Chapter 1
Phenomenological Approaches to Physics. Mapping the Field

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Abstract Much ink has been spilled over the interrelations between philosophy and physics in the late 19th and early 20th century as well as over the emergence of philosophy of science as an autonomous philosophical sub-discipline. Although our understanding of these issues is certainly more nuanced today than it was only a couple of years ago, more work needs to be done in order to arrive at an adequate picture of the intricate relations between philosophy and physics on the one hand and of how philosophical reflections on the physical sciences evolved during the last century on the other. This volume addresses one of the remaining blind spots, namely the role of phenomenology in the development of 20th century (philosophy of) physics. In this introductory chapter, we shed light on the characteristics and historical development of phenomenological approaches to physics, indicate how current debates in philosophy of physics could benefit from phenomenological approaches, and provide summaries of the individual chapters.

1.1 Introduction

One of the more curious aspects of the development of 20th century philosophy is the infamous continental/analytic-divide. Even though there are growing doubts about its philosophical significance, the continental/analytic-split continues to shape the face of professional philosophy. In many areas the reality is still that philosophers who feel at home in one tradition tend to ignore the other. This state of mutual ignorance is particularly noticeable in philosophy of science, where references to

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thinkers from outside the well-established canon of analytic philosophy are even scarcer than in other fields such as ethics, philosophy of mind, or aesthetics.

It has been argued that the relative absence of continental influences on contemporary philosophy of science is a result of the historical contexts from which analytic and continental philosophy have emerged. According to Barry Smith, for instance, "post-Kantian philosophy in the German-speaking world [of the 19th and early 20th century] ought properly to be divided into two distinct strands which we might refer to as the *German* and *Austrian* traditions" (Smith 1994, 1). Smith argues that the works of "Austrians" such as Bernard Bolzano, Franz Brentano, Ernst Mach, or Alexius Meinong are characterized by a sympathy towards British empiricism, by their anti-Kantianism, by the employment of a clear and concise language, and by a strong interest in the special sciences. It is from this tradition that logical empiricism and, by extension, contemporary analytic philosophy of science has emerged. German philosophy, on the other hand, is the tradition from which continental philosophy grew out. What unites thinkers as diverse as Johann Gottlieb Fichte, Georg Wilhelm Friedrich Hegel, Wilhelm Windelband, or Heinrich Rickert is, according to Smith, their idealist or even romantic leanings, their lack in linguistic clarity, and—most important for our purposes here—their neglect of the empirical sciences. It is, so the story goes, especially the ignorance of the sciences "which can be seen to have thwarted the development of a native German tradition in the philosophy of science" (Smith 1994, 4).

Although it would lead us too far afield to discuss Smith's account in detail, it is worth noting that recent years have seen a steady increase in studies contributing to a less Whiggish view of the historical context from which contemporary philosophy of science has emerged. In many of these studies, special emphasis has been put on the neo-Kantian tradition that dominated the German-speaking world at the end of the 19th and the beginning of the 20th century. The renewed interest in neo-Kantianism has advanced our understanding of the history of philosophy of science in several important ways. First, it has become clear that the strict separation between an Austrian and a German tradition oversimplifies the complex personal, institutional, and intellectual interactions between seemingly incompatible philosophical cultures. Take logical empiricism—arguably the pinnacle and endpoint of what Smith refers to as the Austrian tradition—as an example: not only is it the case that many of its leading figures (such as Rudolf Carnap, Moritz Schlick, or Hans Reichenbach) started out as neo-Kantians; despite their sometimes violent anti-Kantian rhetoric, many logical empiricists sided with the neo-Kantians in their rejection of naturalism or their understanding of philosophy as a reflective, second-order discipline (cf. Glock 2015). Second, the contention that a serious engagement with the special sciences has never been part of the German tradition is in fact a highly questionable one: As early as in the 1880s, several inner-scientific developments such as the introduction of non-Euclidean and non-metrical geometries as well as the rise of field and statistical theories in physics attracted the attention of systematically minded Neo-Kantians like Hermann Cohen or Paul Natorp (cf., for instance, Richardson 2006). But even after physics had been revolutionized in 1905 and 1915, Neo-Kantians such as Ernst

Cassirer forcefully countered the claim according to which Kantianism in all of its guises was proven untenable by Einstein's theories of special and general relativity.

The point of the previous remarks is that our understanding of the development of 20^{th} century philosophy of science is certainly more nuanced today than it was only a few years ago. However, since neo-Kantianism is, as we shall see, by no means the only influence from outside the well-established canon of analytic philosophy, still more work needs to be done in order to arrive at an adequate picture of how philosophical reflections on the sciences have evolved over the course of the previous century. The aim of this anthology is to address one of the remaining blind spots, namely the impact *phenomenology* had on the development of 20^{th} and 21^{st} century philosophy of science. In particular, this anthology focuses on the role phenomenology plays in the ongoing attempts to understand the development and nature of physics from a philosophical point of view. What is more, we will also take a closer look at the ways in which phenomenology influenced the development of 20^{th} century physics.

The idea that phenomenological reflections can contribute to our understanding of physics, or even to the development of physics itself, may come as a surprise to some. After all, one might suspect that it is already due to methodological reasons that the relationship between phenomenology and physics is likely to be fraught with difficulties. For phenomenology, as it was conceived by its founding father Edmund Husserl, is an a priori science that proceeds from the first-person perspective and primarily aims at revealing essential structures of consciousness. Physics, on the other hand, is an a posteriori science that proceeds from the third-person perspective and aims at revealing contingent laws and facts about spatio-temporal entities. Why, one could ask, should an a priori study of consciousness contribute to our understanding of a cognitive enterprise that seeks to unveil the deep-structure of reality by empirical means, and, as it is often argued, through a systematic and methodologically regimented exclusion of everything subjective? The aim of this anthology is to give an answer to this (and related) questions and to present phenomenology as a useful framework for the philosophical interpretation of the physical sciences. As we shall see, phenomenological reflections on, for instance, the relationship between mathematics and physics, the role of experience in science, or the relationship between subjectivity and objective knowledge provide rich resources for addressing many of the most pressing issues in (philosophy of) physics.

The structure of this introductory chapter is as follows. Since we do not expect all readers to be familiar with phenomenology, we will start out with an overview of some of its characteristic features in section 1.2. In section 1.3 we will focus on the role physics plays in the works of Edmund Husserl, the founding father of the phenomenological movement. Four topics will be addressed: Husserl's formal philosophy of science; his conception of regional ontologies and its relation to Hermann Weyl's "world geometrry"; Husserl's critique of the "mathematization of nature"; and London and Bauer's phenomenological interpretation of quantum mechanics. While section 1.4 will be concerned with Martin Heidegger's and Merleau-Ponty's views on physics, we shall provide a brief overview of the subsequent chapters in section 1.5.

1.2 Husserlian phenomenology

Giving a brief overview of phenomenology is by no means an easy task. Just as it is hard to say what *the* defining characteristics of analytic philosophy are, there is no general agreement within the phenomenological community on what makes a particular approach truly phenomenological. It is hence mainly for pragmatic reasons that our focus in this section will be on the founder of phenomenology, the Austrian-German philosopher Edmund Husserl. Even though many aspects of Husserl's philosophy have been rejected by later phenomenologists, it is a generally accepted fact that Husserl's oeuvre has set the agenda for subsequent developments in the field of phenomenological philosophy.

Edmund Husserl is one of the most influential and substantial thinkers of the 20^{th} century. A mathematician by training, Husserl paid special attention to the formal sciences at the beginning of his philosophical career. By the turn of the 20^{th} century, however, Husserl had already widened his interests and turned phenomenology into a general method for analyzing the essential structures of consciousness and the role they play in virtually all areas of cognitive practice. Even though the majority of the works that have been published during his lifetime were rather programmatic in nature, Husserl's voluminous *Nachlass*, consisting of some 40.000 pages, contains detailed analyses and significant contributions to almost all philosophical sub-disciplines. In light of the complexity and breadth of his oeuvre, any attempt to break down Husserl's philosophy into a set of defining features will inevitably be incomplete.[1] This limitation notwithstanding, we still hope that the following ten themes give an initial sense of what phenomenology is and why it constitutes a useful framework for the analysis of scientific cognition.

1.2.1 Anti-psychologism

The publication of Husserl's *Logical Investigations* in 1900/01 is widely considered to mark the birth of phenomenology. Husserl himself considered it the "breakthrough" to phenomenology (Husserl 2001b, 3). The first volume of the *Logical Investigations*, the *Prolegomena*, is devoted to a detailed refutation of psychologism, i.e. the thesis that logic is merely a branch of psychology such that logical laws can be reduced to psychological laws (cf., in particular, Husserl 2001b, 40). One of Husserl's main arguments against psychologism is that it is ultimately self-refuting due to its relativistic and skeptical consequences. While it is controversial whether Husserl should be read as subscribing to platonism or some kind of truth-value realism, it is clear that for Husserl logical laws are not a posteriori laws about how we (must) think; the laws of logic are a priori and objective.

[1] Cf., for more detailed introductions to phenomenological philosophy, e.g. Smith 2007, Luft and Overgaard 2012 or Zahavi 2012. The relations between phenomenology and (philosophy of) science are discussed in Kockelmans and Kisiel 1970, Feist 2004, Gutting 2005 or Hyder and Rheinberger 2010.

There is wide agreement that the *Prolegomena*, along with Gottlob Frege's attacks on psychologism, were instrumental for the anti-psychologistic climate that was characteristic for much of phenomenology and early analytic philosophy. However, in the subsection *On certain basic defects of empiricism* (Husserl 2001b, 59-61) Husserl broadens his criticism to include classical empiricism as an ultimately self-refuting position. One of Husserl's main arguments is that empiricism "*destroys the possibility of the rational justification of mediate knowledge*, and so destroys *its own possibility* as a scientifically proven theory" (Husserl 2001b, 59). Husserl's point here is that empiricism does not allow for the possibility of immediately grasping substantial epistemological principles, including principles that would govern any form of inferential reasoning. As a consequence, mediate (i.e. inferential) justification and knowledge would be impossible if empiricism were true. It is interesting to note that one of the most vocal contemporary critics of empiricism, Laurence BonJour, makes basically the same point when he accuses empiricism of amounting to "intellectual suicide" (BonJour 1998; cf. also Berghofer 2018d; Berghofer and Wiltsche 2019).

1.2.2 Intentionality

The second volume of the *Logical Investigations* consists of six interrelated investigations in which Husserl expounds his early phenomenological project. Of particular significance are the fifth investigation that focuses on the *intentionality* of consciousness, and the sixth investigation in which Husserl lays out his vision of a genuinely phenomenological epistemology in which the conception of intentionality plays a pivotal role. Quite generally, the term "intentionality" denotes the "aboutness" or "directedness" that is the mark of the mental. Mental states such as perceptual experiences, wishes or desires are essentially characterized by their being directed at something beyond themselves. What is more, intentionality comes in many different flavors. One can be intentionally directed towards the same object in many different ways, such as when one first believes that one's bike is in the office, and then sees that one's bike is in the office. For Husserl, the ways in which objects present themselves in different kinds of intentional acts are of utmost epistemological importance. Intuitive acts (such as, for instance, perceptual acts) are experiences in which the object is given in a presentive manner, i.e. in which the intended object is not only meant but also immediately present. These acts are contrasted with empty (or signitive) acts in which what is given is not the object in its actual presence, but the object as something that is only meant. While believing that one's bike is in the office is an empty act, the intuitive act of seeing the bike *fulfills* the empty act of believing. For Husserl, fulfillment, i.e. the congruence between the object as it is emptily intended and the object as it is intuitively given, is what distinguishes knowledge from mere belief.

An important achievement of Husserl's mature phenomenology is the discovery of the *horizontal structure* of intentionality. To make a long story short: As phenomenological descriptions reveal, the meaning an object has for an experiencing subject always goes beyond what is directly and immediately given. Consider, for instance, a veridical perception of a material object. At first glance, what presents itself to the experiencing subject is a three-dimensional object in space. However, a more accurate description shows that what is really sensuously given is not a three-dimensional object in space, but only one single profile of the object, its current frontside. To be sure, the experiencing subject could alter her position and make the current backside the new frontside, and vice versa. But this does not change the fact that the intended object is always given in perspectives and that, more generally, objects always and necessarily have more parts, functions, and properties than can be actualized in one single intentional act. What this shows is that there is a describable difference between what is meant through a particular act (a three-dimensional object in space) and what is sensuously given (the object's facing side with its momentarily visible features). Phenomenologically construed, this discrepancy does not represent a problem that must be somehow remedied, e.g. by proposing a theory that explains how a number of seemingly disconnected profiles add up to a homogeneous thing to which we then attribute these profiles. The fact that our intentions always transcend the sphere of direct givenness is rather to be treated as a phenomenologically discoverable feature of experience itself: Fulfilled intentions towards objects are always embedded in horizons of intentions that are momentarily unactualized, but that could be actualized in the course of further acts. Intending is, as Husserl puts it, always and necessarily an "*intending-beyond-itself*" (Husserl 1960, 46).

1.2.3 Description and eidetics

As we have already indicated, phenomenology is a descriptive study of consciousness as experienced from the first-person point of view. Given the fact that in contemporary analytic parlance the term "phenomenology" is often restricted to denote a property of some mental states, namely their "what-it's-like-ness," it could be assumed that phenomenologists are in the business of offering more or less random descriptions of the qualitative characteristics of their own experiences. It is important to note, however, that this construal misses the point of Husserl's philosophy almost entirely. Instead of delivering collections of particular facts about one's own experiences, phenomenology in Husserl's sense is an eidetic science that seeks to generate intuitive a priori knowledge of the essential, i.e. non-contingent, features of consciousness as such. Examples for eidetic laws of consciousness are: "All experiential consciousness is intentional," "Intuitive acts can fulfill empty intentions," or "Physical objects can only be given in perspectives."

