *why it is wrong to understand quantities as properties*. What I want to argue is that quantities are fundamentally different from qualities. The metaphysical basis of a quantity is neither properties nor relations between properties. It is rather based on a

[30] See Tal (2017), p 5.

changing process. Particular to my discussion of physical quantities here, the changing process is the motion of objects.[31]

Section III.1. Quantities are not qualities

In this first section, I would like to demonstrate that quantities are not qualitative properties by showing differences in their fundamental features. Brian Ellis's definition of quantity is as follows: "If one thing can be said to be greater than, equal to, or less than another in a certain respect, then this respect may be called a quantity"[32]. This is a very formal or operational definition. It only states that a quantity is what is in common of the two objects under comparison and is thus the basis of comparison between them, without talking about the nature of quantities. Also, as we will see, such a definition is too broad for my discussion in this thesis, which focuses only on scientific quantities, that is, quantities that can be used in scientific laws.

However, this definition does show an important feature of quantities, namely, they are measurable. Being amenable to measurement is one important condition of a quantity being subjected to scientific study. So my argument is from the perspective

[31] Quantities used in other special sciences are based on the corresponding kind of changes. For example, chemical quantities are based on chemical changes. For those who hold reductionism about the relation between physics and other special sciences, all quantities, including those in special sciences, are based on physical changes, i.e., motions.

[32] See Ellis (1867), p 242.

of the general theory of measurement. This is not meant to be a comprehensive treatment of measurement, but will focus particularly on measurement as related to physical quantities.

The first point to be noted is the intrinsic connection between measurement and comparison. Measurement only comes on the scene when there are at least two objects that are comparable with each other. It does not make sense to talk about the magnitude of something which is the only existence of its kind because there is nothing for it to be compared with. So, measurement is essentially a comparing process and the magnitude we get from measurement is a relative value. In other words, there is no absolute quantitative value of what is measured. The result of a measurement is true or false only relative to the result of measuring another object of the same kind. This is one fundamental distinction between quantity and quality. A quality or an internal property is something that an object has in itself independently of anything else[33]. It is in this sense definite or absolute. By contrast, a quantitative description is only possible and meaningful relative to other quantitative descriptions. If we take all quantitative descriptions that are comparable with each other together to constitute an ordered system, we can say that every quantitative description has its meaning as a member of the system and the magnitudes of what we measure can be systematically changed.

[33] The opposite of this is a relational property, which will be discussed in a later section. I will argue that quantities are not relational properties either.

To get a first impression of the irrelevance of qualities to quantitative description, we can actually consider the simplest case of measurement, i.e., counting. In this case, we are only concerned with the number of objects at issue. Clearly, qualities of objects are irrelevant here. For example, it does not matter whether we are counting sheets of paper or apples. In either case, we abstract away the qualitative properties of objects at issue and each object has no more meaning than the natural number one. So three sheets of paper and three apples are both counted to have the quantitative value three. It will not help if we instead talk about the system composed of the objects since still, a system of three sheets of papers and a system of three apples have the same quantitative value.

This could indeed be generalized to all cases of direct measurement, such as the measuring of length, mass or other fundamental physical quantities. The basic process of direct measurement is as follows. We first pin down conventionally a "base quantity", as the standard of comparison. Then we compare all other quantities of the same kind with this base quantity and the magnitudes of the quantities are the ratios we get from comparison. Therefore, it is to be noted that in this process the base quantity has a function as the natural number one. All that is required for such direct measurement is that what is measured can be directly mathematized, no matter what it is qualitatively. Specifically, this means that the base quantity can be represented by the natural number one and it is also liable to fundamental mathematical operations such as addition and multiplication. Furthermore, there are operational processes for us to represent or regulate comparisons and calculations among quantities. That is, their calculations have corresponding practical operations.

From the above, we get another reason why what is measured should not be taken to be qualitative properties. Measurement is an operation that assigns numerical values to quantities. The possibility of having numerical values is a necessary and sufficient condition for being a scientific quantity. The measuring process is also a mathematizing process in which quantities are given numerical values and are calculated. There is in some sense a systematic mapping between magnitudes of quantities and mathematical numbers[34], and operational relations among quantities and mathematical relations among numbers. However, this mapping does not exist in the case of qualitative properties. Quality, seen as quale, is indivisible and complete in itself. Moreover, all qualities are at the same level. There is no way to just specify a certain quality and take it to be more basic than other qualities. Nor is there a way for us to stipulate some operations which enable us to build other qualities from basic ones. Relations between qualities are not mathematical. We can only say two qualities are similar or dissimilar. Therefore, it makes no sense to talk about calculation of two qualitative properties. Measurement, based on mathematical calculation, is thus not concerned about qualitative aspects of objects.

[34] Ideally, numbers here refer to the non-negative real numbers. The limitation is the imprecision of measuring tools available to us.

The difference between scientific quantities and qualitative properties is even more obvious in the case of derived quantities. Derived quantities are based on more complicated or indirect ways of measurement. There are two possible reasons for indirect measurement, one is due to the theoretical impossibility of direct measurement and the other is the practical impossibility of direct measurement. An example of the first kind is the measurement of color. According to the process characterized above, it is not possible to measure color in a direct way because there is no empirical meaning to talk about the addition of two shades of color. We cannot determine a specific shade of color as base quantity and then compare other shades of color with it because there is no operation to define what is the addition of two base colors. Such quantities, then, can only be measured indirectly. In the case of color, for example, we can only measure electromagnetic radiation which corresponds to and thus could represent various shades of color. The second kind of indirect measurement is due to the lack of measuring facilities or practical inconvenience of direct measuring. An example is the measurement of force, which depends on the measurement of mass and acceleration. Although intuitively we seem to have the ability to compare two forces, practically, there are no tools for scientists to have a direct and precise measurement of the force caused by gravity or magnetism.

We can already get a glimpse of why derived quantities are not qualitative properties before making a detailed examination of their measurement. As John Roche observed, “quantitative concepts which could not be accurately related to them directly, or indirectly, usually could not even be defined with acceptable rigor. Concepts such as impact, power, density, capacity for heat, the ability to conduct heat, illumination, loudness, magnetic intensity, electric charge, electric tension and electric capacitance had to wait, sometimes for centuries, before they could be related precisely to these basic measures and incorporated into exact quantitative science.”[35] About most of these phenomena mentioned, we are very familiar with their qualitative features. For some of them, such as loudness and density, we could even make a direct comparison between magnitudes of two phenomena accurately within a certain extent. However, all these still do not qualify them as quantities that can be scientifically treated. Thus, qualitative features do not constitute the essence of quantities.

