Hegel and the Sciences: Philosophy of Nature in the 21st Century

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Front Cover Image: Cyanobacteria Colony Nostoc. Image generously provided by James Weiss. Editor's comment: This nostoc colony shows at once the messiness and perhaps unseemliness of nature, but also its systematic elegance and curious coherence. For more about the microcosmos, please visit James' channel *Jam's Germs* on YouTube: https://www.youtube.com/jamsgerms

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In memory of Thomas Posch

1974-2019

Hegel and the Sciences: Philosophy of Nature in the 21st Century

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Remembering Thomas Posch

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Hegel And the Observable: Phenomenology, Empirical Science, and the Problem of Scientific Theory[1,2]

JAMES SARES

Introduction

The concern of this essay is twofold: first, to consider Hegel's phenomenological analysis of empirical science, including his criticism of scientific theories explaining the causes behind phenomena with unobservable entities;[3] and second, to apply these concerns to the case of

[1] I thank Robert Crease, Jennifer Carter, Paul Rubery, and two anonymous reviewers for their comments on previous drafts of this essay.

[2] I use the following standard abbreviations for Hegel's works:
SL: G.W.F. Hegel, *The Science of Logic*, trans. by George Di Giovanni (New York: Cambridge University Press, 2010). Cited by page number in the English translation.
EPN: G.W.F. Hegel, *Hegel's Philosophy of Nature*, trans. by M.J. Petry (London: Allen & Unwin, 1970). Cited by section (§) number. 'A' refers to Addition and 'R' to Remark.
PS: G.W.F. Hegel, *The Phenomenology of Spirit*, trans. by A.V. Miller (New York, Oxford, 1977). Cited by paragraph (¶) number.

[3] I use the term 'entity' (or, for stylistic variation, 'entity or structure') to refer most broadly to anything posited as physically real in nature. For further discussion on Hegel's critique of unobservable entities, see also: Thomas Posch, "Hegel's Criticism of Newton's Physics. A Reconsideration." Paper presented at the "Hegel and British Thought" Conference, Oxford University, 2004; and Brigitte Falkenburg, "How to

quantum mechanics more specifically. The dialogue between Hegel and contemporary physics is productive, I claim, not only because it demonstrates the continued relevance of the Hegelian analysis of empirical science but also because it highlights how Hegel's philosophy may require clarification regarding the nature of observation and empirical justification. I understand the 'unobservable' as what is not or cannot be perceived sensuously *as itself* but rather merely hypothesized or theoretically inferred from its postulated effects.[4] Yet, different views on or criteria for perception, observation, and empirical justification may engender debate about Hegel's potential engagements with contemporary empirical science. In turn, this dialogue opens opportunities for examining Hegel's commitment both to phenomenological evidence and to the actually existing, objective determinations of nature. As such, this essay opens avenues for exploring the relationship between these philosophical commitments, especially as they are confounded by the question of observability, in view of contemporary debates in the philosophy of science and empirical science.

I begin my analysis with an examination of the epistemological limitations of empirical science, understood here to include such fields as physics, chemistry, and biology. On the one hand, empirical science provides the philosophy of nature with the "forces, laws, and genera" that it rearticulates as an "organic whole."[5] Hegel emphasizes that the philosophy of nature must be flexible to include the discoveries and concepts of the empirical sciences of the day, characterizing it as taking

Save the Phenomena: Meaning and Reference in Hegel's Philosophy of Nature," in *Hegel and the Philosophy of Nature*, ed. by Stephen Houlgate (Albany: SUNY Press, 1998), pp. 97-136 (p. 130).

[4] This analysis applies only at the level of theoretical *natural/physical* entities or structures, not to the domain of human spirit and its rational products (e.g. states, human laws, etc.).

[5] EPN §246. Note that Hegel's use of the term "force" does not imply his acceptance of *unobservable* or *theoretical* forces, including Newton's centripetal and centrifugal forces. The term "force" also may be understood more broadly to refer to natural powers, compulsions, or potencies in nature.