It is not unreasonable to suspect that there is an irresolvable tension between the methodological principles of phenomenology on the one hand and its lofty aspirations as an eidetic science of consciousness on the other. The worry, in a nutshell, is this: Doesn't phenomenology's self-understanding as a descriptive first-person method exclude the possibility of knowing *general* facts about consciousness as such? After all, while the requirement to proceed from a first-person perspective seems to restrict the phenomenologist to her own consciousness, the commitment to a purely descriptive approach seems to preclude the possibility of general insights. Husserl's answer to this problem is that phenomenologists are required to perform the *eidetic reduction* in order to tease out the invariant components of experience and thus to intuit the essential laws underlying it. In a similar sense in which we must "look through" the factual peculiarities of a series of circular objects in order to intuit an Euclidean circle in its pure ideality, the point of the eidetic reduction is to bracket any considerations concerning the accidental and contingent, and to direct one's attention to essential laws instead.

Following Husserl's remarks in *Experience and Judgment* and elsewhere (cf. Husserl 1973a, 341-348), the intuition of essential laws is preceded by the method of *eidetic variation*: In systematically varying the idea of a material thing, for instance, one realizes that there are features, such as its givenness in perspectives, without which something would no longer count as an exemplar of the kind of thing under consideration. It is thus through the identification of invariants that we gain knowledge of essential laws. It should be noted, however, that this knowledge is not inferential in nature. Essential laws can and must be immediately grasped; like certain mathematical truths they present themselves not to sensory intuition, but to categorial or eidetic intuition.

1.2.4 The epistemic significance of experience

For Husserl, the most fundamental question in epistemology is how subjectivity can be the source of objective knowledge, how "objectivity becomes'presented', 'apprehended' in knowledge, and so ends up by being subjective" (Husserl 2001c, 169). In contemporary terminology, Husserl is an epistemic internalist in a twofold sense. He states that, first, mental states are our justifiers, that "*subjective acts provide the reasons for everything*" (Husserl 2008, 120), and that, second, it is only internal factors that give subjective acts their justificatory force.[2] On Husserl's view, the kind of acts that play the role of justifiers for all sorts of beliefs are *originary presentive intuitions*. What makes this particular category of acts special is the fact that they present their objects as "bodily present," "actually present," or simply "self-given" (Husserl 1997, 12). Since all mediate justification leads back to immediate justification, and since originary presentive intuitions are the source of this kind of justification, originary presentive intuitions also play the role of *ultimate* (albeit fallible) justifiers. The overall image that emerges from Husserl's detailed analyses of different kinds of intentional acts is summarized in the famous *principle of all principles*:

[2] For more details on Husserl's epistemology and his conception of epxeriential justification, cf. Berghofer 2018a, 2019. For how Husserl's approach can enrich current debates in epistemology, cf. Berghofer 2018c.

> No conceivable theory can make us err with respect to the *principle of all principles: that every originary presentive intuition is a legitimizing source of cognition*, that *everything originarily* (so to speak, in its "personal" actuality) *offered* to us *in "intuition" is to be accepted simply as what it is presented as being*, but also *only within the limits in which it is presented there*. (Husserl 1983, 44)

To say that an experience is an originary presentive intuition is to say that this experience presents its object in immediate givenness. However, what this means in concrete contexts depends on the type of experience one is having. Different types of experiences correspond to different types of (originary) givenness, and different types of originary givenness correspond to different types of evidence. Very roughly, one can distinguish between inadequate (perceptual), adequate (introspective), and apodictic (eidetic) evidence. What this means is that, on Husserl's view, perceptual experiences of material objects are just a subcategory of originary presentive intuitions, and that, say, introspective experiences of one's own mental states or eidetic experiences of ideal objects belong into this category as well. Since all these types of originary presentive intuitions can be regarded as experiences in a broad sense, Husserl claims that his phenomenological-epistemological system amounts to a "universal" form of empiricism (Husserl 1971, 89).

1.2.5 Phenomenology as First Philosophy

Husserlian phenomenology is an ambitious project, aiming at nothing less than realizing the venerable idea of a First Philosophy, the ultimate science. For Husserl, this means that for any science, indeed for any piece of knowledge, phenomenology must be capable of elucidating the legitimacy of this science or piece of knowledge. Here is how Husserl puts the basic idea:

> [I]t shall be shown that phenomenology encompasses the whole system of sources of knowledge from which all true sciences must draw their fundamental concepts and statements and the entire force of their ultimate justification [Rechtfertigung]. Precisely for this reason, phenomenology achieves the vocation to be "First Philosophy" in the true sense, the vocation, to confer to all other sciences unity due to ultimate grounding [Begründung] and a link to the ultimate principles and to reorganize all of these sciences as lively organs of a single, absolutely universal science, philosophy in its oldest sense. (Husserl 2000, 200; our translation)

But how can phenomenology, a science of the essential structures of consciousness, serve as the ultimate science? The answer to this question, as indicated above, is to be found in Husserl's analyses of the variety, epistemic force, and systematic role of *experience*. The idea, roughly, is that every piece of knowledge can be traced back to epistemically foundational experiences. To be more precise, it is experiences that bear the mark of originary givenness that play this role. Investigating the sources of knowledge, then, means investigating modes of givenness—the ways experiences present the objects they are directed at. On Husserl's view, different sources of knowledge correspond to different types of experiences, which in turn correspond to different types of evidence. It is thus one of the most important tasks of phenomenology to clarify the different modes of originary givenness.

1.2.6 Husserl's anti-naturalism

When Husserl elaborates on the epistemological significance of different types of experiences, his investigations do not make use of methods usually associated with the empirical sciences. Husserl does not classify experiences according to the bodily organs that produce them. He does not link justificatory force to causality or other external factors such as reliability or truth. What counts for him is how experiences present their contents, how objects are given within the respective experiences. The focus is on the phenomenal character of the experiences, not on any external factors. This emphasis on the internal can be regarded as a consequence of Husserl's anti-naturalism. Naturalism comes in ontological and methodological forms. Here we focus on methodological naturalism. Broadly speaking, in its methodological guise, naturalism states that only the methods of the natural sciences are acceptable forms of gaining knowledge. Accordingly, even philosophy must proceed like an empirical science.

Husserl's descriptive methodology, investigating experiences from the first-person perspective, as well as his eidetic methodology of gaining immediate a priori insights about necessary structures of consciousness are clearly opposed to methodological forms of naturalism. This is because the natural sciences are typically considered to proceed from the third-person perspective.[3] Here the basic idea is that we look at the world and then we quantify, generalize, and mathematize the data delivered by experience. Husserlian phenomenology, by contrast, is concerned with how we look at the world. What does it mean for a subject to undergo certain types of experiences, and what are the a priori correlations between modes of givenness, modes of evidence, and types of objects? Furthermore, Husserl stresses that phenomenological methods do not include inferential methods characteristic of the natural sciences such as induction, deduction, or inferences to the best explanation. Instead, phenomenologists aim at immediately grasping a priori truths.

Finally, Husserl's above-mentioned ambition to introduce phenomenology as First Philosophy, the ultimate science, is also at odds with the spirit of naturalism. Phenomenology is not one science among the other individual sciences. Instead, according to Husserl, phenomenology is the science that clarifies the epistemological foundations of the individual sciences including mathematics and physics, thereby

[3] It should be mentioned, however, that such an apparently clear distinction between the empirical sciences and phenomenology would be blurred if the first-person perspective were incorporated to the natural sciences. For instance, there are trends in current experimental psychology that explicitly argue for incorporating the first-person perspective into science, emphasizing the significance of Husserlian phenomenology. One such proposal is Liliana Albertazzi's "experimental phenomenology" (cf. Albertazzi 2013). As we will see, some phenomenologists, such as Merleau-Ponty, believe that the incorporation of subjectivity is even possible in physics.

bestowing legitimacy on them. While the individual sciences make use of different types of experiences and different types of reasoning, phenomenology must investigate which types of experiences and reasoning are justification-conferring and why this is so.

1.2.7 The life-world

One of the key concepts in Husserl's late philosophy, playing an important role not only in philosophy but also in other areas such as sociology or anthropology, is the *life-world*. Even though Husserl seems to use the term in different, sometimes even conflicting ways (cf. Moran 2012, chapter 6), the life-world, broadly construed, is the world of ordinary objects, the world of tables and chairs, the world as it is immediately perceivable and familiar to us. However, the life-world is not only the pre-scientific world in which we all live. It is also the "meaning-fundament of natural science" (Husserl 1970, 48) and the "realm of original evidences" to which "[a]ll conceivable verification leads back" (Husserl 1970, 127 f.; translation slightly modified).

The characterization of the life-world as both the meaning fundament and the epistemic basis of science makes clear why the life-world concept plays such a pivotal role in Husserl's late attempts to come to grips with the status of modern science in the wider context of human intellectual life. As the title of his last major publication, *The Crisis of European Sciences and Transcendental Phenomenology*, indicates, Husserl considers modern scientific culture to be haunted by a deeply-rooted crisis. However, it is important to note that the crisis diagnosed by Husserl does not concern the sciences themselves, but rather our philosophical understanding of science and thus the meaning science has for us as members of modern society. Husserl's argument, in a nutshell, is this: Since its inception in the 17th century, modern science is bewitched by an objectivist mindset according to which science, and only science, describes reality as it is in itself. As a consequence, the status of the life-world is degraded to that of a mere illusion (cf., in particular, Husserl 1970, 48-53). For Husserl, the main problem with this view is that it is based on a mistaken construal of the relationship between scientific theorizing on the one hand and the realm of pre-scientific experience on the other. As Husserl seeks to show in quite some detail, the mathematical models that are used in science since the time of Galileo require the life-world as their unsurpassable meaning fundament. If this is correct—if the worldview that threatens to eliminate the life-world is necessarily grounded and thus presupposes the lifeworld—, objectivism indeed appears to be flawed: To substitute the scientific image for the life-world of pre-scientific experience would then be like sawing off the branch on which science is sitting. On Husserl's view, the only cure for the objectivist mindset is to engage in the project of a phenomenological clarification of the sciences:

> One must fully clarify, i.e., bring to ultimate evidence, how all the evidence of objective-logical accomplishments, through which objective theory (thus mathematical and natural-

> scientific theory) is grounded in respect of form and content, has its hidden sources of grounding in the ultimately accomplishing life, the life in which the evident givenness of the life-world forever has, has attained, and attains anew its prescientific ontic meaning. (Husserl 1970, 128; translation slightly modified)

1.2.8 Historicity and genetic phenomenology

Husserlian phenomenology is *critical* in the sense that it seeks to unveil the implicit structures that are always already presupposed when we approach the world from within the natural attitude. When dealing with the realm of material things, for instance, the aim of phenomenological analysis is to identify the essential laws that govern the appearance of these things as well as the sorts of intentional acts in which these things are presented. In order to engage in this kind of analysis, it is sufficient to treat material things as objectivities that are already fully constituted. Experiencing subjects have an initial, implicit understanding of what these things are, and the goal of phenomenology is to unpack this initial understanding by descriptive means. By proceeding in this manner, one engages in what is commonly referred to as *static phenomenology*.

Yet, as the later Husserl came to realize, static phenomenology is but one possible approach, and a limited one at that. Instead of taking fully constituted objectivities as a starting point, one can also focus on the *becoming* of these objectivities, their "history of objectivation," as Husserl puts it (Husserl 2001a, 634), and thus on the sedimented layers of constitution that underlie our experience of objects. A particularly telling example of such a *genetic* approach is the late draft essay "The Origin of Geometry" (Husserl 1970, 353-378; cf., also, da Silva 2017). In it Husserl employs a method of regressive inquiry in order to elucidate how the original constitution of geometrical objects came about, and what this "history of objectivation" means for the ideal objectivity we ascribe to them. An important upshot of Husserl's analysis is that the original constitution of geometrical objects such as Euclidean planes crucially depends on life-world practices such as land surveying or the gradual smoothing of real surfaces.

Instead of proceeding from the finished products of constitution, genetic phenomenology attempts to grasp how entire communities of subjects engage in the building up of sense through time. Seen from this perspective, then, constitution is not so much an instantaneous event that is brought about by a solitary subject, but a communal process that is essentially temporal in nature. By emphasizing the temporal character of constitutional processes, Husserl opened an avenue for a more hermeneutically oriented phenomenology, as it is most prominently exemplified in the works of Martin Heidegger. According to Heidegger, historicity—the Heideggerian notion for temporality—is one of the ontological structures that describe Dasein and its being.