Now we can look into the details of the measurement of derived quantities. The measurement of derived quantities is based on base quantities. This is exactly where scientific laws come to play their role. Laws, in the form of formulas, state precisely the mathematical relation between the quantity we are interested in and other quantities which are directly measurable. In the case of force, for example, a Newtonian law of motion says that $F=ma$, in which the mass and the acceleration can both be directly measured. Then the measurement of force is achieved by calculating the product of mass and acceleration. Since I have argued above that these basic physical quantities are essentially different from qualities, the results of calculation of

[35] See J. Roche (1998), p 52.

these base quantities are no less in nature than them, i.e., base quantities, as physical quantities. A complete treatment of base quantities and derived quantities will be given below after the discussion of laws.

Section III.2. The metaphysics of quantities

In the above section, I have only given a negative characterization of quantities, that is, they are not qualitative or intrinsic properties of objects. Here I would like to give a direct metaphysical characterization of quantities, which also paves the way for my discussion of the metaphysical basis of natural laws. However, before doing that, I would like to consider another popular view about the foundation of quantities.

That idea is that a quantity is a relational property. In other words, it is based on relations between objects. As Bigelow characterized this view, "they have argued that properties like length are really construed as disguised relations; that a thing has no such thing as an internal property of 'being some specific length', but rather, its being a certain length is wholly constituted by its being 'longer than' certain things and 'shorter than' others."[36] This view is better than the view which takes quantities to be internal qualities in that it realizes an important characteristic of quantities, namely, they are relative.

[36] See Bigelow (1988), p 72.

However, taken only as what is given above, this view at best can be seen to reflect the characteristic of the measuring process, i.e., the comparing of different objects. It is, in some sense, a re-definition of "length". It replaces the notion "length" with the notion "relative length", but the concept length itself remains unanalyzed, as it appears in the words 'longer than' and 'shorter than'. Further explication is needed to clarify its standpoint on the metaphysical basis of quantities.

Now there are two possible further explications that are available. One explication still bases quantities fundamentally on qualitative properties of objects, only adding the complication that quantities are based on relations between these properties. For example, in the case of the quantity length, this view would hold that "having a length of 3 centimeters" is not an internal property of a rod, but it is a property that a rod has in comparison with another rod. The comparison itself is between some properties that both rods have. The first problem of this view is that there are obvious counterexamples that cannot be explained in this way. One such example is speed. Speed is not something that we could get by comparing objects. It is fundamentally not about objects at all. An object itself does not have properties which can be called speed. Rather, only the motion of an object can be characterized in terms of speed. Ellis has pointed out this special case of speed, but he excluded such an example from his general treatment of quantities as "an exception"[37]. However, I do not see any justification for this exclusion. This is rather an important indication that we should

[37] See Ellis (1966), p 24.

look for some other unified explanation of quantities. Besides, a more serious problem facing such a view is to explain how this comparison between properties is possible. As I have emphasized above, qualitative properties, no matter how similar they seem to be, are independent of each other. It seems unclear to me what definite sense they could give to comparisons between properties taken purely qualitatively. Finally, I want to emphasize that just like the above unmodified view, this view cannot explain the mathematical features of these comparisons, that is, the fact that there is a mapping between magnitudes of quantities and numbers, and also between relations between magnitudes and mathematical calculations.

The other seemingly more promising explication is an operational account, which takes the sense of concepts such as "longer than" and "shorter than" to wholly consist in the corresponding measuring processes. For example, in the case of length, if we put two rods with one of their ends together, the longer the rod, the greater length we think it has. And when two rods of base length are put together in a succession end to end, the resulted longer rod stands for the result of the addition of two base lengths.

However, an operational account is still unsatisfactory. The problem is not just that it begs the question I am urging here. Instead of addressing the question, it dismisses the question about the metaphysical foundation of quantities. More importantly, this very attempt to dismiss the metaphysical question fails. In other words, the operational process it gives cannot really serve as the foundation of a quantity. This is because the quantitative concept that it aims to explain is tacitly used in the operational process. In the measuring process of length described above, for example, we need to judge which rod is longer. The specific operations that we carry out to determine this are of course not established arbitrarily. What they are based on is exactly the concept "being longer" or "being shorter", which already contained and thus presupposes the concept "length". This is, however, exactly what is meant to be explained by the whole measuring process that determines "being longer" or "being shorter". We have to already have known what "length" means in the first place. This same mistake is also made by any account which tries to explain the concept of length by means of a measuring tool, such as a ruler, whose construction is based on the concept length in the first place. Moreover, an operational account leaves unsolved the problem about the foundation underlying our measuring processes, which is more pressing in cases of quantities whose measuring processes are not as intuitive as the quantity length. Generally, there seems to be some principle grounded in the nature of a quantity which guides our specific measuring operations of this quantity. An operationalist explanation of quantities seems to be putting the cart before the horse.

To solve these problems, I propose that we replace this picture of objects and their properties with the picture of the motion of objects. In the latter picture, an object is understood only as the practitioner of certain actions or behaviors, e.g., movements. So its qualities, whether internal or relational, are irrelevant in this case. Preserving all the features of its behavior, an object can indeed be idealized to a single point, which is a common practice in sciences such as physics. What matters for consideration of quantities is the whole changing process of the object's action. A quantity, then, captures some aspect or dimension of this process. For example, in Newtonian mechanics, the physical fact under study is the motion of an object and quantities such as force, mass all capture different aspects of this fact. In electromagnetism, the physical fact at issue is electromagnetic radiation of electrically charged particles and quantities such as voltage and magnetic flux denote some aspects of this fact.

This is more obvious in cases of indirect measurement when concrete scientific experiments are carried out and recorded in order to both define and measure derived quantities. For example, in the case of the quantity force, we give different pushes to an object and record the velocity of its motion under each occasion. The process here is the object's motion given the push and what force stands for is exactly what makes this object to move at the very beginning of the motion. It is precisely by means of this process that the concept force is defined. Also by means of this process it is measured, i.e., by calculating the product of mass and acceleration. This account can also be applied very easily to quantities such as speed.

However, we should realize that a process like this is also involved in the measurement of base quantities. Not only derived quantities are aspects of physical facts, base quantities are also about physical processes rather than any single object tout court. Take the quantity mass as an example. What we do is to "bounce objects off each other, and by measuring their velocities before and after the bounce, figure out the ratios of their m's [masses].”[38] This is how the quantity mass is introduced and measured, i.e., by means of the bouncing motion of objects. So, the quantity mass is defined to be an object’s “resistance to acceleration (a change in its state of motion) when a net force is applied”[39]. What it captures is the resistance aspect of the whole bouncing process of the object.

What is misleading in this case of mass is that this aspect of moving is believed to be related to some property of objects. It seems to be due to some nature of objects that different objects move differently given the same push. This is also what misleads many people to treat the concept mass as denoting some property of objects. However, this confusion would be cleared if we always keep in mind the process by which this concept is introduced and what it is originally meant to capture when it is introduced. As we have seen, the concept mass is defined by a bouncing process and is also meant to capture some aspect of this motion. This is the only sense that the concept mass has in its scientific usage. Whether this aspect of motion is attributed to some property of the moving object or not is indeed irrelevant to its scientific usage. It belongs to our further speculation about mass and needs further independent proof. In fact, as will be discussed below, the thought that mass is due to some property of objects is scientifically untenable. Generally, we should distinguish between a

[38] See https://van.physics.illinois.edu/qa/listing.php?id=278
[39] See https://en.wikipedia.org/wiki/Mass

quantitative concept that is descriptive of the motions of objects and some qualitative property of objects that may be responsible for the motions.