"material prepared out of experience."[6] The empirical scientist[7] has the power to grasp that which is "universal in nature" and thus arrives at one type of valid conceptual apprehension of reality.[8] Indeed, in describing observed phenomena in terms of concepts and mathematical formalism, empirical science allows for an intelligible account of the appearing of what might, in today's terminology, be labeled "natural kinds,"[9] understood as "the truth, objectivity, and actual being of the things themselves" rather than something merely "subjective and belonging to us."[10] With the term "natural kind," I refer to the distinct qualitative levels of natural being (the mechanical, the chemical, the biological, and so on), the structures and determinations that necessarily apply to these levels, and the objective and observable classes of entities (including also laws, forces, genera, processes, and relations) that may fall under or among them. On the other hand, empirical science is speculative in a 'bad' sense when it mistakes mathematical formalism for physical reality, posits theoretical entities or unobservables behind phenomena in order to explain them, or ignores the role of explanation and interpretation in connecting mathematical formalism or other empirical concepts to observed phenomena. In view of these phenomenological concerns, Hegel denies that these speculations allow one to ascend to judgments on objective truth.

The final section engages quantum mechanics more specifically. Given that empirical science gives empirical material for the philosophy of nature to "translate" into a systematic totality that demonstrates the

[6] EPN §246A.
[7] I refer to the "empirical scientist" and "empirical science" as involving the observation and investigation of natural being, including the discovery of phenomenological laws and structures of natural being, and the classification of natural kinds. These discoveries and classifications can then be disseminated to those who do not the training or specialty to investigate nature in this rigorous way—or those who have not reflected critically or systematically on that which they observe of nature in daily life.
[8] EPN §246.
[9] Falkenburg also uses the term "natural kind" in her discussion of this matter. See: Brigitte Falkenburg, "How to Save the Phenomena," p. 109.
[10] EPN §246A.

conceptual determinations behind the development of different qualitative levels of natural being,[11] a contemporary Hegelian philosophy of nature must be able to respond to the theoretical development of quantum mechanics. I argue that Hegel's phenomenological analysis of empirical science can be applied to realist interpretations of quantum mechanics, particularly for their positing of unobservable causes behind measured observations. However, the scale of quantum phenomena requires clarification of the nature of observability in Hegel's analysis of empirical science more generally. With an analysis grounded in the first two sections, I argue that different criteria for observability and epistemic justification in empirical science may influence how one understands the significance of quantum mechanics—including whether it has any significance at all—for a contemporary Hegelian philosophy of nature.

Hegel's Phenomenological Analysis of Empirical Science

In this section, I trace the tension in Hegel's account of empirical science between phenomenological analysis and the discerning of natural kinds. I argue that, for Hegel, empirical science can be justified in positing natural kinds only when it limits itself to what is observable and avoids the collapse of qualitative differences between distinct levels of nature. I consider the role of subjective explanation in connecting the concepts it posits as essential determinations of natural being with the objects of sense perception to which they apply. I consider how the need for this "middle term" of explanation may present problems for discerning natural kinds non-arbitrarily yet how Hegel's two standards for their justification

[11] EPN §246A. For Hegel, empirical sciences achieve (in its proper bounds) the articulation of natural kinds and determinations that are "put into orderings and classes" and "exhibit an organized form" (EPN §246). These kinds of and their relations are then presented according to the systematic conceptual development of the philosophy of nature (and which Hegel argues they exhibit); however, I cannot examine the precise nature of this development in depth here. See also: Brigitte Falkenburg, "How to Save the Phenomena," p. 100.

resolves this concern.

The most important sections of the *Phenomenology* for considering empirical science are the chapters titled "Force and Understanding" and "Observing Reason," which articulate the structures of empirical scientific knowledge and the standards for the validity of that knowledge. The Force and Understanding chapter involves a number of intricate conceptual developments that cannot be engaged here. Briefly, however, the chapter begins by defining force as the unity of being-in-itself and being-for-other. Because any one force must be for another, the object of investigation turns to a system of forces whose members are both solicited and soliciting. Although reality seems to dissolve under the fleetingness of individual forces, the understanding rearticulates them in terms of physical laws or equations that recapture being in the flux of becoming, or what Hegel calls "the stable image of unstable appearance."[12] A first "static kingdom" of laws rearticulates the fleeting forces in such a way as to render them into the intelligible, static laws or expressions. An "inverted world" is then posited to *explain* or *interpret* how these static laws relate to each other and to the sensuous world. This "world" is understood to be the inaccessible *beyond* abstractly opposed to (despite being the truth of) the world of appearance.[13] Ultimately, the indifference of appearance and its beyond cannot be supported because it cannot explain the movement from unity of law to multiplicity of phenomena. As such, a second "inverted world" is posited that takes the supersensible/intelligible realm to "overarch" the other world and to "have it within itself."[14] Appearance comes to be a difference that this 'inner' or 'essential' world has *within itself*, a difference that turns out to be an affirmation of self-identity.