1.2.9 Embodiment and intersubjectivity

Whereas in the natural attitude we take the objectivity of the world as a starting point, the aim of phenomenology is to give a detailed account of how objectivity is constituted in consciousness in the first place. Yet, to treat objectivity as an analysandum not only means to focus on the sense of transcendence we usually ascribe to certain (ideal or real) objects. It also means to account for the kind of transcendence we ascribe to other subjects, the interrelations between them, and the sense of sociality that characterizes how the life-world presents itself to us. Husserl's analyses of the phenomenon of intersubjectivity roughly fall into three categories. First, Husserl seeks to offer detailed descriptions of the kinds of acts through which a subject experiences other subjects as both similar but also irreducibly different from oneself. In this context, special emphasis is put on acts of *empathy* and the "analogizing appresentation" in which they are grounded. Second, Husserl studies acts of empathy as the basis of our practical, moral, aesthetic, and emotional evaluations. Third, and perhaps most important, the mature Husserl offers an account of how intersubjectivity figures as a necessary condition for the possibility of experiencing the world as something objectively existing, as something that is there "for us." Consider, for instance, the perceptual experience of a material thing. As we have mentioned earlier, to perceive a thing also always means to co-intend a horizon of aspects that are absent in the currently present perception, but that could be actualized in the course of a continued perceptual encounter with the thing. This, however, raises the question concerning the constitutive status of these co-intended aspects. Going through Husserl's writings, two answers seem to prevail: Husserl sometimes claims that absent but co-intended aspects are constituted as aspects of the thing that were or could be actualized through past or future experiences. On other occasions, Husserl writes as if co-intended aspects were constituted as actually perceivable possibilities. Yet, as Zahavi has shown in detail (Zahavi 2001), the mature Husserl rejects both earlier views and opts for an interpretation that emphasizes the role of intersubjectivity. On this interpretation, absent but co-intended aspects are not merely constituted as the contents of possible experiences *I* could have, but as the contents of possible experiences *every member of an open community of subjects (including both foreign subjects and myself) could have*. Or, to put it in Husserl's own words:

> Every appearance that I have is from the very beginning a member of an open, endless, but not actualized range of possible appearances of the same, *and the subjectivity of these appearances is the open intersubjectivity*. (Husserl 1973d, 289; our translation)

Husserl's account of perceptual experience allows us to address another important topic, namely that of embodiment. On Husserl's view, perceptual episodes consist in the continuous "probing" of intentional horizons, i.e. in the attempt to harmonize new incoming sensuous data with the anticipated aspects that are co-intended through the horizon. However, in order to generate new sensory input, the perceiving subject must engage in several bodily activities such as ocular movements or the variation of the subject's bodily location in space. For Husserl, such kinaesthetic abilities not only shape our perceptual interactions with reality—the fact that consciousness must be embodied is indeed an eidetic law that governs how the world presents itself to us.

1.2.10 Epoché, transcendental reduction, and transcendental idealism

Many of Husserl's early followers—especially those in the "Munich Circle"—were attracted by what they saw as a strong commitment to realism in early phenomenology. It thus came as a surprise to many that Husserl transformed his phenomenological project into a form of transcendental philosophy, effectively claiming, for instance, that "*an object existing in itself is never one with which consciousness or the Ego pertaining to consciousness has nothing to do*" (Husserl 1983, 106). Even though Husserl's "transcendental turn" already took place around 1905, his transcendental project was first developed in print in *Ideas I*.

Crucial for Husserl's transcendental phenomenology are two interrelated methodological devices, the epoché and the transcendental reduction. The epoché is the *suspension* of the *general thesis of the natural attitude*, i.e. our naive, pre-reflective belief in the mind-independent existence of the world and its objects. The epoché, then, enables the transcendental reduction which introduces a particular reflective attitude towards the world (Husserl 1960, 21; Husserl 1970, 152). After the epoché and the transcendental reduction have been performed, our attention is redirected from the objects we experience to the experiences themselves, to the givenness of the objects within experience, to the appearing of the objects, to the phenomena. It is these phenomena, as they appear after the general thesis of the natural attitude has been suspended, that make up the field for transcendental-phenomenological research and description.

The mature Husserl leaves no doubt that, on his view, phenomenology and transcendental idealism necessarily go hand in hand. In the *Cartesian Meditations*, for instance, we read that "[o]nly someone who misunderstands either the deepest sense of intentional method, or that of transcendental reduction, or perhaps both, can attempt to separate phenomenology from transcendental idealism" (Husserl 1960, 86). However, how Husserl's peculiar brand of transcendental idealism ought to be interpreted is still one of the most controversial topics in Husserl scholarship. The main question, of course, concerns the relationship between consciousness and the external world: Does transcendental phenomenology only imply that the *meaning* or *sense* of the intended objects is constituted by consciousness? Or does transcendental phenomenology advance the more radical claim that the objects themselves are constituted by consciousness and that, consequently, there is no reality beyond the phenomena? Basically, there are three lines of interpretation. First, there are those who understand Husserl's transcendental idealism as a purely methodological endeavor that is consistent with both metaphysical realism and metaphysical idealism (e.g., Carr 1999; Crowell 2001). Second, there are those who argue that transcendental phenomenology inevitably culminates in a form of metaphysical idealism (e.g., Smith 2003; Meixner 2010). Third and finally, some commentators argue that transcendental phenomenology has “metaphysical implications” (Zahavi 2003, 11) in that it can be considered “a rejection of metaphysical realism” (Zahavi 2010, 85), however without thereby collapsing into some sort of metaphysical idealism (Zahavi 2010, 81). Here we do not wish to take sides. However, clearly, one’s stance concerning the exact interpretation of Husserl’s transcendental phenomenology has implications for the phenomenological interpretation of science, for instance with respect to the scientific realism debate.

1.3 Husserl and (philosophy of) physics

Browsing through his voluminous oeuvre, one’s overall sense is that Husserl was a rather isolated thinker, a thinker who was so absorbed in tinkering with improvements of his philosophical system that he invested relatively little energy in a detailed engagement with the intellectual context of his time. For instance, when Moritz Schlick leveled a series of attacks at him, Husserl reacted only once in the foreword to the second edition of the *Logical Investigations*. While it would have been an easy task to respond to Schlick’s rather questionable objections in a forceful and philosophically rewarding manner, Husserl simply rejects them as “nonsense” (Husserl 2001c, 179) without substantiating his verdict in any way. Matters do not seem to be different in regard to the wider scientific context in which phenomenology stands: The fact that the most productive decades of his career were also marked by several fundamental revolutions in physics and mathematics seems to receive next to no attention in Husserl’s philosophical writings. For instance, the name “Einstein” is, to the best of our knowledge, mentioned less than ten times in all 42 volumes of the *Husserliana* edition (cf. Husserl 1970, 4, 125-126, 295; Husserl 1973b, 229; Husserl 2002, 297).

In light of these circumstances, it seems natural to assume that Husserl did not participate in the intellectual developments of his day and that, consequently, the attempt to extract philosophically illuminating analyses of the physical sciences from Husserl’s writings is a pointless exercise. In our view, however, such a conclusion would be premature. For one thing, there is historical evidence indicating that Husserl had a better understanding of the physics of his day than most of his writings may suggest. In a recently published article (Hartimo 2018), Mirja Hartimo has analyzed Husserl’s private library and came to the conclusion that books and articles on the development of theoretical physics outweigh those on other scientific disciplines (including mathematics and psychology) both in number and in the intensity of Husserl’s markings and annotations. As Hartimo points out, Husserl had not only familiarized himself with the special and general theory of relativity already before the 1920s. He was also aware of the developments in quantum mechanics as well as of the interpretational issues arising from these novel physical paradigms. To be sure, this basic familiarity with the physics of his day does not make Husserl a philosopher of physics in the present-day sense of the word. At a minimum, however, it should make us more confident that Husserl’s oeuvre contains at least some clues indicating how a genuinely phenomenological framework for the interpretation of physics may look like.

1.3.1 Husserl's formal philosophy of science

Even though physics, *per se*, does not play a major role in Husserl's early works, the *Logical Investigations* contain several remarks that are relevant from the perspective of a general philosophy of science. Judged by today's standards, the early Husserl seems to advocate a rather conservative construal of scientific methodology. Unlike phenomenology and other eidetic disciplines, the empirical sciences are said to rely on indirect methods which have "deduction, verification and [...] repeated modification" (Husserl 2001b, 160) as their main components. Furthermore, the early Husserl strongly emphasizes the role of demonstrative reasoning by arguing that "every explanatory interconnection is deductive" (Husserl 2001b, 147) and that every scientific explanation depends on "the explanatory ground of a law, from which a class of necessary truths follow" (Husserl 2001b, 146).

Readers familiar with the history of philosophy of science will not fail to notice the similarities between these remarks and the model of scientific method that was widely discussed until the 1960s under the label of *hypothetico-deductivism* (cf., e.g., Hempel 1966). In its simplest form, the idea behind hypothetico-deductivism is that a theory is confirmed (or disconfirmed) by its true (or false) observable consequences. Consider, to use an example used by Popper (2002, 38), the general hypothesis that pieces of thread will break whenever they are loaded with weights exceeding the thread's tensile strength. This general hypothesis logically entails the singular-predictive statement that a thread with a tensile strength of 1 kilogram will break if it is loaded with a weight of 2 kilograms. If experimental data proves the singular-predictive statement to be true, then the general hypothesis is thereby confirmed (or, on Popper's account, corroborated). If, on the other hand, experimental data proves the singular-predictive statement to be false, the hypothesis must be rejected or at least modified.

It should also be noted that hypothetico-deductivism is isomorphic to one of the classical accounts of scientific explanation, the so-called *deductive-nomological model* (Hempel 1965, 335-276; Popper 2002, 38-40). In line with Husserl's aforementioned remarks about explanation, the point of this model is that an empirical occurrence is explained if it can be deduced from a set of premises that includes at least one law that is necessary to the deduction. On this view, then, the fact that a piece of thread is broken is explained by deducing the singular statement describing this occurrence from a general, law-like statement ("All pieces of thread will break whenever they are loaded with weights exceeding the thread's tensile strength") and certain singular statements specifying the initial conditions ("The tensile strength of the broken thread was 1 kilogram"; "The weight that was put on the broken thread was 2 kilograms").

Given his early remarks on the matter, it comes as no surprise that some commentators claim that “Husserl [subscribes] to something like the hypothetical-deductive model” (Hardy 2013, 29), and that, more generally, Husserl’s vision of science “resembles that of the logical empiricists” (Gutting 1978, 47). Like his contemporaries in Vienna and Berlin, Husserl seems to be a proponent of what is nowadays called the *syntactic view* of scientific theories: On this view, theories are conceived of as linguistic entities, or, to be more precise, as axiomatized systems of sentences, analyzable in terms of predicate logic. This view, of course, fits well with hypothetico-deductivism: Roughly put, the idea is that the axioms of the system—the underived laws fundamental to the theory—allow for the deduction of general hypotheses. From these general hypotheses, singular-predictive statements are derived. And, finally, these singular-predictive statements are compared with corresponding experimental reports. Building on this general framework, proponents of the syntactic view such as, for instance, Rudolf Carnap, have advanced the radical idea that “*the logic of science takes the place of the inextricable tangle of problems which is known as philosophy*” (Carnap 2002, 279). Hence, all philosophy does—or, at least, ought to do—is to engage in the logical analysis of science by studying the linguistic features of scientific theories. On Carnap’s view, then, philosophy is nothing but *logic of science*, or, to use the German expression, *Wissenschaftslogik*.

Now on the face of it, Husserl’s position does not seem to be entirely at odds with Carnap’s. To be sure, Husserl would have had little sympathy for the radical idea that all meaningful problems in philosophy are problems concerning the logical syntax of the language of science. But Husserl is very outspoken in his conviction that phenomenology must, first, provide a clarification of the natural sciences, and that, second, logic plays a crucial role in the realization of this task. Consider, for instance, the following passage from the *Logical Investigations*:

> Whether a science is truly a science [...] depends on whether it accords with the aims that it strives for. Logic seeks to search into what pertains to genuine, valid science as such, what constitutes the Ideal of Science, so as to be able to use the latter to measure the empirically given sciences as to their agreement with their Idea, the degree to which approach it, and where they offend against it. (Husserl 2001b, 25)

As a closer look reveals, however, there are fundamental differences between Carnap’s *Wissenschaftslogik* on the one hand and Husserl’s appreciation of logic as a “theory of science” on the other. These differences become readily apparent when one takes into account that what Husserl calls logic is a much broader discipline than it is for the proponents of the syntactic view.

For Husserl, the term “science” denotes any systematic discipline in which we rely on theories in order to represent a particular domain of objects. Furthermore, all theories share certain essential properties which, on Husserl’s view, are logical in nature. Hence, there must also be a scientific discipline that studies these essential logical properties, and that, accordingly, specifies the ideal conditions under which a theory can be said to be truly scientific. In Husserl’s terminology, this meta-discipline is called *pure logic*. Since it studies what makes scientific theories truly scientific, logic is, strictly speaking, the *theory of theories*.

As Husserl points out in *Formal and Transcendental Logic* (Husserl 1969, 33-36), classical formal logic is characterized by its two-sidedness: As *formal apophantics*, it studies the domain of judgments by fixing pure meaning categories such as "Concept, Proposition [or] Truth" as well as "*elementary connective forms* [...] e.g. the conjunctive, disjunctive, hypothetical linkage of propositions to form new propositions" (Husserl 2001b, 153). Since every science will crucially rely on judgment and argument, apophantic logic constrains the formal structure of any possible theory with respect to its language, vocabulary, and grammar.

The systematic study of all possible forms of judgments, arguments, and their components is, without doubt, an important task. Yet, since judgments and arguments are always about something—since pure meaning categories always have pure object categories as their correlates—, formal apophantics must be complemented by what Husserl calls *formal ontology*, i.e. the formal-mathematical "theory of *something in general* and of its derived forms, thus of concepts like 'object,' 'property,' 'relation,' 'plurality,' and the like" (Husserl 1973a, 11). One can think of formal ontology in terms of a theoretical account of all possible objects of whatever kind, or, alternatively, in terms of a science of possible being. And since Husserl claims that knowledge of possibilities precedes knowledge of the actual (Husserl 1983, 190), formal ontology constrains the formal structure of every actual theory with respect to its object domain: The domain of an actual theory must, of course, be possible and for this reason has to comply with the laws of formal ontology.

Husserl even went a step further by extending and generalizing his formal philosophy of science into what he calls a *pure theory of manifolds*, i.e. "a science of the conditions of the possibility of theory in general" (Husserl 2001b, 155). Loosely put, the basic idea is this: To every theory corresponds a field of knowledge, i.e. a domain of objects to which the theory applies. Within the theory of manifolds—a mathematical theory that grew out of Riemann's attempts to generalize the concept of space—, only the form or structure of these fields of knowledge is taken into account. A manifold is thus an objectively structured collection of objects bearing certain relations. A theory of theories in the highest sense would then be a purely formal account of the nature of manifolds as such. A formal-mathematical meta-theory of this kind would allow us to define and to study the possible forms of all formally possible theories as well as the most general form of the world that science seeks to describe.