Now I would like to investigate another base quantity, length, which also causes much confusion. The reason why it is usually taken as a property of objects and why it is hard to conceive of length as descriptive of motions is because of the confusion between this quantitative concept ‘length’ and the property of objects being extended. Being extended is a qualitative, intrinsic property of all material objects. It is because material objects are extended that we can measure the length of an object. However, this property is only a precondition for the measurement of length, not the basis of length. The concept length and its measurement are based on something completely different. They are established in the first place before we can apply them to concrete material objects. Specifically, length can in some sense be seen as the distance travelled by an object during its motion. It is concerned with the “distance” aspect of a moving process. One important advantage of conceiving of the quantity length in this way is that it can give a unified account of measuring the length of a rigid body and the length of displacement caused by motion. The length measurement of rigid bodies is a special case of the general measurement of the length of displacement, in which the motion at issue is carried out in Euclidean space. A detailed discussion of length measurement in different spaces will be given below.

In conclusion, we can see that quantities are not “static” categories like qualitative properties of objects. Rather, quantities arise from a process. Specifically, physical quantities, which we are particularly interested in, represent aspects of physical motions. Base quantities such as length, time and mass are basic not because they are properties that all objects possess. Rather, they are basic because they characterize some most basic aspects of the simplest physical motion. The motion they are based on is the free motion of objects and the aspects that these quantities describe are possessed by all physical motions, simple or complex.

So the reason why different objects can be compared with each other in the measurement of a quantity is that they are doing the same kind of action about which the quantity is concerned. This common kind of action constitutes the basis of comparison. Strictly speaking, it is not objects or their properties that are under comparison, but objects’ actions or behaviors.

The specific features of quantities and quantitative relations, especially their mathematical characteristics, have their proper grounding in the specific moving processes of objects. For example, the transitivity of quantitative relations is derived from the continuity of the changing process underlying each quantity. The reason why quantities have numerical representations and why they are amenable to mathematical calculations is due to the mathematical structures of the concrete process of physical motions. These claims and what I mean by “mathematical structure” can only be explained and understood after my discussion of laws in the next section. Before doing that, however, it would be helpful to clear up a possible doubt at this point.

The doubt is that apparently we are considering some similar qualities in the process of comparison. This is especially the case in the cases of direct measurement. When we measure quantities such as mass or length, aren't we comparing some qualitative properties of objects? Also, we give different names to measurements based on the same mathematical principles. Isn't it here where qualitative properties come into play? They somehow indicate to us what aspects of objects or systems are under study. For example, we are measuring the length of an object, not its weight, and we know what unit we should use after the number, e.g., meter or kilogram.

It is to be noted that I do not deny that quantities have some qualitative content involved in them. Nor do I deny that this could be a plausible way to identify a quantity or differentiate between different quantities. For example, we observe that rods with different shapes are extended over different ranges, which can be compared with each other. This is how we measure the quantity length. Or we feel different pressures when different sizes of solid balls are put on our hands, this is how we give sense to the quantity weight. Different quantities do have different qualitative appearances. However, what is important here is that they do not constitute the essence of quantities, especially quantities that can be used in scientific laws. Their role of helping us recognize different quantities and measurements is no argument for their fundamentality to a quantity. Fundamentally, quantities are not based on qualitative properties of any objects.

To be specific, we should investigate the relation between the qualitative content contained in the measurement and what I have said about quantities above, i.e., that they are aspects of a changing process. The changing process of an object's movement leads to different qualitative manifestations. For example, consider the movement of a car, in which case the motion is the process at issue. This moving behavior of the car results in qualitative differences. That is, some qualitative phenomena can be observed as manifestations of this action of the car. For example, the position of the car changes from point a to point b. The time at the beginning of motion is t1 while the time at the end is t2. Corresponding to the first phenomenon is the quantity length or distance. So, in this case, a quantity does have its qualitative manifestations, which may even become practically justified criteria for quantitative judgements. However, there is no reason for us to suppose that this is the case for all quantities, especially derived quantities. Some quantities may have no obvious qualitative manifestations corresponding to them. More importantly, qualitative alterations are only manifestations of the underlying mechanism which causes such alterations, e.g., the motion of the car. As a result, we can say qualitative alterations are only an appearance of the fundamental underlying action of objects. Fundamentally, it is the underlying process of an object's action that is the metaphysical basis of quantities.

In conclusion, objects have physical properties, which in some cases have corresponding physical quantities. For example, objects are extended. This property is related to the quantity length. The existence of physical properties is a precondition for all our scientific practice. However, they only serve as a precondition and are not really involved in actual scientific study. As we have seen, the scientific concepts, as quantities, resulted from experimental observations or operations are different in kind from these primary properties.

Chapter IV. Laws

Section IV.1. Ontology of laws

The above interpretation of quantities paves the way for my discussion of the metaphysical basis of laws. Quantities are prominent constituents of scientific laws. A most straightforward characterization of laws is that they are about relations among quantities. Further speculations about such relations are obviously needed. It has been argued in the last chapter that quantities are aspects of physical facts about the motion of objects. What I want to argue about laws is that they are metaphysically based on physical facts about motions of objects as well.

One special kind of laws is definitional laws, that is, laws that are used to define quantities. For example, the law $P = mv$ is actually a definition of the quantity momentum. In these cases, the metaphysical basis of measurement of that defined quantity is also the metaphysical basis of the law. So like physical quantities, the basis of a law is also some behavior or action of objects or physical events as a whole, such as the motion of a particle. More specifically, it is the same physical fact involved in the measurement of quantity defined by the law.

More generally, the establishment of mathematical relations among quantities in a law is based on a physical fact of motion. This fact is the motion of objects involved in the experiment or the observation that we carry out to establish a certain law. Take the Newtonian second law as an example. Scientists record the acceleration of different moving objects and corresponding pushes given to them. Then they discover that force is positively correlated with the acceleration of the object. So there is a linear relation between force and acceleration. As a result, scientists name the quotient of these two quantities 'mass' and attribute it to the moving objects. It is after these processes that this second law has the form $F=ma$. The kind of physical facts at issue in this case is the motion of an object when it is given a push. All three quantities here, i.e., mass, acceleration and force, depict aspects of this kind of physical fact. The relations among them is also based on this same kind of fact.