One element for formulating Hegel's phenomenological analysis of empirical science comes after this stage of analysis. As it turns out, Hegel writes, the structure of unity-in-difference is nothing other than the

[12] PS ¶149.
[13] *Ibid.* ¶143-144.
[14] *Ibid.* ¶160.

explanatory activity of thought itself. The very positing of the supersensible realms is the product of an attempt of the thinking subject to *explain* how the laws of empirical science relate to the multiplicity of appearances it seeks to rearticulate. Here scientific law refers to the relationship between concepts, which is often expressed by measurable quantities that model this relationship approximately. Hegel gives the example of gravity, the concept of which essentially unifies distance and velocity.[15] This explanation operates so as to posit distance and velocity as distinct yet related to each other, thus "superseding the differences present in the law."[16] Yet, it also posits this unity to be "equally and immediately a sundering, for it supersedes the differences and posits the oneness of Force."[17] In other words, explanatory activity alternates in its 'movement' between the diversity of appearances and the unity of law, such that this alternation is a reflection of its *own* activity rather than a process that the law posits *for itself*. A scientific law explains nothing on its own, outside of the intellectual activity relating it to experience.[18] As such, Hegel writes, "the reason why 'explaining' affords so much self-satisfaction is just because in it consciousness is, so to speak, communing directly with itself, enjoying only itself."[19] Because the law must be *supplemented* by explanation, the 'movement' from unity to multiplicity (and back) is done not by the formalism itself but rather by the subject itself.

When Hegel writes that explanation is the communion of consciousness "only" with itself, he is not claiming that the formulation of scientific laws and concepts has no connection with objectivity. Instead, he points to the need to investigate how the essential determinations of objects appear as valid in and through the sensuous contents of conscious

[15] Note that this reference to gravity need not be read to refer specifically to the Newtonian law of universal gravitation. In EPN §261-262, the very concept of gravity (regardless of theoretical paradigm) is shown to develop out of the concepts of motion and matter.
[16] PS ¶163.
[17] *Ibid.* ¶163.
[18] I thank Mary Rawlinson for emphasizing this point in personal correspondence.
[19] PS ¶163.

experience. The *opposition* between an inner world of laws/essences and the sensuous objects of experience is overcome through the activity of explanation in Force and Understanding; for the "instinct"[20] of reason, this explanation is successful because sense perceptions conform to and exhibit this conceptuality as their *own* essentiality.[21] Objects and their essential determinations are unknowable except as they appear *for consciousness*—that is, as the unifying structures or determinations *of* the sensuous contents of conscious experience.

In the discussion of scientific law in Observing Reason, Hegel describes the active process by which the investigator of nature seeks to discover this conceptual infrastructure. The subject knows this essentiality explicitly by investigating how the contents of conscious, perceptual experience appear according to these objective determinations. As such, Hegel is concerned with exploring the conditions under which empirical science is justified, as a practice, in making its claims to these essential determinations. Specifically, Hegel writes that the scientific laws (and other natural kinds) prove themselves valid under two conditions: first, that they are "manifested in the world of appearance" and second, that they are also a "Notion" in themselves.[22] The first point underscores observability via sense perception. The second point refers to how these conceptual determinations become explicitly known through the activities of observation and conceptual articulation. Indeed, although these conceptual determinations reflect the essential structures or natural kinds present "in"[23] the sensuous world, the intellectual activity of abstraction must discover it out of perceptual experience. Thus, Hegel underscores that the purpose of abstraction is to overcome immersion in "empirical material."[24]

[20] PS ¶246.
[21] *Ibid.* ¶242.
[22] *Ibid.* ¶250.
[23] As discussed below, under a constructionist interpretation, these concepts provide a valid or adequate "conceptual framework" for explaining how the 'in itself' of nature appears in experience. See: Tom Rockmore, *German Idealism as Constructivism*, (Chicago: Chicago University Press, 2016), p. 108.
[24] PS ¶251.

For instance, gravity explains the falling of a rock as one of its essential determinations as material, though the individual rock falling does not exhaust the concept of gravity. Similarly, Hegel discusses the process by which the concepts of negative and positive electricity are separated from resin and glass such that neither is "any longer attached to a particular kind of thing."[25] With these examples, Hegel emphasizes that the validity of natural kinds lies in that they are not restricted to individual occurrences or observations but rather are judged as essential determinations of that phenomenon or kind of phenomenon, whenever and wherever it may appear.