Even though much more could and should be said about Husserl's formal philosophy of science, these remarks suffice to bring the differences between Husserl and the syntactic view into sharper focus. As a result of the fixation on language that was prevalent among logical empiricists and their followers, proponents of the syntactic view took it for granted that theories are linguistic entities, that, consequently, the reconstruction of theories is achieved in the framework of first order predicate logic, and that theories are (partially) interpretable by connecting principles such as bridge laws or reduction sentences. For reasons that we cannot discuss in detail here (cf., for a general overview, Winther 2016), this view has been superseded in the 1960s by a rival conception that sees scientific theories not primarily as linguistic entities (but as non-linguistic entities such as models), and according to which the right tool for the reconstruction of theories is not logic but mathematics. As Thomas Mormann has shown in detail, Husserl's formal philosophy of science is an early anticipation of this shift in attitude because "[f]or Husserl it is *not* sufficient for a philosophically adequate description of an empirical theory to describe only its linguistic features; what is needed as well is a *mathematical description* of its models or *formal ontology*" (Mormann 1991, 61). Husserl can thus be seen to be an early forerunner of the *semantic view* as it was later introduced by Patrick Suppes, Bas van Fraassen, and others.

1.3.2 Regional ontologies and Weyl's "world-geometry"

Pure logic in Husserl's sense is an a priori discipline that studies the most general form of possible theories independently from their material content. From the perspective of the pure theory of manifolds, for instance, "'+' is not the sign for numerical addition, but for any connection for which laws of the form $a + b = b + a$ etc., hold" (Husserl 2001b, 156-157). It is clear, however, that a phenomenological interpretation of the sciences cannot restrict itself to this purely formal level. Formal ontology, which studies the essence of anything whatsoever, must be complemented by *regional ontologies* that study the essential forms belonging to particular material domains. At the highest level of generality, Husserl recognizes three essentially distinct material domains (or, in Husserl's preferred terminology, *regions*): nature, consciousness, and culture (Husserl 1989). Furthermore, the material essences under which all possible individuals in a given region fall are hierarchically ordered: While regional categories (such as "thing" or "color") are on top of the hierarchy, eidetic singularities (such as particular shades ascertainable in individual objects) are at the bottom.

Since, as we have already mentioned, Husserl claims that "*the cognition of 'possibilities' must precede the cognition of actualities*" (Husserl 1983, 190), both formal and regional (or material) ontologies are indispensable to the foundations of all empirical sciences. While formal ontology develops a concept of form as applicable to any objectivity whatsoever, regional ontologies determine in eidetic universality what must belong to a particular entity in order to fall within the extension of a particular region. It is precisely in this sense that one of the main functions of regional ontologies is "*that of rationalizing the empirical*" (Husserl 1983, 19): The constitution of particulars within a certain realm always already refers back to formal-eidetic and material-eidetic laws that constrain how these particulars can in fact be constituted. For instance, subjects always and necessarily constitute material things as *spatial* entities *in time* without, however, having an explicit grasp of the material essences of space and time that determine the objective sense of spatio-temporal objecthood. In order to overcome this naïveté—in order to clarify the "posit of reality" made within a particular domain—, it is necessary to exhibit the essential characteristics and structures peculiar to each member of a certain class of entities. The "rationalization of the empirical" thus consists in the reflective endeavor to systematically study and explicate essential laws.

In the eyes of many, Husserl's goal to rationalize the empirical through a priori regional ontologies may appear as a remnant of a bygone era in which philosophers of science could still lose themselves in excessive system-building without paying attention to the realities of scientific practice. There are two important qualifications to be made, however: First, even though Husserl holds that regional ontologies are necessary for "*the interpretation, the ultimate interpretation, of the empirical sciences of reality*" (Husserl 2008, 98), this does not entail the subordination of science to armchair philosophizing. In *Ideas I*, for instance, Husserl explicitly states that *geometry* is the ontological discipline studying the essential laws pertaining to crucial aspects of material thinghood, and that the physical sciences made the first steps towards the goal of a "rational physics" when the revolutionaries of the 17th century amalgamated the empirical study of physical reality with mathematics.

Second, as Thomas Ryckman has shown in great detail and admirable clarity, Husserl's conception of regional ontologies as well as other parts of his methodological toolbox did in fact exert a decided impact on the development of contemporary physics. The main protagonist of Ryckman's book-length study is Hermann Weyl, one of the premier mathematicians and theoretical physicists of the 20th century whose scientific and philosophical thinking was deeply influenced by Husserl.[4] Even though phenomenological traces can be found in many places of Weyl's oeuvre, the context of Ryckman's instructive case study is Weyl's critical-reflective analysis of Einstein's general theory of relativity. According to Ryckman, Weyl's reformulation of gravitational and electromagnetic theory within the framework of a "purely infinitesimal geometry" can be understood as the phenomenological attempt to fully *rationalize* the empirical, as it is constituted in the general theory of relativity (cf., for the following, Ryckman 2005b and, for a less technical summary, Ryckman 2005a).

The general theory of relativity, as it was presented by Albert Einstein in 1915, is formulated in the mathematical language of Riemannian geometry. A feature of this geometry is that it treats the magnitude and the directions of vectors quite differently: Assuming that we have two points p and q at finite separation in the manifold, then the metric of Riemannian geometry does not permit direct comparison of two vectors A at p and B at q with respect to their direction. What is permitted, however, is the direct comparison of the magnitude (or length) of A and B. It was this possibility of direct length comparisons between distant points of the manifold to which Weyl took exception. Instead of naively presupposing the global availability of a measuring rod, Weyl sought to recast general relativity in the framework of a "purely infinitesimal geometry" that only "recognize[s] the principle of the transference of a length from one point to another point infinitely near to the first" (Weyl 1923, 203). Weyl's non-Riemannian geometry thus permitted the unit of scale to vary (smoothly) from space-time point to space-time point; from this new degree of freedom, he was able to show that Maxwell's electromagnetism, in addition to Einstein's gravitation, could be incorporated into the metric of space-time. Hence was born the contemporary idea that a physical theory must be "gauge invariant," i.e. remain invariant under transformation of certain local degrees of freedom. As reinterpreted in the context

[4] Cf., for detailed information concerning the personal relationship between Husserl and Weyl, Ryckman 2005b, chapter 5.

of quantum mechanics by Weyl himself in 1929, the derivation of electromagnetism from gauge freedom pertains not to a factor of scale but to the arbitrary phase of the electron wave-function represented by the Abelian (i.e., commutative) group U(1). Yang and Mills in 1954 further generalized Weyl's idea of local gauge invariance to non-Abelian Lie groups (O'Raifeartaigh 1997); it is no overstatement to say that non-Abelian gauge fields are the very core of the Standard Model of contemporary particle physics of which the most recent triumph is the experimental detection of the Higgs boson at CERN in 2012.

What is particularly relevant in the context of this chapter is the rationale behind Weyl's line of thinking. Quite generally, Weyl engages in a reflective analysis of general relativity that is supposed to elucidate the very meaning of the "posit of reality" made in Einstein's theory. In order to do so, Weyl pays special attention to the regional ontology underlying general relativity, i.e. the supposed mathematical representation of the material essence of space-time. The question Weyl seeks to address is how such a mathematical representation can be constructed in a phenomenologically permissible way. The first step in Weyl's analysis is to identify an arbitrary point in the space-time manifold with an idealized cognizing subject. This cognizing subject is surrounded by a so-called tangent space, an infinitesimal Euclidean space associated with every point in the space-time manifold. From the viewpoint of the cognizing subject, only the tangent space is the locus of *Evidenz*, or originary presentive intution—everything that lies beyond the tangent space cannot present itself in direct, originary givenness. This, of course, is also the reason for Weyl's rejection of direct length comparisons between distant points of the space-time manifold: The fact that this operation presupposes the global availability of an idealized measuring rod shows that direct length comparisons transcend the sphere of intuitive givenness and must thus be replaced by a phenomenologically permissible procedure. In order to live up to the phenomenological demand "*to work completely consciously, 'to trace back to Evidenz'*" (Husserl 2008, 440), Weyl's procedure of length comparison consists in the parallel transportation of a comparison vector in infinitesimal increments along the path between the points p and q. Since the unit of scale ("gauge") is re-configured at each point on the path between p and q, there is no longer any need for globally available measuring rods or any other intuition-transcending auxiliary tools. Weyl's "world-geometry" can thus be seen as a "remarkably sustained attempt to probe the 'darker depths' of the 'origins' of the objective physical world portrayed in relativity theory through mathematical construction guided by the phenomenological method of 'essential analysis'" (Ryckman 2005b, 117).

1.3.3 The mathematization of nature

While his early philosophy of science is largely constructive, the late Husserl strikes a more critical tone in his assessment of mathematized sciences and the role they play in the wider context of contemporary intellectual life. As we have already mentioned, the late Husserl considers *objectivism* to be the main reason for the deeply rooted crisis that, on his view, haunts modern scientific culture. Objectivism in Husserl's sense combines two claims that are familiar from contemporary forms of scientific realism and naturalism: first, that knowledge of the "world in itself" can only be acquired through the methods of the sciences, and that this aim is already achieved at least in some areas; second, that there is no perspective over and above the scientific perspective from which, in principle, all meaningful questions can be answered.

The attempt to reject objectivism in all of its guises is a unifying thread that runs through virtually all stages of Husserl's development. Yet, a variation of this topic that comes to the surface only in his last major publication, the *Crisis*, is that objectivism emerged as an unintended by-product during the scientific revolution of the 17th century. Husserl thus takes a historical approach to show how the objectivist mindset arose from a naive understanding of the methodological innovations that mark the birth of modern physics. Husserl's foray into the history of science serves a therapeutical purpose: Today objectivist tendencies are so deeply ingrained in the thinking of most philosophers and scientists that they find it difficult even to imagine any other way of looking at science. Once the historical roots of objectivism are exposed, however, it becomes easier to acknowledge its status as an unfounded metaphysical hypostatization of scientific methodology.

According to Husserl, the formative moment in the development of modern physics was Galileo's reformation of scientific method, which consisted in a complete amalgamation of mathematics and experimentation. To be sure, as Husserl clearly recognizes, Galileo's use of mathematics was not unprecedented in the history of the physical sciences. But what distinguished Galileo from the tradition before him is that he did not just make occasional use of geometrical models in order to "save the appearances" in this or that segment of reality. Husserl argues that Galileo was after something much more radical, namely the complete "mathematization of nature [through which] nature itself is idealized under the guidance of the new mathematics [and] becomes [...] a mathematical manifold" (Husserl 1970, 23). So, according to Husserl, the radicalism of the Galilean project lends itself to the thesis "that everything which manifests itself as real [...] must have its mathematical index" (Husserl 1970, 37) and must therefore be translatable into the language of geometry. Mathematizability thus becomes an ontological criterion: In order to be included among the primary qualities, a property must be amenable to quantification and geometric representation. Secondary qualities like color or odor, on the other hand, do not belong to the domain of what is objectively real.[5]

On Husserl's view, the conviction that mathematics is a reliable guide towards the one true description of physical reality makes up an important component of our modern scientific mindset. Nowadays, this conviction is backed up by reference to the immense predictive and practical success of modern mathematized science. During the first half of the 17th century, however, Galileo's call for a complete amalgamation of mathematics and physics was just a bold methodological conjecture that could

[5] Although there have been critical voices as well (Ihde 2011), Husserl's interpretation of Galilean science had a strong impact on several Galileo scholars, especially on the French historian of science Alexandre Koyré. Cf., for a discussion of the relationship between Husserl and Koyré, Parker 2017.

only be substantiated by metaphysical means, i.e. by assuming that the deep-structure of reality is in fact mathematical in nature. What is more, since Galileo failed to inquire into the meaning and origin of geometry, his methodological revolution is also marked by a fundamental naïveté: In a similar sense in which Weyl criticized Einstein for what he saw as an uncritical adoption of the already existing framework of Riemannian geometry, Husserl takes exception to the fact that Galileo merely inherited Euclidean and Archimedean proportional geometry from the tradition before him. For Husserl, Galileo's unwillingness to deal with questions concerning the origin and meaning of geometry is a "fateful omission" (Husserl 1970, 49) that ultimately lies at the heart of modern objectivism. Yet, in order to understand the reasons for this verdict, it is necessary to say a word or two on Husserl's own take on the "primal establishment" (Husserl 1970, 362) of geometrical thinking (cf., for further details, Wiltsche 2016, 2019).

Although they are ubiquitous in Galilean science, abstract objects such as ideal spheres or frictionless planes are nowhere to be found in the life-world of pre-scientific experience. These objects only come into existence through a special mental operation through which one generates a limiting case against which actual instances of spherical bodies and real planes can be projected. But how does this mental operation come about? Following the late Husserl of the *Crisis*, there are two preconditions for the original constitution of something like a frictionless plane: first, the acquaintance with real surfaces of different degrees of flatness; and, second, the acquaintance with tools that give us the "technical [...] capacity to make [...] the flat flatter" (Husserl 1970, 25). Looking at a series of real surfaces with increasing degrees of flatness, one can either ponder over practical ways to push the limits of technological perfection. Or one can ignore questions of technological realizability and instead focus on the ideal limiting pole "towards which the particular series of perfectings tend" (Husserl 1970, 26), namely, the abstract, empirically unrealizable conception of a perfectly flat plane. However, what is needed in order to grasp this ideal limiting case in a distinct and self-conscious manner is a "peculiar sort of mental accomplishment: idealization" (Husserl 1970, 348). Idealization in Husserl's sense is the process through which the vague, imprecise, and morphological concepts with which we describe real things are replaced by exact, precise, and mathematical concepts. Hence, it is a progression of similarities between concrete things, and an additional act of idealization in which abstract objects such as frictionless planes find their "primal establishment."