In cases of more complicated laws, their dependence on physical facts of motion becomes less obvious because the actual discovery and final formulation also involves calculation, speculation and intuitive insight. For instance, consider the general law of gravity and Einstein's field equations. At initial stages of establishing both laws, scientists analyze the empirical data available and ponder the possible form of laws they want to establish. However, this does not invalidate what we have said about the basis of laws. What is important is that the final proof of the laws conjectured is still some physical motion of objects, which is to be observed either directly in the real world or in experiments. This is sometimes called "the final quantitative test"[40]. In the case of the general law of gravity, Newton's final proof of this law is by observing the motion of the Moon, measuring its orbital period, the radius in its circular orbit and the acceleration of its motion. It is this orbital motion of the Moon or other planets that is the basis of this law. Similarly, in the case of Einstein's field equations, its final proof depends on our observation of motions such as the shift of travelling light.

In conclusion, what physical quantities pick out is some aspects or dimensions of the whole event or fact. And laws express the mathematical relations among different features of facts. However, since in a single law, these quantities are all features of one and the same event, it would be more appropriate to say that laws express the mathematical structure of a physical event, instead of using the word "relation".

So far on my interpretation, the laws are all presented in the form of equations, which state apparently the mathematical relations among quantities. Someone might question whether this formal presentation does justice to laws expressed in the form

[40] See Hjorth, Poul G. (2000), p 7.

of conditional sentences. Expressed in this way, the Newtonian second law would read as follows: whenever an object of mass *m* is acted upon by a force *f*, it moves with an acceleration *f/m*. Such statements might leave the false impression that dispositional properties are involved in laws, such as the dispositional property of tending to move with an acceleration *f/m* in this case. It is mistaken to treat "tending to move with an acceleration f/m" as a dispositional property because a dispositional property of objects is something that is responsible for the corresponding effects in an important sense. This sense is that such a property has an active interaction with the environment and is an indispensable part of the causal story explaining the effects. For example, being fragile is a dispositional property of objects in that it is causally responsible for various displays such as breaking into pieces of objects when hit. Such a property has to be alluded to in order to explain why the object would break when hit.

However, the situation is different in the case of objects' motion. First, moving with a certain acceleration is a phenomenon that actually happens whenever a force is present. It is the very effect that needs to be explained. So it cannot be taken as the cause at the same time. If motion were really due to some property of objects, such a property has to, in some sense, be "behind" or underlie the effects that we actually observe. Simply adding the word "tending to" in front of the phenomenon does not automatically validate the existence of any property of objects. Second, we should see that motion is a special kind of change. The status of motion of an object does not belong to the nature of that object. By contrast, properties of objects and phenomena related with them constitute an important part of an object's nature. Therefore, "tending to move with a certain acceleration" should not be seen as a property of objects or its effect. Finally, scientifically speaking, no properties of objects at all need to be resorted to when explaining why objects move in this way. For instance, relativity theory explains motions purely by means of the structure of space-time. Hence, although we can say an object has a tendency to move with an acceleration f/m, it is not a dispositional property of objects.

Someone might then comment that even if we admit that no properties are involved in laws, still, we need some dispositional property to ground the law as a whole. My contention is that neither are there any dispositional properties involved in laws, nor do they play any role in grounding scientific laws. Besides the reasons I have given above in the second chapter, there are some further reasons why dispositional properties are not the basis of laws.

First, it is scientifically impossible to pin down a single dispositional property as the ultimate cause of the phenomena that a law is about. The first sense of impossibility lies in the variety of the phenomena to which a single law can be applied. For instance, the law $F = ma$ holds not only for motions of objects on the earth, but also for orbital motions of planets. The causes of motion in these two cases, however, are vastly different. In the first case, the causes of motion are the external force exerted on the object and the gravitational force while in the second case, it is only gravitational force. So there is no unique object that we could find whose dispositional property could explain the law at issue. The second sense of impossibility is that there could in fact be more than one causal story that is valid for explaining a single phenomenon. For example, to explain the orbiting motion of the Earth around the Sun, we could either say that there is gravitational force between the two planets, or we could use relativity theory and explain it by the curvature of space-time. Both accounts can successfully explain the orbiting motion, but they obviously involve different objects and mechanisms. As a result, we can see that even to a single phenomenon, we could not say definitely which object's dispositional property, if any, is responsible. So dispositionalists's intention to base laws on some dispositional property is at odds with actual scientific theories.

Second, such a talk of dispositional properties is a redundant addition to the talk about motions of objects. It plays no role that cannot be played by the fact of motion of objects as to the explanation of laws. For example, the law that whenever an object of mass m is acted upon by a force *f,* it moves with an acceleration *f/m* can be adequately explained by the fact that an object of mass *m* moves with an acceleration *f/m* when it is pushed by a force *f*. There is no need for us to further suppose a property of the object which might underlie its motion, such as the dispositional property of moving with an acceleration *f/m* upon being pushed by a force *f,* which is actually just a paraphrase of the motion itself. Otherwise, we would violate the principle of parsimony. Moreover, such a supposition should be avoided for at least two reasons. First, the motions of objects are empirical facts that are directly observed while dispositional properties are metaphysical suppositions of ours. Consider the empirical nature of scientific practice, it would be undesirable to include metaphysical entities if it could already be adequately explained empirically. Also, the targets of sciences are material objects. Unlike living beings whose actions or behaviors are active or autonomous, the actions, especially motions of material objects are thought to be totally passive. They are to be explained by the outside factors of environment, not its own properties. As a result, talking about the dispositional properties of objects besides their motions is unnecessary, counter-intuitive and mysterious.

In basing natural laws on facts of motions, we can see that the question usually asked about why quantities have such relations with each other is no longer justified. This is because the relations among them are not external but internal. They are related just because they are all about one and the same fact.

There is another advantage of this view of scientific laws to be noted. It helps us understand the relation between different systems of laws. This further includes two cases. In the first case, there are different laws that are developed to describe the same phenomena. For example, Newtonian mechanics, Lagrangian mechanics and Hamiltonian mechanics are all systems of classical mechanics. That is, they all can only be applied to slow motions of macroscopic objects. Although laws in the

Lagrangian mechanics and the Hamiltonian mechanics employ different concepts and appear widely different from Newtonian laws, in no way are they denials of Newtonian laws. They are alternative descriptions of the same phenomena and are equally justified. In the second case, there are systems of laws being modern developments of traditional laws. The typical example is Relativity theory and Newtonian theories. The view that natural laws are based on physical facts as a whole can explain why, when Einstein and other scientists later discovered relativity theory and developed more mature forms of dynamical laws, we did not just abandon Newtonian laws and completely replace them. This is because the validity of Newtonian laws is based on facts that are really happening in this world, that is, the motion of slow-moving objects. In so far as the motions of macroscopic objects under everyday conditions are concerned, Newtonian laws are accurate descriptions of these phenomena. As a result, the truth or validity of Newtonian mechanics is not to be denied. Relativity theory is superior to Newtonian laws in the sense that it unifies motions of low speed with motions of high speed so that it can be applied to both kinds of motions. These two systems of laws are concerned with different ranges of motions, each being justified by the motions that it is concerned with. As a result, Relativity theory does not replace the traditional laws. Rather, it expands the domain of motions that can be studied and thus expands its own range of validity.