The two criteria for the validity of scientific law are further clarified in Hegel's subsequent discussion of the organism. The Observing Reason chapter moves from investigating physical laws to investigating the determinations of the organism to investigating the psychological laws governing observation itself. This development mirrors a development toward more explicit *self*-relation. Thus, for Hegel, the idea of scientific law does not apply as clearly to the organism because, by definition, a law puts together two (or more) determinations that each "have an independent, indifferent subsistence of its own, the relation of the aspects being shared between them as a twofold determinateness corresponding to that relation."[26] For example, while distance and velocity do not directly refer to each other, reason discovers their relatedness and formulates the concept of gravity accordingly. In contrast, the organism involves an explicitly purposive self-relation between its inner determinateness and external appearance. Similarly, Hegel claims that magnetism cannot be expressed through a law in the *Philosophy of Nature* given "the inseparability of the two [polar] determinations," whereas a law is supposed to demonstrate a "mutual freedom" between its sides.[27] It seems that this remark contradicts Hegel's invocations of acid/base and negative/positive electricity as examples of scientific law in the *Phenomenology*, since both examples also

[25] PS ¶251.
[26] *Ibid.* ¶278.
[27] EPN §270R.

involve the inseparability of one conceptual determination from the other. Hegel even lauds this conceptual complementarity for indicating the non-arbitrariness of scientific laws applied to these phenomena.[28] Leaving this seeming inconsistency aside, what is important is that any scientific law or concept is not arbitrarily posited but rather refers to how nature actually appears. As such, although not all of natural being is structured according to laws in Hegel's specific sense, the criteria for judging the validity of laws applies to all other essential determinations of nature.

Nevertheless, to emphasize once more, all of nature also involves a difference between these essential determinations and the sensuous individuality in which they present themselves to observation. Since the conceptual structure implicit in sensuous experience must be made explicit by thought, this conceptuality is never immediately given *as known* in observation. The empirical scientist is tasked with abstracting and knowing this essentiality and recognizing its appearance in sensuous experience. Thus, an ineliminable aspect of the activity of empirical science is judging the extent to which the phenomena at hand correspond with the various conceptual terms that are employed to understand it. Given its need to abstract concepts from and to apply concepts to sensuous experience, empirical science always requires the explanatory power of thought as the 'middle term' for its activity. Observing Reason cannot overcome the difference between its method of knowing and the being to which this knowing refers. As such, the *Phenomenology* leaves the investigation of nature behind in the attempt to overcome this difference—that is, to attain truth by rendering knowing perfectly adequate to being—in the examination of human spirit and the articulation of spirit's essence in the pure philosophical science of logic. Unlike this pure philosophical science, empirical science seems to be inherently open to the problems of misrecognition and misapplication of concepts. As such, the problem for empirical science becomes justifying that what is abstracted from experience in conceptual or lawful form actually applies as its truly

[28] PS ¶251.

objective determinations.

Brady Bowman argues that Hegel is a skeptic about empirical knowledge because it never attains to the apodictic, self-developing necessity found in pure logic.[29] However, this reading of Hegel is not generally accepted in the secondary literature, and rightly so. First, such a radical skepticism about empirical knowledge would seem to contradict Hegel's emphasis on the ability of empirical science to obtain knowledge of the "universal" (i.e. conceptually articulated determinations of nature) as "the truth, objectivity, and actual being of the things themselves."[30] This is so, even if one may not consciously recognize it and even if the concepts one grasps are not put into properly systematic presentation according to Hegel's standards. Second, Bowman's emphasis on the underdetermination of scientific laws—whereby the same phenomenon can be explained in multiple ways without ultimate justification for any one interpretation—is directed toward theoretical laws posited in scientific theories. I argue below that scientific theory cannot be judged as objectively true anyway under Hegel's *phenomenological* analysis.[31] Instead, Adrian Johnston underscores the structural "isomorphism" between subjectivity and objectivity that allows for the disclosure of reality as "law-like, and hence, comprehensible in the form of posited laws with predictive power."[32] Similarly, Brigitte Falkenburg argues that, for Hegel, knowledge of natural kinds is discernable from experience and that valid phenomenological laws exist objectively, over against an empiricist view that would deny there to be any real laws in nature.[33]