The take-home message of Husserl's genetic inquiry is that the original constitution of abstract objects depends, first, on life-world experiences of real things, and, second, on higher-order acts of idealization. However, as Husserl also makes clear, these two preconditions are not yet sufficient to account for the "ideal objectivity" (Husserl 1970, 356) which we normally ascribe to abstract objects. According to Husserl, this kind of objectivity is only attained if the meaning of abstract objects is consolidated and stabilized by detaching it from the intellectual accomplishments of singular subjects. Husserl calls the process through which such a consolidation is achieved *sedimentation*. Crucial to this process of sedimentation is the externalization of original, intuitive thought by means of formal notations: Once abstract objects have been constituted in intuitive acts of idealization, these objects can be "liberated from all intuited actuality" (Husserl 1970, 44) through further acts of formalizing abstraction. One of the historical examples Husserl gives for this process is the algebraization of geometry (Husserl 1970, 43-48). Considering, for instance, the proportional geometry that operates at the heart of Galilean mechanics, it is clear that the concepts used by Galileo retain their reference to the material contexts that originally gave meaning to them. This is particularly obvious in the case of Galileo's graphical representations of levers, weights, or planes: Although the referents of these representations are without doubt abstract objects, the symbols used by Galileo are easily recognizable as idealizations of sensible shapes that can be found in the life-world of pre-mathematical experience. It is exactly this intuitive connection between geometric symbols and the underlying sensible shapes that is undermined when the materially determined concepts ofproportional geometry are replaced with purely formal algebraic expressions. Innovations such as the Cartesian coordinate system allow for the direct translation of complex geometrical properties into the formal language of algebra. As a consequence, complex geometrical problems can be solved by means of materially undetermined algebraic equations.

The processes of sedimentation and formalization are of utmost importance for Husserl's overall argument as well as for his historical critique of objectivism. Once a field such as geometry is formalized, it can become a "calculating technique" in which strings of symbols are manipulated "according to technical rules" (Husserl 1970, 46) and without regard for the content to which these symbols correspond. This means not only that it becomes possible to solve geometrical problems without repeating the intuitive acts that were necessary for the original constitution of geometrical objects. It also means that one can solve equations in an almost game-like fashion, i.e. without even asking for what the purely formal symbols stand for or how they were bestowed with meaning in the first place. For the development of modern mathematized science, this "*technization* of formal-mathematical thinking" (Husserl 1970, 48; our emphasis) is both a blessing and a curse. It is a blessing because science would be practically impossible if novices were under the constant pressure to think everything anew. However, as Husserl repeatedly stresses in the *Crisis*, formalization is also a curse because it harbors the danger of a dangerous forgetfulness with regard to science's roots in the life-world of pre-theoretical experience.

The kind of objectivism that originates in the works of Galileo considers the mathematical models that are built and applied in the physical sciences as the best candidates for delivering truthful representations of the "world in itself." And since the distance between the world, as it is allegedly represented in these models, and the life-world of pre-scientific experience dramatically increases the further science progresses, it becomes harder and harder to reconcile the "scientific image" with the "manifest image." Objectivism reacts to this problem in a very straightforward manner, namely by arguing "that the common sense world of physical objects [...] is *unreal*" (Sellars 1991, 173; our emphasis). Yet, relegating the life-world to the status of an illusion not only produces the crisis which Husserl opposes so vehemently in the *Crisis*. If Husserl's genetic analysis of the origin of mathematics is correct, then the demotion of the life-world also leaves us in a quandary with respect to the unsurpassable foundation of scientific cognition: On the one hand, objectivism implies that the life-world is nothing but a veil that needs to be removed in order to catch a glimpse of the deep-structure of the "world in itself." At the same time, however, the methods through which this veil ought to be removed presuppose the life-world as their necessary "meaning-fundament." If this is true, then objectivism leaves us in a paradoxical situation indeed: To advocate objectivism is, as we have said earlier, to saw off the branch on which science is sitting.

In light of Husserl's rejection of objectivism, an obvious question arises: If, phenomenologically construed, scientific theories are not truthful representations of the "world in itself," what are they then? Or, to put the question differently, how should philosophers with phenomenological leanings react to the still ongoing disputes between different forms of scientific realism on the one hand and different forms of scientific anti-realism on the other? Even though this question has been widely discussed, there is no general consensus within the secondary literature: While there have been attempts to render phenomenology compatible with anti-realist lines of thought (Wiltsche 2012, 2017; for critical reactions: Reynolds 2018, chapter 3; Berghofer 2017), others have argued that nothing prevents the phenomenologist from adopting a realist stance (Gutting 1978; Harvey 1986, 1989; Belousek 1998; Soffer 1990; Vallor 2009; Hardy 2013). Still others have claimed that Husserlian phenomenology lacks any particular impact on the scientific realism debate and thus resembles Arthur Fine's deflationist "NOA" (Rouse 1987).

1.3.4 Phenomenology and quantum mechanics

Although Husserl never publicly commented on the emerging quantum paradigm, his phenomenology had at least an indirect impact on quantum mechanics through the work of the German physicist Fritz London. While not widely known in philosophical circles, it is no overstatement to say that London is a truly remarkable figure who—like many other scientists during the first half of the 20th century—transcended the disciplinary boundaries between philosophy and physics (cf., for an insightful biography of London, Gavroglu 1995). Nowadays London is mainly remembered as the founder of quantum chemistry. However, a number of substantial contributions to theoretical physics and philosophy of physics as well as four nominations for the Nobel Prize in Chemistry and one nomination for the Nobel Prize in Physics attest to the wide scope and significance of his thinking. Yet, interestingly enough, London began his academic career not as a scientist, but as a philosopher. His doctoral dissertation *Über die Bedingungen der Möglichkeit einer deduktiven Theorie* was supervised by the Munich phenomenologist Alexander Pfänder and appeared in Husserl's *Jahrbuch für Philosophie und Phänomenologische Forschung* in 1923. As Mormann has noted, London's thesis can be regarded as a piece of Husserlian-style mathematical philosophy of science which deals with "a set theoretic concretization of Husserl's largely programmatic account of a *macrological* philosophy of science" (Mormann 1991, 70).

After graduating from the University of Munich at the age of 21, London's focus shifted to physics where he was mainly interested in the newly emerging field of quantum mechanics. After studying previous attempts to unify gravity and electromagnetism, London formed the idea that quantum mechanics could be the right framework for the task at hand. As it turned out, London's idea was immensely fruitful: Building on Weyl's work on unification, London was among the first to realize that the gauge invariance underlying electrodynamics is, other than Weyl had expected, not a scale invariance *but a phase invariance*.[6]

What is most relevant in the context of this chapter, however, is London's work on interpretational issues of quantum mechanics. In 1939 London published a monograph entitled *La Théorie de l'Observation en Mécanique Quantique* together with the French physicist Edmond Bauer. This work has two main objectives: First, London and Bauer seek to offer a "concise and simple" (London and Bauer 1983, 219) account of the measurement problem in the spirit of von Neumann's groundbreaking *Mathematische Grundlagen der Quantenmechanik* (1932). Providing the axiomatic foundations of quantum mechanics, von Neumann's book was one of the most influential works of early quantum mechanics and his "conception of the measurement problem became the framework of almost all subsequent theories of measurement" (Jammer 1974, 474). Since London and Bauer were in broad agreement with von Neumann, their monograph was not intended as a counter project, but as a more accessible version of von Neumann's highly technical work which, to add insult to injury, was written in German.

Second, London and Bauer seek to shed more light on the relationship between the observed and the observer, thus aiming at clarifying the role of consciousness in quantum mechanics. Although it was clear for von Neumann "that it is impossible to formulate a complete and consistent theory of quantum mechanical measurement without reference to human consciousness" (Jammer 1974, 480), he said very little about what consciousness is or what role it plays in quantum mechanics. In fact, "it was the London and Bauer treatment that effectively cemented consciousness into the 'received view'" (French 2002, 470). We shall say more on London and Bauer's take on the role of consciousness in quantum mechanics in a moment. Before that, however, some brief remarks about the measurement problem are in order.

At the heart of quantum mechanics there are two seemingly conflicting principles: On the one hand, we have the Schrödinger equation that describes the evolution of the quantum state over time. The Schrödinger equation is a unitary, deterministic, and linear equation. Its linearity entails that the sum of two solutions is again a solution to the equation. This, then, is the principle of quantum superposition that highlights the wave character of quantum objects. The quantum state of a system is described by its wave function. The superposition principle entails that wave functions can be added together to form a new wave function.

On the other hand, there are the principles dealing with the *apparent collapse of the wave function*. The collapse postulate states that when a measurement takes place, the wave function collapses such that the quantum state is not in a state of

[6] For an excellent analysis of the historical origins of gauge theory as well as an overview of its role in string theory, cf. O'Raifeartaigh and Straumann 2000.

superposition anymore, but now has a definite value. The necessary character of this postulate stems from the apparent fact that we never observe superposition states but only definite values. For instance, when we measure the spin of an electron, we never observe a superposition of spin-up and spin-down. What we observe is always the electron being in one of these states. Understanding the apparent collapse of the wave function is the core of the measurement problem.

Let us now turn to London and Bauer's approach to the problem. For our purpose, it is instructive to begin at the very end of their monograph. Here, they point out that the whole debate about the measurement problem relates to a much broader philosophical issue, namely "the determination of the necessary and sufficient conditions for an object of thought to possess objectivity and to be an object of science" (London and Bauer 1983, 259). They continue by adding that "[m]ore recently Husserl [...] has systematically studied such questions and has thus created a new method of investigation called 'Phenomenology'" (London and Bauer 1983, 259). Given this explicit reference to Husserl, and given Lodnon's background in phenomenology, it is easy to agree with commentators such as Gavroglu (1995) and French (2002) that the way London and Bauer set up the measurement problem has a distinctively phenomenological ring to it. As we have seen earlier, the most fundamental problem in Husserl's epistemology concerns the question as to how "objectivity becomes'presented', 'apprehended' in knowledge, and so ends up by being subjective" (Husserl 2001c, 169). When London and Bauer raise the problem of how "an object of thought" can be objective and be scientifically investigated, then this is easily identifiable as a variation of Husserl's original question. What is more, London and Bauer also agree with Husserl's anti-naturalistic stance by claiming that "[p]hysics insofar as it is an empirical science cannot enter into such problems in their generality" (London and Bauer 1983, 259). Hence, although they insist that physics can at least lead to significant "'negative' philosophical discoveries" (London and Bauer 1983, 259), London and Bauer consider the measurement problem primarily as a problem of (phenomenological) philosophy.

Concerning the specific problems surrounding quantum mechanics, London and Bauer make it clear that "[t]he heart of the matter is the difficulty of separating the object and the observer" (London and Bauer 1983, 220). On their view, modern physics reveals that "the idea of an observable world totally independent of the observer, was a vacuous idea" (London and Bauer 1983, 220). Here we see what they mean by saying that physics can lead to significant negative philosophical insights. According to London and Bauer, "the formalism of quantum mechanics already implies a well-defined theory of the relation between the object and the observer, a relation quite different from that implicit in naive realism, which had seemed, until then, one of the indispensable foundation stones of every natural science" (London and Bauer 1983, 220). As we shall see later, it is this very idea that had a tremendous impact on Maurice Merlau-Ponty; the idea that modern physics, and quantum mechanics in particular, undermines (naive) realism, and that our most sophisticated theories undermine the expectation that science could possibly offer an entirely objective account of the world.

Let us now turn to London and Bauer's proposed solution to the measurement problem and the role they ascribe to the observer's consciousness. The first thing to note is that, in their view, a measurement is only complete when the outcome "has been *observed*" (London and Bauer 1983, 251). The observer, then,

> possesses a characteristic and quite familiar faculty which we can call the "faculty of introspection". He can keep track from moment to moment of his own state. By virtue of this "immanent knowledge" he attributes to himself the right to create his own objectivity. (London and Bauer 1983, 252))

London and Bauer thus come to the conclusion that

> it is not a mysterious interaction between the apparatus and the object that produces a new ψ for the system during the measurement. It is only the consciousness of an "I" who can separate himself from the former function $\Psi(x, y, z)$ and, by virtue of his observation, set up a new objectivity in attributing to the object henceforward a new function $\psi(x) = u_k(x)$. (London and Bauer 1983, 252)

After rightly pointing out that terms such as *immanent knowledge* "clearly demand a phenomenological reading" (French 2002, 484), French interprets London and Bauer's take on the separation between the ego and the superposition as follows:

> This separation should not be thought of in terms of consciousness "causing", in whatever sense, the wave function to collapse, but rather in Husserlian terms, as that of a *mutual separation* of both an Ego-pole and an object-pole through a characteristic act of reflection. (French 2002, 484)

As French adds, this phenomenological reading of their solution to the measurement problem has the additional advantage of avoiding the main objections that have been brought forward against London and Bauer.

1.4 Beyond Husserl

Although the focus in this chapter is on Husserl, this should not be taken to suggest that other figures of the phenomenological movement did not engage with physics in novel and creative ways. In what follows, we will indicate some directions in which a genuinely phenomenological analysis of the physical science was taken by later phenomenologists. To be sure, space limitations prevent us from providing a comprehensive overview of the entire field of post-Husserlian phenomenology of science—discussions of, for instance, Oskar Becker (1973), Elisabeth Ströker (1997), Patrick Heelan (1983), Joseph Kockelmans (1966) or Don Ihde (1991) will have to wait for another occasion. In our view, however, there are two figures in particular who merit closer consideration: Martin Heidegger and Maurice Merlau-Ponty. Since both philosophers had a tremendous impact on the entire phenomenological movement, a brief discussion of some of their key insights will help to gain a better understanding of how phenomenological analyses of the physical sciences evolved in the second part of the 20th century.