Before moving on to discuss the form of laws, I would like to analyze the laws in the field of electromagnetism to further illustrate my view since so far, given that so far I have only used Newtonian laws as examples. One of the fundamental laws of electromagnetism is the Lorentz force law, i.e., $\boldsymbol{F} = q\,(\boldsymbol{E} + \boldsymbol{v} \times \boldsymbol{B})$, where × is the vector cross product, "which gives the force acting on a point charge *q* in the presence of electromagnetic fields"[41]. To see more clearly the content of this law, we could write it in its more explicit form: $\boldsymbol{F}(r;\ \dot{r},\ t, q) = q[\boldsymbol{E}(r; t) + \dot{r} \times \boldsymbol{B}(r; t)]$, "in which **r** is the position vector of the charged particle, *t* is time, and the overdot is a time derivative"[42]. So we can see that the basic variables of this law, position vector ***r*** and time *t*, are typical quantities as explicated above.

It is important here to understand what *E* and *B* really are in this law and other laws of electromagnetism. Although they are technically called electric and magnetic fields, which are names of substances, in the laws, they are essentially *vectors.* As such, they are typical quantities and are different from quantities in Newtonian laws only in that vectors have not only magnitude, but also direction. In other words, the concept "field" as it appears in laws does not denote any physical objects or entities tout court, but these objects are mathematised as "functions of the space and time coordinates"[43]. Specifically, the magnetic field is $B(x, y, z, t)$ and the electric field is $E(x, y, z, t)$.

As a result, formally speaking, this law expresses mathematical relations among quantities. Theoretically, fields may be given different interpretations. There may

41 See Jackson, John (1999), p. 2.
42 See https://en.wikipedia.org/wiki/Lorentz_force
43 Ibid.

indeed be proposals to treat a field as "a "real" physical entity, filling the space in the neighborhood of any electric charge"[44]. However, it is also possible to "formulate classical electrodynamics as an "action-at-a-distance" theory, and dispense with the field concept altogether"[45]. So in some sense, the concept field is like the concept force, which is subject to modification or revision given further theoretical development. The point is that whatever interpretation the concept field is given by a physical theory, it does not affect the truth or the establishment of laws involving this concept. The justification of the Lorentz force law, for example, lies in the experiments that are about motions of electrons.

Section IV.2. The form of laws

In this section, I will talk about the form of law statements. The default form of laws that is supposed by most philosophers in their discussions is "(all) Fs are Gs", in which F and G stand for some universals or properties. Some voices of objection have indeed been raised. For instance, Russell distinguishes between "crude generalizations" or "approximate regularities"[46] and fundamental equations of science. The first kind are statements such as "Salt dissolves in water", "Gases expand when heated at constant pressure". Such statements contain collective nouns denoting objects in our ordinary life and they are purely qualitative descriptions. Russell only

[44] See Griffiths (1999), p 61.
[45] Ibid. P 61.
[46] See Russell (2009), p 271.

takes fundamental equations to be scientific laws. Here, following Russell, I argue that "Fs are Gs" is not the form of law statements. This is not a linguistic claim. I am not denying the pragmatic usage of the word "law" for referring to these statements. Rather, they are not natural laws understood strictly as the most fundamental and accurate rules we could possibly find of the events in the natural world.

I deny them to be natural laws in the strict sense, however, not for the same reason as Cartwright. Cartwright denies these statements to be laws because she thinks that they are *ceteris paribus* laws and *ceteris paribus* laws are false. A ceteris paribus law is "a law that holds only in special circumstances"[47]. "These laws, read literally as descriptive statements, are false, not only false but deemed false even in the context of use."[48] I disagree with her view on *ceteris paribus* laws mainly for two reasons. Firstly, when these statements are added with the modifier "*ceteris paribus*", although they are still not laws in the sense as urged by me, they are indeed true statements and they can be used for everyday explanations. Secondly, I doubt whether we could ever find a law that does not need this modifier, both practically and theoretically. All physical laws are valid within a certain boundary. It is obvious that statements of the form "Fs are Gs" need "*ceteris paribus*" clauses for their validity. But law statements that are taken to be fundamental or even equations also have limiting conditions for their truth. For example, Newtonian laws are not valid for situations "at very small

[47] See Cartwright (1983), p 47.
[48] Ibid. p 52.

scales, very high speeds"[49]. Even Einstein's equation is not valid in the microscopic world. Generally, there is no reason to suppose that any laws or equations found by scientists today, no matter how basic it seems at present, are boundless, and not confined to any special circumstances. On the contrary, this is exactly what we should expect given the metaphysical basis of laws. All scientific laws and their discovery are based on certain specific physical facts. The particularity of these facts determine that laws based on them have only relative generality, not absolute generality. As a result, we can actually say that all laws are *ceteris paribus* laws. Then, this particular prefix which is supposed to mark out a specific kind of laws becomes useless or superfluous. Also, if as contended by Cartwright, *ceteris paribus* laws are false, then all laws would be false.

My denial that these statements are law statements in the strict sense results from my general view about natural laws as argued above. Specifically, laws are essentially quantitative and not qualitative. They are about mathematical relations among physical quantities. Only by satisfying these criteria can statements or equations be properly called natural laws. However, F and G in statements "Fs are Gs" stand for universals or qualitative properties and the relation between F and G is qualitative, not quantitative or mathematical. Moreover, we have demonstrated above that quantitative relations are not further based on some dispositional properties. As a result, these qualitative statements are unable to express the fundamental laws of

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[49] See https://en.wikipedia.org/wiki/Newton%27s_laws_of_motion.

nature. Scientific laws, fundamentally based on physical facts of motion, are described by means of quantities, not qualities.

A correct grasp of the form of law statements is important because misunderstandings may misguide our investigation of laws. For example, the question: "what is the nature of that relation between the Fs and Gs, to which a law-statement refers, whose obtaining entails the above? Is it a special kind of regularity relation between the actual Fs and Gs or a contingent relation between the two universals, F-ness and G-ness?"[50] is a wrongly construed question. It is based on the wrong view of the form of laws.

Now another question presents itself, namely, the relation between genuine laws and "crude generalizations". Cartwright has discussed this question in her 1983 book. There she uses a somewhat different terminology. She distinguishes between "phenomenal laws" and "fundamental laws". Roughly speaking, phenomenal laws can be equated with crude generalizations and fundamental laws are the laws in the strict sense as explicated above. As to the relation between them, Cartwright mentions one view called the "generic-specific account". Simply put, this view is that "the fundamental laws are basic and that the others hold literally 'on account of' the fundamental ones."[51] "Phenomenological laws are what the fundamental laws

[50] See Liu (2004), p 366.
[51] See Cartwright (1983). p 102.

amount to in the circumstances at hand."[52] Cartwright disagrees with this view and her own view, roughly speaking, is that phenomenal laws are more true than fundamental laws. "The basic laws and equations of our fundamental theories organize and classify our knowledge." "The great explanatory and predictive powers of our theories lies in their fundamental laws. Nevertheless, the *content* of our scientific knowledge is expressed in the phenomenological laws."[53] It is beyond the scope of this thesis to give a detailed discussion of these two views. I will instead argue for my own view as an indirect demonstration of their implausibility.