1.4.1 Martin Heidegger

Even to mention Heidegger in the context of a serious philosophical engagement with the sciences might be enough to raise some eyebrows. After all, in light of remarks such as that "[s]cience does not think" (Heidegger 1968, 8), or that "science's knowledge [...] already has annihilated things as things long before the atom bomb exploded" (Heidegger 1971, 168) it seems hard to deny that parts of Heidegger's oeuvre are characterized by a pessimistic, if not hostile attitude concerning the sciences. However, recent years have seen an increase in studies highlighting the constructive potential that lurks behind the seemingly anti-scientific façade of Heidegger's philosophy (cf., for a general orientation, Kockelmans 1985; Glazebrook 2000, 2012). Heidegger, who studied physics for two years, and kept close contact with leading physicists such as Werner Heisenberg or Carl von Weizsäcker, is not only said to have "had a remarkable knowledge of both physics and biology" (Kockelmans 1985, 17). Some commentators go so far as to argue "that philosophy of science was at the center of his project and its development throughout his career" (Rouse 2005, 124).

While Heidegger's philosophy is sometimes acclaimed as both a rejection and an advancement of Husserl's phenomenology, one cannot help but notice certain similarities between parts of their philosophies of science. To begin with, although Heidegger's stance towards naturalism can generally be seen as somewhat ambiguous (cf. Rouse 2005), he agrees with the Husserlian sentiment that the natural sciences are in principle incapable of investigating themselves in a philosophically satisfactory manner: "The moment we talk 'about' a science and reflect upon it, all the means and methods of this science in which we are well versed fail us" (Heidegger 1967, 177). This is equally true of biology, where we "cannot put biology under the microscope" (Heidegger 1967, 177), and of physics, which "itself is no a possible object of a physical experiment" (Kockelmans 1970b, 170). If this view is correct, it not only follows that serious reflections on any particular science must transcend the standpoint and methodological repertoire of that science. For Heidegger, the limitations of any particular methodology also result in a pluralist image of science: Instead of absolutizing one particular discipline with its own specific methods and values, Heidegger seems to promote a vision of science in which different methodologies and sets of values can coexist without standing in a relation of super- or subordination. Joseph Kockelmans summarizes the pluralistic sentiment of Heidegger's philosophy of science as follows:

> The rigor of mathematical physics is exactness. An event can be considered as an event of nature if, and only if, it is determined beforehand as a kinematic magnitude. Such a determination can be effected by means of measurements and with the help of their resulting numbers and the calculations performed on them. However, [...] the exactness of mathematical physics is not due to the fact that it calculates exactly; it must calculate exactly, precisely because the mode in which it is bound to its own realm of objects by its *original project* has the character of exactness. That is why the humanistic sciences can be rigorous without for that matter being exact. (Kockelmans 1970a, 189; our emphasis)

What is particularly noteworthy about this passage is Kockelman's remark that, on Heidegger's view, a particular science "is bound to its own realm of objects by its *original project*." "Project" or "Projection" (in German: *Entwurf*) is a technical term in Heidegger's philosophy, and clarifying its meaning will allow us to highlight another similarity between Husserl's and Heidegger's views on science.

Heidegger's interest in science—and in physics in particular—is already evidenced in one of his earliest works, his 1916 habilitation lecture "Der Zeitbegriff in der Geschichtswissenschaft" (Heidegger 1978, 413-433). Quite generally, Heidegger's aim is to distinguish the historical sciences from physics on the basis of the concepts of time that are operative in both disciplines. The approach he chooses to tackle this issue is in perfect agreement with the basic tenets of Husserlian phenomenology: Instead of presupposing certain pre-established conceptions of time, physics, or history, Heidegger employs a method of regressive inquiry in which one begins with a particular existing science and then works back to determine the formal and material conditions underlying it (Heidegger 1978, 417-418). The outcome of Heidegger's analysis is that the very essence of modern physics, as it was inaugurated by Galileo and Newton, lies in the *mathematical projection of nature*. What this means can be made clear by considering a crucial passage from *Being and Time*:

> What is decisive for its development [the development of mathematical physics] does not lie in its rather high esteem for the observation of "facts", nor in its "application" of mathematics in determining the character of natural processes; it lies rather in *the way in which Nature herself is mathematically projected*. In this projection something constantly present-at-hand (matter) is uncovered beforehand, and the horizon is opened so that one may be guided in looking at those constitutive items in it which are quantitatively determinable (motion, force, location, and time). Only "in the light" of a Nature which has been projected in this fashion can anything like a "fact" be found and set up for an experiment regulated and delimited in terms of this projection. The "grounding" of "factual science" was possible only because the researchers understood that in principle there are no "bare facts". In the mathematical projection of Nature, moreover, what is decisive [...] is that this projection *discloses something that is a priori*. (Heidegger 1962, 413-414)

This passage contains several insights that deserve closer attention. To begin with, by stating "that in principle there are no 'bare facts'", Heidegger anticipates the debate over the *theory-ladenness of observation*, as it is discussed in "mainstream" philosophy of science since the 1960s. What is clear in light of the above-quoted passage is that Heidegger opposes the idea that scientific facts could ever be "neutral" in the sense that they can be disentangled from the theoretical framework in which they are situated. For Heidegger, however, theory-ladenness does not primarily occur on the level of scientific *theories* that are said to impinge on the perceptions of scientists. Heideggerian theory-ladenness is much more fundamental because it has to do with the a priori conditions that must already be in place in order for concrete scientific work to be possible. Before a scientist can even begin to collect data, to devise theories, to make calculations, or to design experiments, the "world" or "region" at which the scientist aims must already be constituted in a way that makes it amenable to a particular kind of scientific inquiry. In the case of modern physics, this primal constitution of the region is achieved through what Heidegger calls the *mathematical projection of nature*, which "maps out in advance the way in which the procedure of knowing is to bind itself to the region that is opened up" (Heidegger 2002, 50). Since it determines in advance what counts as a being and as experience, the mathematical projection itself is, on Heidegger's view, not grounded in experience of beings—it is a priori.

From these remarks it should be evident that there are clear affinities between the Heideggerian notion of a mathematical projection of nature and Husserl's conception of regional ontologies. Heidegger would most certainly agree with Husserl that, explicitly or implicitly, the special sciences are necessarily grounded in regional ontologies which are a priori, and which express the essence—or, to put it in Heideggerian terms, the "basic state of being" (Heidegger 1962, 246)—of the entities in their domain. What is more, Heidegger also agrees that these regional ontologies can only play their foundational role if they have been, first, explicated, and, secondly, critically examined:

> *[A]ll ontology, no matter how rich and firmly compacted a system of categories it has at its disposal, remains blind and perverted from its ownmost aim, if it has not first adequately clarified the meaning of Being, and conceived this clarification as its fundamental task.* (Heidegger 1962, 31)

Seen from this perspective, then, it is not surprising that Heidegger praises Hermann Weyl for his insight that in "the theory of relativity in contemporary physics [...] the notion of field is normative" (Heidegger 1997, 81; cf., regarding the relationship between Heidegger and Weyl, Webb 2009, chapter 5; Sieroka, this volume). Unfortunately, Heidegger does not go into any detail of Weyl's reformulation of general relativity theory. As one can suspect, however, Heidegger correctly identified Weyl as a philosophically-minded physicist who took up the hermeneutical task of critically engaging in an "interrogation of being," as it becomes manifest in Einstein's theory.

Although, as we have seen, there are interesting parallels between Husserl's and Heidegger's philosophies of science, there are also points of divergence. Perhaps the most fundamental difference concerns the starting point from which phenomenological analysis must proceed. As Henry Pietersma has aptly put it, the point of departure for Husserl is "that a human being is basically a knower [...,] that whatever engages a human being is (or at least should be) based on what she knows or justifiably believes" (Pietersma 2000, 86). As a consequence, the most fundamental task in Husserlian phenomenology is to spell out the conditions under which subjects may be said to have achieved the goal of knowledge, both in scientific and everyday contexts. While there is, of course, still ample room for ontology and metaphysics, Husserl's transcendental phenomenology is, first and foremost, an epistemological project. Heidegger, on the other hand, strongly opposed any claim to the primacy of knowledge. Quite the opposite, knowledge, according to Heidegger, is but a derivative mode of *being-in-the-world*, i.e. the fundamental ground upon which every further determination of Being rests. Heidegger's argument, in a nutshell, goes as follows: Traditionally, knowledge has always been characterized as some kind of relation between (at least) two relata, someone who knows, and something that is known. The task of epistemology, then, is to specify exactly how this relation must look like in order for genuine knowledge to occur. On Heidegger's view, however, any separation between two (or more) relata is itself the result of a particular projection, which—like any other projection—refers back to Dasein's essential state of "being-in-the-world." Consequently, the most fundamental question in philosophy is not epistemological in nature; it is rather the *ontological* question concerning the nature and understanding of *Being*.

Heidegger's "ontological turn" has far-reaching consequences for his philosophy of science: In *Being and Time*, Heidegger attacks what he calls the "logical conception of science" (Heidegger 1962, 408) that focuses on systems of statements or mathematical models as the finished product of research, and then raises the question of how these representational vehicles can be used to mirror particular empirical target systems. The point of Heidegger's argument is that this conception must be replaced with what he calls an "existential conception of science [that] understands science as a way of existence and thus as a mode of Being-in-the-world" (Heidegger 1962, 408). If one accepts this existential conception, one no longer conceives of science as a project that is primarily geared towards the accumulation of truthful (mental, linguistic, or mathematical) representations of reality. Following the existential conception, science is, first and foremost, something human beings *do*—it is an activity that is essentially linked to tools and equipment, and that aims at a local manifestation of reality in experimental settings and instrumental work. In their everyday research, scientists are not primarily concerned with entities, their properties, or with the relations between them. What scientists are actually concerned with is technological equipment that must always already be understood as being useable for a particular purpose, and that is best understood in being so used. Hence, from the viewpoint of an existential conception of science, *practical understanding* has priority of *theoretical knowledge*.

By giving phenomenology an existential-hermeneutic twist, Heidegger was one of the main influences for the emergence of what later became known as *hermeneutic philosophy of science* (cf., for a general overview, Babich 2016). Philosophers such as Theodore Kisiel, Joseph Kockelmans, Patrick Heelan, Babette Babich, Dimitri Ginev, Joseph Rouse, or Don Ihde employ methods and insights from phenomenology, hermeneutics, and post-positivist philosophy of science in order to gain a firmer grasp on science as an embodied, culturally and historically situated practice that materializes itself in what Patrick Heelan has called "readable technologies" (Heelan 1983).

1.4.2 Maurice Merleau-Ponty

Among the three classical phenomenologists we discuss in this chapter, Maurice Merleau-Ponty is the one whose work contains the most detailed analysis of contemporary physics. It is well known that Merleau-Ponty cared deeply about the sciences.[7] His work on psychology in particular is a common starting point for many contemporary phenomenologists who are conducting research at the interface between philosophy of mind, psychology, and the cognitive sciences. What is less well

[7] Cf., for discussions of Merleau-Ponty's views on the exact sciences, e.g. Kisiel 1970; Rouse 1986; Matherne 2018; Romdenh-Romluc 2018.

known, however, is that Merleau-Ponty also explicitly addressed physics, aiming at a deeper understanding of how physics and philosophy can enrich each other, and of how a genuinely phenomenological philosophy of physics might look like. This is true, in particular, of the essay "Modern Science and Nature," which was part of a lecture course Merleau-Ponty held at the Collège de France (Merleau-Ponty 2003, 81-122). Here, he carefully engages with quantum mechanics, outlining his more general phenomenological approach to physics. Unfortunately, it seems that Merleau-Ponty's interest in philosophy of physics came to the fore only quite late in his career: While the aforementioned lecture course *La Nature* was held between 1956 and 1960, and thus one year before his death, his treatise *The Visible and the Invisible*, which also addresses physics in general and the "relations between the observer and the observed" (Merleau-Ponty 1968, 15) in particular, was published only posthumously.

In his philosophy of physics, Merleau-Ponty discusses the limits of objectivity and raises the question as to whether physics could ever deliver a picture of the world that also incorporates the physicist who observes and experiments. On his view, modern physics and quantum mechanics in particular exemplifies or at least leads to such a new kind of physics, which—unlike classical physics—not only "posits nature as an object spread out in front of us, [but rather] places its own object *and its relation to this object in question*" (Merleau-Ponty 2003, 85; our emphasis). It is in this context that Merleau-Ponty discusses the aforementioned London and Bauer interpretation of quantum mechanics, adding that the emerging picture could be called a "participationist conception" or a "partial realism" (Merleau-Ponty 2003, 97-98).[8] This is a striking similarity both in content and in terminology to a recent interpretation of quantum mechanics that goes by the name *QBism* and is also often referred to as a kind of "participatory realism" (Fuchs 2017). Two contributions to this volume are explicitly dedicated to a discussion of this interpretation of quantum mechanics.