The first thing to note is that proper law statements and crude generalizations are both about motions of objects. However, although they both describe such facts, they describe them in very different ways. Crude generalizations are qualitative descriptions. They have the practitioner of an action as the subject and then attribute features to this subject. For example, in the statement "salt dissolves in water", the subject of the statement is salt, which is the performer of the whole action. Then the statement attributes a predicate to this subject, describing its action, state or quality. The predicate in this case is "dissolving in water", which describe the dissolving behavior of the subject salt. On the other hand, genuine law statements as explicated above are quantitative characterization of facts of motions of objects. Unlike a crude generalization, a law statement does not have the specific practitioner of an action as

[52] Ibid. p 103.
[53] Ibid. p 101.

the subject. Nor do they give any direct predication of this subject. Instead, they employ concepts that are quantities as explicated above. Law statements are about quantities and relations among them, not any subject or predicate.

As a result, we can see that of one kind of motions of objects, there can be two kinds of descriptions: qualitative descriptions, namely the crude generalizations, and quantitative descriptions that are scientific laws. They are different only with respect to the manner of description and the degree of reliability of the resulting statements. Crude generalizations are imprecise and unreliable while quantitative statements are taken to be laws, which are accurate and reliable. As a result, in some sense, we can take crude generalizations as the appearance of the underlying quantitative laws. However, they are both justified by the relevant facts that they describe, each independent of the other. So it is wrong to think that one of them is more basic than the other. It is also wrong to think that crude generalizations contain more information or "content" than law statements. As I have argued, they are both descriptive statements of physical facts and contain different information about the facts. In conclusion, crude generalizations are not laws in the strict sense. Crude generalizations and law statements are two different kinds of ways of describing physical facts of motion and they are independent of each other.

Now I will give a direct formal treatment of the form of law statements. First, it is important to note the intimate connections among quantities, physical facts and scientific laws. As has been shown above, quantities are based on physical facts. They are descriptions of different aspects of physical facts. At the same time, laws are derived from physical facts as well. As a result, there is a close connection between quantities and laws.

This is obvious in the case of derived quantities, whose measurement apparently depends on laws. However, this is actually also the case when it comes to direct measurement. The measuring processes of base quantities also involve laws. This is rarely recognized because the laws involved in direct measurement are so trivial or we are so accustomed to it that we take this for granted.

I will take the measurement of length as an example. The measuring process characterized above, i.e., that when two rods of base length are put together in a succession end to end, the resulting longer rod stands for the result of the addition of two base lengths, only works in Euclidean space. This measurement is correct only in Euclidean space. This is because it obeys rules only valid in Euclidean space, i.e., axioms and postulates of Euclidean geometry. The design principle of a rod as a measurement tool is exactly Euclidean geometry. More specifically, Euclidean geometry postulates that "given two points, there is a straight line that joins them."[54] The Pythagorean theorem also applies in this space. The distance between point 1 and point 2 in this space is thus $d^2(1,2) = (x_1 - x_2)^2 + (y_1 - y_2)^2$, with $\{x_1\ y_1\}$ and

[54] See https://www.britannica.com/topic/Euclidean-geometry.

$\{x_2\ y_2\}$ being coordinates corresponding to these two points, respectively. It is because of these postulations of features of space that we can take the connecting of rods as the addition of distances.

However, this is not the case in other kinds of physical space-time. Non-Euclidean space has different geometrical structures with different laws. Instead of being flat, non-Euclidean space is curved and their Ricci scalar curvature is not equal to 0. So the connection of rods no longer makes sense in this space and can no longer be a measurement tool[55]. Here our measuring must be accordingly based on different laws in this space. In other words, our calculations of lengths obey formulas of non-Euclidean geometry. For example, in Lobachevskian space, Lobachevski geometry rather than Euclidean geometry holds. Accordingly, the distance between two points 1 and 2 is $\cosh\left(\frac{d(1,2)}{a}\right) = \frac{1-x_1x_2-y_1y_2}{\left(1-x_1^2-y_1^2\right)^{1/2}\left(1-x_2^2-y_2^2\right)^{1/2}}$, where "a is a fundamental length which sets the scale of the geometry"[56].

So even in very basic measurements, the measuring is still based on physical laws. This involvement of laws is reasonable given the dependence of quantities on physical facts. A physical fact is a fact governed by physical laws. So the measurement of

[55] Here, I am talking about an inappropriateness in a very strict sense. Although practically, addition of rods of suitable length together with integral could give us a scientifically-acceptable approximation of the actual distance, the result is at best only an approximation. It is not the actual accurate distance that I am urging here.

[56] See Weinberg S. (1972), p 6.

quantities, as based on physical facts, is unavoidably under the governance of natural laws as well. Consequently, physical laws are pervasive in all measurements.

Put formally, we can use variables, such as x or y, to stand for non-negative real numbers. The law that is obeyed in the measurement of base quantities is a mathematical formula containing variables. So the result of measuring or the magnitude of a base quantity can be represented as a function of variables, e.g., $f(x)$. The function can be simple or complex. In the above example of length measurement, the function in non-Euclidean spaces are much more complicated than that in Euclidean spaces. The law that is used in the process of measuring derived quantity is also a function, whose domain however, is not variables denoting natural numbers, but rather functions that stand for base quantities. So technically, the function standing for derived quantities is a functional, $f[g(x), h(y)]$ with x, y being non-negative real numbers.

In conclusion, a base quantity is fundamentally a function $f(x)$ and a derived quantity is fundamentally a functional $f[g(x), h(y)]$. It is to these functions and functionals that we give each its proper name in physics such as force or mass.

Now as to the form of laws, it is undoubtedly equations because only equations state relations among quantities. Furthermore, because the quantities, either basic or derived, are functions or functionals, equations containing these quantities mostly are called differential equations. More specifically, equations involving derived quantities are called functional differential equations. As a result, the form of natural laws is differential equations.

Chapter V. Further developments

In this chapter, I will clarify my view of laws by further explicating characteristics of laws understood as mathematical structures of facts in more detail. There are several features that are commonly deemed to be trademarks of lawfulness, such as being general, and being necessarily true. There have been a great number of debates around whether natural laws or physical laws really possess these features.

The first thing I want to point out about my account of laws is that it is a realist view, or in Cartwright's words, a "facticity view of laws". "It is the view that laws of nature describe facts about reality."[57] However, it is a realist account not in the sense as given by Cartwright. In her explication, this view thinks that "laws of nature tell how objects of various kinds behave: how they behave some of the time, or all of the time, or even (if we want to prefix a necessity operator) how they must behave"[58] and these things are "real concrete things that exist here in our material world, things like

[57] See Cartwright (1983), P 54.
[58] Ibid. P 55.

quarks, or mice, or genes."[59] These are not contentions of my view. I do not think laws are about particular objects of the world, nor do they dictate the behaviors of these objects. Instead, according to this mathematical structure view, laws are about motions of an object or objects. These motions are empirical facts that we can directly observe in the world. Laws are not themselves facts in the world, but they describe the facts that are really happening, i.e., the motions of objects. It is in this sense that laws describe facts about reality and they are no less or more real than the particular facts. We should note that this view does not reduce the generality of physical laws. Natural laws remain general in that they describe the common mathematical structure shared by the same kind of motions of objects.

Such an understanding of the facticity of laws is immune to one of Cartwright's charges against the view that fundamental laws are real. The objection is that "not only do the laws of physics have exceptions, they are not even true for the most part, or approximately true."[60] If laws are understood to be predictions of behaviors of objects, as Cartwright did, then admittedly, given a certain situation, objects may well not behave as predicted by the law. However, in the view I have just proposed, laws are not predictive but descriptive. This is not a denial that objects behave in accordance with laws. The point, rather is that this obedience is not due to the laws' ability to somehow predict or stipulate rules. On the contrary, this is because laws

[59] Ibid.
[60] Ibid. p 54.

state some feature of motions of objects. As such, there is nothing to which there could be an exception. It does not make sense to talk about exceptions because what matters here is only the physical facts that laws depend on and that are actually happening. These facts are the basis of physical laws and it makes no sense to talk about the validity of laws outside their proper realm.

Section V.1. Causal explanation

Now there may arise a worry about the predictive power that we usually attribute to laws. If law statements are only descriptive statements, how should we understand the well-accepted opinion that objects behave in accordance with laws? The answer to this question, I think, is the same as that to the question of how to understand the scientific explanation related to laws if laws are taken to be such descriptive statements.

As acknowledged by Bigelow and Pargetter, "to give the causes of an occurrence is obviously to contribute to an explanation of that occurrence. There may be other sorts of explanation as well, but clearly the giving of causes can contribute to one sort of explanation"[61]. In this section, I will only concentrate on this kind of explanation related to causation, i.e., causal explanation. Moreover, I will constrain my discussion to those causal explanations which make use of laws.

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[61] See Bigelow, Pargetter (1990), p 299.

The typical representative of this model of explanation by subsumption under laws is the Hempel-Oppenheim view, according to which "explanation consists in deductive or inductive subsumption of that which is to be explained (the explanandum) under one or more laws of nature"[62]. More specifically, "the basic pattern is that something to be explained is derived by a sound inference from a (conjunction of) the laws of nature, together with the so-called initial conditions"[63]. From this, we can infer that laws employed for explanation must already contain causal relations. They are what Cartwright calls "causal laws", which "state that when one type of event occurs, some other particular type of event will occur"[64].

However, as we have demonstrated above, natural laws are not in this form, which links two kinds of events. Moreover, as can be easily inferred from my view of laws, causality is not in the content of the law itself. Both the quantities in a law and the law itself arise from a physical fact about motion as a whole. Scientific laws are pure descriptions of mathematical structures of physical facts. As a result, they contain no causal information at all. There are, strictly speaking, no causal laws. So this account of scientific explanation as based on this conception of causal laws has to be abandoned. In what follows, I propose a new understanding of causal explanation

[62] See Salmon (1998), p 69.
[63] See Bigelow, Pargetter (1990), p 300.
[64] See Richard (2006), p 264.

given what I have said about laws. This new account, as we shall see, also includes a new understanding of singular causation.

Let A and B stand for two events, then I contend that A is the cause of B, or the statement “A causes B” is true, only if some quantities in event A and some quantities in event B fall under one single scientific law. So although A and B are two separate events that have nothing to do with each other, quantities involved in event A are related to quantities about event B in the same sense as two quantities in a law are related with each other. It is under these conditions that A can be said to be the cause and B be the effect and it is in this sense that the law at issue explains the event that A causes B.

To better illustrate my view, consider the example of a stone breaking a window. The causal relation in this case is obviously that the stone is the cause and the window’s breaking is the effect. However, this causal relation holds not because, as thought by the traditional view, that these events are an instance of a law that states “throwing a large stone at a window must cause the window to break.”[65] This is not a legitimate law statement. Instead, the law involved here is the law P = mv, i.e., “If *m* is an object's mass and **v** is the velocity (also a vector), then the momentum is P =mv”[66]. Specifically, for the physical fact of throwing a stone there is the quantity momentum.

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[65] See Richard (2006), p 265.

[66] See https://en.wikipedia.org/wiki/Momentum.

This quantity describes the momentum aspect of this fact. However, according to the *law of conservation of momentum*, such a momentum is completely transferred to the window at the moment of strike and thus it also describes the momentum aspect of the motion of the breaking window. About this same fact, we also have the quantity mass. So, we now have two quantities, momentum and mass, which both describe the motion of the breaking window. Now we can apply the law $P = mv$ and get the result that the velocity of the window would be P/m. Hence, the causal relation between two different kinds of events is established on the relation among quantities of a single fact or event.

As a result, the concept of singular causation is not eliminated by my view of natural laws. It is made sense of as urged by Cartwright and Wesley Salmon to play various roles such as accounting for effective strategies. Like Cartwright, I also take singular causal claims to be primary. However, contra both Cartwright and the Humean, there are no generic causal facts because no causation at all appears at the level of laws, as has been demonstrated above. Still, singular causal facts depend substantially on non-causal scientific laws. However, it is not that we directly have a law which connects the cause with the effect. Rather, scientific laws only feature indirectly here. The quantities in this law arise from two different events at issue on the one hand, but on the other hand, they are also descriptions of one and the same fact. This same fact which the law ultimately depend on may be one of the events we are concerned about, as in the above example; or it may be a third fact different from both the two events.

Either way, the crux is that the quantities that originally describe different facts are finally combined and subsumed by a single law. Then we can say these two facts have a causal relation.

Causation, as existing between singular events, then has no connotation of necessity as usually implied when it is taken to be at the generic level. For example, causation in the case of causal law "C causes E", where "C and E are to be filled in by general terms"[67] as conceived by Cartwright, is a necessary relation. C and E are necessarily related because this relation is derived from of a dispositional property of objects. Such a generic necessary causation is denied by my account of laws. A causal relation between events A and B does not mean that A and B are necessarily related. The law underlying a causal relation could be said to be necessary. However, once their quantities could not be combined to a single law, events A and B would not be causally related and any events possessing the required quantities would have such a causal relation. So this understanding of causation indeed preserves the intuition in the intervention argument as identified by Richard Corry, that is, "it is always possible that the cause described by a causal law could occur, but something else could intervene to prevent the effect from happening"[68].

[67] See Cartwright (1983), P 22.
[68] See Corry, etc. (2006), P 264.