According to Merleau-Ponty, physics in its most sophisticated form abandons the goal of delivering an entirely objective picture of the world. Instead, it incorporates the physicist herself, and thereby accounts for the fact that the life-world is always and necessarily the meaning-fundament of all scientific endeavors. Consider the following passage from *The Visible and the Invisible*:

> Philosophy is not science, because science believes it can soar over its object and holds the correlation of knowledge with being as established, whereas philosophy is the set of questions wherein he who questions is himself implicated by the question. But a physics that has learned to situate the physicist physically, a psychology that has learned to situate the psychologist in the socio-historical world, have lost the illusion of the absolute view from above: they do not only tolerate, they enjoin a radical examination of our belongingness to the world before all science. (Merleau-Ponty 1968, 27)

[8] Merleau-Ponty adopts this terminology from the French physicist and logician Paulette Destouches-Février. Below we see in more detail how strongly Merleau-Ponty was influenced by Destouches-Février. For a portrayal and further development of the approaches of Destouches-Février and her husband Jean-Louis Destouches, cf. Bitbol 2001, 1998.

Of crucial importance for Merleau-Ponty's overall position is the rejection of two traditional assumptions: first, that there is a "physical object in itself" (Merleau-Ponty 1968, 15) which exists prior to our theorizing, and thus "has an individual existence" (Merleau-Ponty 2003, 92); and, second, that determining the nature of this object is the main goal of physical research. Instead, Merleau-Ponty recognizes the "relations between the observer and the observed [as the] ultimate physical beings" (Merleau-Ponty 1968, 15).

Another topic that receives much attention in Merelau-Ponty's philosophy of physics concerns the question about the nature and role of measurements. This question is, to be sure, of special relevance in quantum mechanics where, as we have seen, the role of observations and measurements seems particularly mysterious. Contrasting the measuring apparatus in classical physics with the measuring apparatus in quantum mechanics, Merleau-Ponty comes to the conclusion that while classically "the apparatus is the prolongation of our senses," in quantum mechanics "[t]he apparatus does not present the object to us." Instead, "[i]t realizes a sampling of this phenomenon as well as a fixation. [...] Known nature is artificial nature" (Merleau-Ponty 2003, 93).

In light of the above, one may wonder how Merleau-Ponty's position relates to the contemporary scientific realism debate. Given his rejection of the idea that physical objects are things in themselves, and given his analysis of the measuring apparatus in quantum mechanics, it seems natural to consider him a scientific anti-realist. On closer inspection, however, things are not that simple. The first thing to note is that Merleau-Ponty is very outspoken in his negative assessment of one of the more popular versions of scientific anti-realism, namely instrumentalism:

> Physics should not be conceived as a search for the truth, it should give up determining a real physics: it would be only an ensemble of measurements linked to equations, allowing [us] to foresee the result of future measurements. Formalist physics receives all freedom, but it loses its ontological content. It signifies no mode of being, no reality. Like all radical nominalism, this nominalism cannot articulate itself. (Merleau-Ponty 2003, 95-96)

After dismissing instrumentalism without much argument, Merleau-Ponty goes on to say that it would also be a mistake to adopt an idealist position. Drawing on the work of the French physicist and logician Paulette Destouches-Février, Merleau-Ponty claims that the problem with idealism is that, just like realism, it amounts to a form of objectivism. To be more precise, idealism is an objectivism that "objectifies human representations" (Merleau-Ponty 2003, 96). Contrary to objectivism, Merleau-Ponty is convinced that "[t]he relations between reality and measurement must be conceived outside of the dichotomy of in-itself/representation" (Merleau-Ponty 2003, 96). As we have seen above, acknowledging that "[p]hysics cannot be realist in the classical sense" but "cannot be idealist, either," Merleau-Ponty chooses to call his position "a 'partial realism' or a 'participationist' conception" (Merleau-Ponty 2003, 97-98). This terminology, adopted from Paulette Destouches-Février, highlights the interrelatedness and inseparability of the observer and the observed. What is more, the term "partial realism" indicates that Merleau-Ponty seeks to find a middle ground between instrumentalism on the one hand and a full-blown realism on the other. Hence, returning to our initial question, we need to ask: What are the specific features of the kind of realism Merleau-Ponty endorses?

In this context, Merleau-Ponty says, we must begin with "distinguish[ing] several meanings [of reality]" (Merleau-Ponty 2003, 98): first, a "plane of reality, where objects exist in themselves and where the properties that we attribute to them are intrinsic" (Merleau-Ponty 2003, 98). After dismissing this realist notion of reality, Merleau-Ponty goes on to mention, second, an intersubjective plane of reality, "where reality is constituted uniquely by the 'results of measurement'" (Merleau-Ponty 2003, 98). Since this notion is too instrumentalist for Merleau-Ponty, he finally introduces "a third plane, the structural plane" (Merleau-Ponty 2003, 98). After doing so, Merleau-Ponty reproduces a long passage from Destouches-Février which we will quote in full:[9]

> From the fact that this plane transcends the subjective-objective duality, the structural relations dress an absolute character up in the framework of theory. In effect they are independent of the results and of the process of measurement. They are however relative to the species of the system studied. By their independence from the results of observations, they dress up a certain objectivity, comparable to the Platonic objectivity of the Idea vis-à-vis its sensible realizations. But on the other hand, this independence which detaches them from all sensible contact with the object could make them refuse objectivity. In effect they refer not to an object, but to certain mathematical forms necessary for the description of the relation of the subject to the object. They present the same ambiguity if we envisage them under the angle of reality; to the extent that they appear completely detached from the results of measurement—that is, from the immediate meeting with the objects studied—they lose all reality, and their nature approaches mathematical being; but we just saw that the whole critique of knowledge withdrawn into modern physics consisted exactly in unmasking the illusory character of the phenomenal reality as just as sensible as rational. Of such kind that the character of reality seems to have to take refuge, preferably in the structural plane, relatively more independent, permanent, and coherent than the two preceding planes. Moreover, the fact that structures are determined by the theory in which they intervene—since they schematize the general conditions on the observers in their relations with the objects—confers unto them a reality that purely mathematical beings independent of all sensible signification do not possess. (Destouches-Février, as quoted in Merleau-Ponty 2003, 98)

Although Merleau-Ponty does not do much to clarify or go beyond these remarks, it seems clear that the partial realism of Merleau-Ponty and Destouches-Février is in many ways similar to a currently popular version of realism, namely structural realism (for more details, cf. Ladyman 2016 and Berghofer 2018b). Instead of taking a realist stance concerning the unobservable objects posited by our best theories, structural realists claim that we should limit our epistemic and/or ontological commitments to the mathematical or structural content of theories. In light of Merleau-Ponty's pronouncement to take the "mathematical forms necessary for the description of the relation of the subject to the object" as the fundamental entities of physical theorizing, his partial realism has indeed much common ground with contemporary structural realism. Of course, the vast majority of contemporary structural realists take the observer-independence of physical theories for granted, and would not, consequently, regard structural relations as relations between subject and object.

[9] Unfortunately, the fact that Merleau-Ponty is quoting Destouches-Février here is easily overlooked in the English translation because the quotation marks are missing (Merleau-Ponty 2003, 98).

One might even be tempted to suspect that Merleau-Ponty's position collapses into a very peculiar form of structural *idealism*. However, since for Merleau-Ponty the structural relations between observer and the observed cannot be reduced to anything subjective or mental, his position clearly has a realist flavor to it. In particular, and as mentioned earlier, there are interesting parallels between Merleau-Ponty and QBism, according to which quantum mechanics tells us something very important about reality, namely "that reality is *more* than any third-person perspective can capture" (Fuchs 2017, 113).

It is crucial to note that Merleau-Ponty's position is by far the strongest we have discussed so far. In order to see why, let us return to a claim that is widely endorsed by virtually all phenomenologists, viz. the claim that physics, at best, can only yield a perspectival image of reality. Typically, this perspectivity is said to arise due to the role subjectivity plays in our cognitive interactions with reality. An argument to this effect can be found, for instance, in Hermann Weyl's *Philosophy of Mathematics and Natural Science* (Weyl 1949, 110-113): For Weyl, the driving force behind modern physics is the attempt to objectify reality through a systematic exclusion of everything subjective. Historically, the first steps in this direction were made when Galileo and others introduced the distinction between primary and secondary qualities, and moreover argued that mathematizability is a reliable criterion for what can count as objectively real. On this view, then, only primary qualities belong to the inventory of objective reality because secondary qualities like color or odor are not amenable to direct mathematizability due to their subjective character. As Weyl observes, the development of physics culminated in purely symbolic representations of the world where everything that is granted physical significance must find its expression in mathematical symbols.

Following Weyl's historical narrative, the systematic exclusion of everything subjective appears to be a regulative idea in the Kantian sense, i.e. a prescriptive telos that gives physical research its normative direction. As with all regulative ideas, however, the focal point towards which the movement of symbolization strives will never be fully realizable. The reason for this is, according to Weyl, that even the most abstract mathematical tools still carry the trace of transcendental subjectivity. Consider the following passage from *Philosophy of Mathematics and Natural Science*:

> How is it possible to assign to the points of a point-field marks or labels which could serve for their identification or distinction? The labels are supposed to be self-created, distinctive and always reproducible symbols, such as names, numbers (or number triples x, y, z, etc.). Only after this has been accomplished can one think of representing the spectacle of the actually given world by construction in a field of symbols. All knowledge, while it starts with intuitive description, tends toward symbolic construction. No serious difficulty is encountered as long as one deals with a domain consisting of a finite number of points only [...]. The problem becomes a serious one when the point-field is infinite, in particular when it is a continuum. A conceptual fixation of points by labels of the above-described nature that would enable one to reconstruct any point when it has been lost, is here possible only in relation to a *coordinate system*, or frame of reference, that has to be exhibited by an individual demonstrative act. The objectivation, by elimination of the ego and its immediate life of intuition, does not fully succeed, and the coordinate system remains as the necessary residue of the ego-extinction. (Weyl 1949, 75)

Much could be said about this telling passage (cf. Ryckman 2005b, 128-136).[10] In our view, however, the take-home message is this: Whenever we seek to establish a link between the mathematical formalism and observational data—for instance, when we carry out measurements—it is necessary to introduce a coordinate system in order to single out individual objects from a continuously extended object domain. Yet on Weyl's view, it is precisely this implementation of a coordinate system that reintroduces subjectivity into the purely symbolic representation of reality. The reason for this claim is straightforward: For Weyl the origin of the coordinate system is the most formal representation of the physicist's lived body, her "zero point of orientation" (Husserl 1989, 166); the axes of the coordinate system, on the other hand, determine the physicist's orientation in space. On this interpretation, then, the perspectivity of every symbolic representation of reality is indeed mandated by physics itself: Whenever we seek to establish a link between the mathematical formalism and reality, a coordinate system must be introduced. Yet whenever a coordinate system is introduced, subjectivity creeps back into our purely symbolic representation of the world.

In light of what has just been said, it is clear that Weyl fully embraces the claim according to which every symbolic representation will necessarily be perspectival in nature. Yet for Weyl this is a meta-theoretical claim that tells us something about how to understand physics and how to interpret its results: Physics is fine as it is, but we need to keep in mind that its purportedly objective methodology is essentially limited in scope. Now there can be no doubt that Merleau-Ponty also accepts the perspectivity of our scientific image of reality. For Merleau-Ponty, however, this claim is not the result of a reflective analysis from outside of physics. Quite the opposite, on Merleau-Ponty's reading, quantum mechanics itself implies the strong ontological claim that the classical picture of a purely objective, observer-independent physical reality is untenable, and that every complete physical description of reality must incorporate the physicist as well as her experience. Seen from this perspective, then, quantum mechanics has the potential to live up to the ideal of a fully rationalized, critical, and ultimately *phenomenological* physics.

1.5 Summaries of the chapters

In this section, we provide summaries of all chapters in this volume, so as to permit the reader to identify those most likely to be of interest to her.

[10] For instance, readers familiar with Husserl's oeuvre will not fail to notice Weyl's allusion to section 49 of *Ideas I*: The notion of the "coordinate system as the necessary residue of the ego-extinction" is, of course, a reference to Husserl's thought experiment of the "absolute consciousness as the residue of the annihilation of the world" (Husserl 1983, section 49). Moreover, it interesting to note that the trained mathematician Husserl also explicitly refers to the "origin of the coordinate system" (Husserl 1973c, 116; our translation) in order to elucidate the role of the embodied subject in our cognitive engagements with the world.

In his chapter "Explaining Phenomenology to Physicists," Robert Crease sheds light on the objective and significance of philosophy of physics, distinguishes different traditions within the field, and focuses on one in particular, namely the phenomenological tradition. Crease starts out by emphasizing "the unavoidability of philosophical commitments in science." Recently, physicists such as Stephen Hawking, Leonard Mlodinow, or Sander Bias have dismissed philosophical reflections on physics as useless, thus echoing Richard Feynman's dictum that "philosophy of science is about as useful to scientists as ornithology is to birds." As Crease rightly observes, however, physicists are already engaging in "amateur philosophizing" when they reflect on physics or its relationship to philosophy. Since philosophy seems inevitable whenever we raise questions concerning, for instance, the aim of physics or its place in the ensemble of intellectual practices, it might be better, as Crease argues, to construe the difference between physicists and philosophers as a difference of stances. The scientist, in her scientific stance, objectifies what is being studied. The philosopher, in his philosophical/phenomenological stance, is interested in the relationship between the scientist and her object of study. Concerning philosophy of science, Crease distinguishes between analytic, pragmatic, and phenomenological traditions. For the phenomenologist, the individual sciences need to be epistemically grounded in a more fundamental science, namely phenomenology. This means that the aim of phenomenology is "to reflectively justify scientific activity, and describe how it arises out of the grounds of human experience." In the final section of his chapter, Crease addresses the project of a *phenomenology of physics*. The phenomenology of physics thematizes the framing in which physical research is conducted and recognizes this framing as a human product. In this context, Crease discusses three different paths the phenomenology of physics can take.