As a final remark, note that the above discussion is limited to causation as related to natural laws, that is, how laws feature in the explanation of singular causal facts. As a result, it is not a denial that there are general causal talks in science, which might be contained in scientific theories. But the important point is that such causal talk does not lie in scientific laws.

Section V.2. Idealizations in laws

In this section, I would like talk about idealizations or abstractions involved in laws. This has been discussed by Cartwright and used by her as one of the arguments against the truth of fundamental laws and also for the construal of fundamental laws in terms of capacities. In this section, I argue just the opposite, that is, fundamental laws are true. I show this by giving an alternative explanation of idealizations which accords with my general account of laws.

As characterized by Cartwright, "in idealization, we start with a concrete object and we mentally rearrange some of its inconvenient features – some of its specific properties – before we try to write down a law for it."[69] The typical examples are Galilean idealizations, "which underlies all modern experimental enquiry"[70], such as a frictionless plane, "ideal gases or perfectly rigid bodies"[71]. "The fundamental idea of

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[69] See Cartwright (1989), p 187.
[70] Ibid. p 191.
[71] Ibid. p 203.

the Galilean method is to use what happens in special or ideal cases to explain very different kinds of thing that happen in very non-ideal cases."[72] Cartwright then proposed that this method "presupposes tendencies or capacities in nature"[73]. As to abstract laws that are established at the end of idealizations, they "do not literally describe the behavior of real material systems". Fundamental laws, i.e., general abstract equations, as they stand, do not describe reality accurately[74]. To render them applicable to the real world, we have to "make some approximations", or "add a phenomenological correction factor"[75] to fundamental equations so that we could finally get a new equation which gives a correct description. In other words, "approximations take us away from theory and each step away from theory moves closer towards the truth."[76] Again, this process or account "presupposes an ontology of capacities"[77]. This is the general idea that Cartwright has about fundamental abstract laws and idealizations involved in them.

To examine this position, we could analyze the example of an amplifier model which Cartwright used in her argument. In this example, we need to calculate the small signal properties of an amplifier. This is done in two ways, one by calculation based on the equation $|A_v| = \frac{R_L}{r_e+(r_b+R_s)(1-\propto)}$ and the other by direct measurement. The

[72] Ibid. p 191.
[73] Ibid. p 188
[74] Ibid. p 203.
[75] See Cartwright (1983), p 111.
[76] Ibid. p 107.
[77] See Cartwright (1989), p 202.

result is that the theoretically predicted value of midband gain of the amplifier based on the fundamental equation is widely different from the actual measured value of the amplifier. Only when the fundamental equation is modified by adding a term which accounts for the factor missing in the original equation does it describe reality successfully. This example, as conceived by Cartwright, shows clearly that fundamental laws cannot capture reality accurately.

However, I would like to argue that this example cannot really demonstrate that the fundamental equation is wrong. The problem is that there is no so-called actual value of the midband gain. As I have emphasized at the very beginning of discussing measurement, the magnitude of a quantity is a relative value. So the comparison between two magnitudes is meaningful only when their measurements are based on the same law, which, so-to-speak, puts them in the same measuring system. However, in Cartwright's example, there is no reason to think that the two measurements, the calculation and the direct measurement, have the same basis or use the same law. Indeed, since the resulting magnitudes are different, these two measurements should have been based on different laws or principles. Then, it does not make sense to just judge that the directly measured magnitude is true and the other is wrong since they are based on completely different laws. Cartwright can only make such judgements if she could show that the law that the calculation is based on is wrong and the principle that direct measurement uses is correct. This is, however, exactly what she aims to demonstrate. As a result, the example employed by Cartwright fails to establish that fundamental laws or equations are wrong.

Now I turn to showing why fundamental equations are true in the real world despite idealizations involved in them. Remember that what a law essentially captures, as I have argued, is the structure of a physical fact. As a result, it is the relation among the quantities established by a law that matters for its truth, rather than any specific magnitude of a quantity. Fundamental equations are said to be idealized because they omit some factors of a fact without consideration. This means that it is only concerned with some quantities of a physical fact. However, as long as the relations depicted are right, the law is correct. Adding further quantities to the original equation does not change the relation among the original quantities. This is obvious when the form of laws before and after the addition are similar, as in Cartwright's example. However, even when the form of laws seems completely different, such as Einstein's law of relativity compared with Newton's laws, the original laws or equations are still true, which is independently proved by the physical facts.

In conclusion, fundamental equations do describe correctly the relation of the quantities in them, which is proved by the physical facts that they are based on. When they are modified by adding more quantities, the resulted equation could be said to be more comprehensive or mature. New equations may be able to be applied to more cases than the original equations. However, they are not any truer than the original ones.

Conclusion

My account of laws is fundamentally different from the traditional accounts of laws, including Humean, universalist and essentialist theories, in our ideas about the metaphysical basis of laws. In this thesis, I have demonstrated that the metaphysical basis of physical laws is a physical fact of motion. Specifically, quantities in laws are not properties, either intrinsic or relational. By contrast, traditional theories including Humean theories, dispositionalist theories and universalist theories all take properties to be the fundamental basis of laws. This has a direct influence on these theories' construction of the form of laws, which grounds their further discussions. I have pointed out several problems of confusing quantities with qualities and proposed a new understanding of laws given the correct interpretation of quantities.

Different quantities represent different aspects of a physical course of change, such as motion. Mathematical relations among quantities are determined by the actual motion that we observe. In other words, the basis of laws is not any individual, but rather an event or a fact as a whole. As a result, instead of talking about relations among quantities as if they are independent with each other, it would be more appropriate to take these quantities as constituting the structure of a fact and make the whole structure to represent the mathematical features of a changing process. It is in this sense that I call laws “mathematical structures”.

Traditional misconceptions of laws, to a large extent, originate from the appearance of our measuring process and the unexamined intuitions about causation. On the surface, we are indeed comparing two different objects or their properties. However, we have to investigate what underlies the comparing processes. Then we would see that individuals or properties are only appearances. What is essential is actually the physical movement that objects carry out. A correct understanding of causation is possible only after we have investigated the nature of natural laws. The investigation of laws should not be misled by unreliable intuitions about causation.

As I have pointed out above, this account of laws respects the empirical nature of scientific discussion. In this respect, it inherited the most important legacy of Humean theories. However, it is different from traditional Humean theories in how the laws are actually linked with reality. It follows the spirit of Russell’s investigation of laws in a detailed analysis of actual scientific laws. In some sense, the view I have proposed in this thesis is a minimalist view about laws and scientific explanations. From the perspective of this picture, the very nature of scientific laws entails that they are unable to tell us what philosophers call the essence of objects. It respects the empirical nature of scientific practice and demystifies it from fantasies that philosophers have attached to the sciences. But exactly in this way, we can see why scientific practice is a reliable and effective tool for our investigation of the natural world because of its modesty. Further speculations about the natural world could further be carried out based on scientific laws that we have found. These are, however, outside the realm of accuracy or preciseness that laws provide to us. This is why there exist competing scientific theories which nonetheless share the same scientific laws.

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