Mirja Hartimo's chapter "Husserl's Phenomenology of Scientific Practice" addresses Husserl's approach to the natural sciences, arguing that his goal is to *describe scientific practice*, rather than to impose norms or restrictions on the sciences. Hartimo comes to the bold conclusion that "Husserl is the first philosopher who took seriously the importance of concrete and diverse scientific practices." After discussing the relationship between mathematics and physics, Hartimo sheds light on the development of Husserl's position on this matter. Her focus is on *Ideas I*, *Formal and Transcendental Logic*, and *Crisis*. The aim of her analysis is to show that while Husserl in *Ideas I* subscribes to the idea of a pre-established harmony between mathematics and physics—an idea shared by his Göttingen mathematical colleagues—, he eventually emphasizes the difference between the two disciplines. In *Formal and Transcendental Logic* Husserl introduces what he calls the method of "Besinnung" that seeks to investigate the intentional genesis of the sciences. Yet the goal of "Besinnung" is not to examine and judge the sciences from above, but to be as close to scientific practice as possible. Ultimately, the outcome of Husserl's transcendental analysis is that mathematics and mathematical physics need to be clearly separated. In this context, Hartimo points to interesting similarities between Husserl's intentional analysis and Penelope Maddy's study of the development of applied mathematics. The take-home message of Hartimo's chapter is that, although Husserl's views concerning the sciences change, the goal of his phenomenological analysis remains the same: *to provide a phenomenological clarification of scientific practice*.

In his chapter, Paolo Palmieri addresses a question raised by Husserl in the *Crisis*: Why do the deductive methods employed in mathematical physics yield so much clarity although the axioms are anything but self-evident? Palmieri approaches this problem through three case studies that exemplify three different stages of the development of modern physics: Galileo's mathematical natural philosophy as the birth of modern physics; Helmholtz' analysis of human sound perception in terms of an infinite series of anharmonic oscillators; and the birth of quantum mechanics as brought forth by Heisenberg's paper "Über quantentheoretische Umdeutung kinematischer und mechanischer Beziehungen" in 1925. There is an interesting connection between Palmieri' case study based approach and Mirja Hartimo's chapter. This is because, as we have seen, the ambition of any phenomenological analysis is to be as close to the object of study as possible, in our case scientific practice and its historical development. Phenomenologically construed, there is no royal road to the practice of physics. Although phenomenology can, as in the case of Weyl's world-geometry, serve as a guide, phenomenologists are not in the business of imposing a priori rules on physics. Instead, physics is, at least to some degree, what physicists do. Or, to put it in Palmieri's own words: "A phenomenologically oriented philosophy of physics is grounded in a non-colonialist, subdued appreciation of legitimately autonomous and ethnically diverse mathematical and empirical styles that manifest themselves through history and are ultimately rooted in natural languages and in the life-worlds of the physicists."

Norman Sieroka's chapter addresses a blind spot in Weyl scholarship. While some ink has been spilled on Weyl's earlier writings and on his relationship to Husserl's phenomenology, not much has been done to elucidate the connections between Weyl and Heidegger. As Sieroka observes, this is surprising since there are quite a few places in Weyl's later writings where he discusses Heideggerian phenomenology in detail. Heidegger's influence is perhaps most obvious in the case of Weyl's claim that modern physics and mathematics develop towards an *existential standpoint*. Sieroka seeks to clarify the background of this claim by focussing on Weyl's notion of *symbolic constructions*. Although Weyl relies on several Heideggerian concepts in order to understand the role of symbols in physics, he does so in ways that would not have found Heidegger's approval. According to Sieroka, a particularly telling example is Heidegger's distinction between being *ready-to-hand* and being *present-at-hand*. While Heidegger insists that symbols can only be present-at-hand, Weyl rejects this on the basis that symbols—such as concrete strokes on a blackboard—are physical objects that can be manipulated. The gist of Sieroka's chapter is that in his later writings Weyl aims at establishing some middle ground between Heidegger and Cassirer—a middle ground that avoids both Heidegger's separation of science from human existence and Cassirer's scientism.

In his chapter, Matthias Egg aims at revealing an unexpected parallel between Husserl's late philosophy of science and a currently popular version of scientific metaphysics defended by James Ladyman and Don Ross. At first glance, the prospects of finding any common ground between the argument in Husserl's *Crisis* and contemporary scientific metaphysics seem dim, to say the least: As the late Husserl is at pains to show, the success of modern mathematized physics has misled scientists and philosophers to accept a dangerous metaphysical hypostatization of scientific methodology. By buying into what Husserl calls *objectivism*, they commit the mistake of confusing highly idealized mathematical models with truthful representations of reality, thereby demoting the life-world of pre-scientific experience to the status of a mere illusion. Although, as Egg admits, Husserl's criticism of objectivism also affects parts of Ladyman's and Ross' naturalistic program, there are at least two points of convergence: First, there is agreement that we need to abstract away from our naive encounter with the world as well as from our practical interests in order to make a truly fundamental science possible. Second, there is agreement that the sciences must be interpreted in a way that makes them relevant for the practicalities of everyday life. Egg argues that these two points of convergence imply a commitment to *weak metaphysics*, i.e. "the articulation of a world-view based on a certain stance." Despite the differences between them, Egg manages to bring Husserl's phenomenology of science and scientific metaphysics into a fruitful dialogue that is likely to spark further debates in the future.

Lee Hardy addresses the question of whether Husserl's phenomenological reflections on modern physics are consistent with scientific realism. In its most basic form, scientific realism is the view that scientific theories aim at a literal description of reality, and that we have reasons to believe that at least some of the claims of our best theories are (approximately) true. Scientific anti-realists, on the other hand, either hold that science does not aim at truth at all, or that we should restrict our epistemic and/or ontological commitments to what theories say about the observable world. As this initial characterization suggests, the main object of dispute between realists and anti-realists are the so-called *unobservable entities*, i.e. entities like atoms, quarks, fields or forces. Concerning such unobservable entities, Husserl seems to take up a straightforward position: For instance, Hardy draws our attention to section 20 of *Ideas I* where Husserl proclaims that "[i]f *'positivism'* is tantamount to an absolutely unprejudiced grounding of all sciences on the 'positive,' [...] on what can be seized upon originaliter, then *we* are the genuine positivists" (Husserl 1983, 38). As Hardy notes, Husserl's self-identification as a positivist is potentially problematic in light of the current scientific realism debate. This is because "an ontology restricted to perceivable physical objects [...] and an instrumentalist interpretation of scientific theories [seems] incapable of doing justice to the rapid and impressive advance of the physical sciences into the hidden regions of the unobservable." However, based on a careful analysis of the distinction between physical things, ideal objects, and theoretical entities on the one hand and between scientific theories and scientific laws on the other, Hardy argues that Husserl's phenomenology of physics is nevertheless "entirely compatible with a realistic construal of scientific theories." This means that, according to Hardy, Husserl's approach to physics remains a viable option for scientific realists.

In their chapter, Arezoo Islami and Harald A. Wiltsche address one of the most important problems at the interface between philosophy of physics and philosophy of mathematics, namely the so-called *applicability problem*. The problem, in a nutshell, is this: Why is it that mathematical methods and models are so successful in physics? Most notably, this problem has been raised by Eugene Wigner in his essay "The Unreasonable Effectiveness of Mathematics in the Natural Sciences." There exist a number of different approaches to this problem, none of which enjoys general consent among philosophers. Islami and Wiltsche thus aim at a distinctively transcendental-phenomenological approach. For them, this implies a shift from the *why-question*—Why is mathematics is so successfully applied in physics?—to the *how-question*—How do physicists apply mathematical methods and models? As it is typical for phenomenological approaches, the focus is on scientific practice. More precisely, Islami and Wiltsche claim that "[a]ddressing the how-question from a first-person perspective puts us in a position to gain a firmer grip of the intentional structures that are operative in concrete cases of mathematical-physical theorizing." Building on the distinction between a *synchronic* and a *diachronic* analysis of the ways in which mathematics is applied in physics, Islami and Wiltsche argue that the applicability problem, as it is traditionally viewed, disappears as soon as we realize that the objects of modern physics are the result of a quite peculiar form of constitution which transcends the strict separation between an abstract and an empirical sector of reality.

Thomas Ryckman's chapter addresses one of the pillars of modern physics: the gauge principle. Given its crucial role in, for instance, the standard model of particle physics, in string theory or in general relativity, it is not surprising that prominent voices have called for an elucidation of the gauge principle as one of the most important tasks of philosophy of physics. Ryckman argues that revisiting the philosophical-phenomenological motifs that led Weyl to introduce the gauge principle in the first place can contribute to this task. Ryckman begins his discussion with Weyl's thesis that in order to understand the world, physics must proceed "by bottom-up symbolic construction starting from mathematical relations in the infinitely small." For Weyl, physical laws must be grounded in *Evidenz*, and *Evidenz*, in fundamental physics, is only to be found in the infinitely small, since the range of intuition of the cognizing subject, i.e., the ego-center, is regarded to be limited to its immediate spatial-temporal neighborhood. Ryckman identifies this line of thought as a commitment to transcendental phenomenological idealism in a Husserlian spirit. Towards the end of his chapter, after shedding light on the transcendental-phenomenological origins of the gauge principle and the role it plays in modern physics, Ryckman brings up an issue that puzzles many contemporary physicists and philosophers of physics: Since gauge transformations lead to new degrees of freedom that appear to be redundancies, it seems that the gauge symmetries does not correspond to symmetries of nature, but only to symmetries of our symbolic representations of nature. Concerning these arbitrary purely mathematical degrees of freedom, Ryckman argues that "the arbitrariness can be understood phenomenologically, as each point indifferently can be considered the locus of an experiencing, constructing ego." In our view, Ryckman's phenomenological clarification of (the origins of) the gauge principle is not only of utmost historical importance, but paves the way towards at a better understanding of the mathematical structure of modern physical theories as well as of the world these theories purport to describe.

Steven French aims at paving the way for a phenomenological approach to the notorious measurement problem in quantum mechanics. The interpretation offered by London and Bauer serves as the starting point of his chapter. By shedding light on Fritz London's phenomenological background, French argues convincingly that the interpretation of London and Bauer goes beyond von Neumann's interpretation in that it aims at a *phenomenological clarification of the role of consciousness* in the apparent collapse of the wave function. This is not to say that the observer and her consciousness are to be placed outside of a quantum mechanical description, thus mysteriously causing the wave function to collapse. Rather, the observer must be included into the quantum mechanical description: When observation takes place, a separation occurs in the sense that the "object and subject poles of the relationship between the knower and the world emerge." It is this embeddedness of the observer and the observed within a common theoretical structure that is of particular interest to French. On his view, a phenomenological reconstruction of the London and Bauer interpretation results in a position that avoids the objections that have been traditionally raised against von Neumann as well as against London and Bauer. What is more, in the final section of his chapter, French sketches how a phenomenological interpretation of quantum mechanics could be introduced into current debates about the interpretation of quantum mechanics. In particular, French highlights how a phenomenological approach could adopt plausible elements of rival interpretations such as Dieks' perspectivalism, Rovelli's relationalism, or Everett's many-worlds interpretation without being obliged to postulate branching worlds or branching minds. Without a doubt, French's chapter will be an important stepping stone for further attempts to position phenomenology as a fruitful framework for the interpretation of quantum mechanics.

In his chapter, Michel Bitbol addresses certain systematic similarities between a novel interpretation of quantum mechanics, QBism, and phenomenological motifs, particularly as we find them in Husserl and Merleau-Ponty. Bitbol identifies three features of QBism that are shared by the phenomenological tradition. The first concerns the first-person approach. The idea, in a nutshell is this: Phenomenology is well-known for its demand that philosophy, as the ultimate science, must proceed from the first-person perspective in order to account for objective knowledge in terms of the underlying structures of (transcendental) subjectivity. QBism seems to follow a similar trajectory by aiming "to reconstruct a new, self-conscious, type of objective knowledge, [and by] starting everything afresh from the first-person standpoint of knowers and agents." The second common feature is the demand to direct our attention away from the external objects of physical theorizing, and focus on the mental acts that present these objects instead. According to Bitbol, many proponents of QBism "proceed phenomenologically" by suspending their judgments concerning the existence of external objects and by redirecting their attention "towards the epistemic function and the practical use of the symbols of quantum mechanics." The third common feature concerns the claim, popular among defenders of QBism, that quantum mechanics only tells us something about the *expectations* we should have concerning the outcomes of experiments. Bitbol argues that this line of interpretation is in many ways similar to Husserl's conception of horizontal intentionality. This third common feature takes center stage in the final chapter of this volume.

In the final chapter of this volume, Laura de la Tremblaye discusses similarities between a QBist and a phenomenological epistemology, particularly addressing the conception of horizontal intentionality in Husserl's theory of perception. One distinctive feature that is shared by QBists and phenomenologists is the recognition of the central role of the subject and her experiences. The QBist slogan "experience first" is identified as a basic phenomenological principle. What is more, Tremblaye argues for a phenomenological reading of QBism that links the Husserlian notions of anticipation and fulfillment to the QBist understanding of the measuring process in an astonishingly straightforward way. In this picture, "the perceptual horizon parallels the QBist quantum state, the perceptual act corresponds to the physicist's measurement and the modification of my possible horizon corresponds to the modification of the state vector after the measurement." Finally, Tremblaye addresses one important distinction between QBism and the Copenhagen interpretation. While QBism and the Copenhagen interpretation share many important similarities, the Copenhagen interpretation does not single out the subject and her experiences. It ascribes a central role to measurements but not to the subject conducting the measurement. Accordingly, the Copenhagen interpretation remains within the third-person perspective. QBism, on the other hand, aims at a first-person interpretation of quantum mechanics. In this sense, Tremblaye concludes that "if interpreted phenomenologically, QBism reveals the special relations that unite the physicist and her experience, as well as the nature of the knowledge of which theoretical physics is a special case."

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