Yet, if we accept Johnston and Falkenburg's readings, the precise nature of the *objectivity* of these natural determinations may engender

[29] Brady Bowman, *Hegel and the Metaphysics of Absolute Negativity*, (Cambridge: Cambridge University Press, 2015), pp. 134-157.
[30] EPN §246A.
[31] Brady Bowman, *Hegel and the Metaphysics of Absolute Negativity*, p. 151.
[32] Adrian Johnston, *A New German Idealism: Hegel, Žižek, and Dialectical Materialism*, (New York: Columbia University Press, 2018), p. 57.
[33] Brigitte Falkenburg, "How to Save the Phenomena," p. 113.

debate. In view of the isomorphism between subjectivity and objectivity, Hegel might be read as arguing that empirical science can grasp objective determinations as they apply to nature as it is 'in itself' independently of the subject's *experience* of natural being. Johnston cites Hegel's criticisms of transcendental idealism, for instance in the start of the "Subjective Logic" section of the *Science of Logic*, where Hegel argues against the supposed absurdity that true knowledge is only of "false appearances"[34] and that objectivity is only ultimately of the "I" itself.[35] This immanent critique of Kant, including of the emptiness of the concept of the thing-in-itself, gives Hegel an impetus for arguing that conceptual determinations "cut across" the subject/object distinction so as to be "objective (as substantially 'in themselves' apart from all knowing subjects) and subjective (if and when they also become 'for themselves' through human mindedness and like-mindedness)."[36] Subjectivity is here understood as "nothing other than the self-reflectivity or -reflexivity of substantial objectivity itself,"[37] which gains support in Hegel's logical demonstration of the development of cognition out of the various determinations of objectivity that it comes to know in their own conceptuality. While I cannot examine this demonstration in any detail, including its possible deficiencies, I note only that one can find strong textual justification for Johnston's reading. Indeed, Hegel writes that the knowing subject "refers to an external world" with "absolute certainty of itself, in order to elevate its implicit reality" to articulated conceptual truth.[38] The subject posits the "entire essentiality of the objective world" as identical to its concept of it.[39] Thus, for Hegel, subjective cognition—as part of its conceptual determination—has the reflexive power to know the objective world in which it exists as it truly is.

[34] Adrian Johnston, *A New German Idealism*, p. 48.
[35] See the discussion of SL pp. 515-516 in: Adrian Johnston, *A New German Idealism*, pp. 45-47. I leave possible defenses of Kant on this point aside.
[36] Adrian Johnston, *A New German Idealism*, p. 55.
[37] *Ibid.*, p. 51.
[38] SL p. 696.
[39] *Ibid.*

While Johnston interprets these claims to indicate that Hegel takes the subject to be able to know the 'in itself' independently of its appearing in experience, such a position may be problematic from a phenomenological point of view. Even the thought or projection of these determinations as existing independently of experience must be posited in experience by the subject—including the subject who thinks the purely logical categories themselves as the very source of the justification of such a projection. As such, Tom Rockmore argues that, for Hegel, the concepts of empirical science are objective because they are "tested" and reformulated according to the conscious *experience* of objectivity.[40] Phenomena thus have a "dual status within and outside consciousness" insofar as the appearing of objects depends on the construction of "conceptual schemes […] to cognize conscious experience" at the same time that these concepts must be tested in their adequacy for engaging experience itself.[41] Thus, this interpretation might question how experience itself is structured so as to engender true judgments on natural kinds. Indeed, this "constructivism" is a critical reflection on how the positing of certain determinations cannot but belong to the subject's experience of nature *in its phenomenality* alone. Here Rockmore claims to avoid reproducing the problem of the noumenon, insofar as his interpretation focuses on the immanent contents of experience itself without judgment about either an external reality causing it or its having its source in subjectivity itself (since experience always involves a distinction between subject and object). For Rockmore, Hegel's *phenomenological* analysis suspends both metaphysical realism and idealism as intuitively or experientially empty in favor of this immanent interrogation of the "dual status" of phenomena.[42] This reading provides an alternative for obviating

[40] Tom Rockmore, *German Idealism as Constructivism*, p. 108.
[41] *Ibid.*, p. 110.
[42] Problematizing Rockmore's reading, Hegel nowhere suspends belief in the existence of nature external to subjectivity, as the *transcendental* (Husserlian) phenomenologist might. On the other hand, if Hegel is read to reject this suspension of judgment, I leave open whether his philosophy can provide an adequate rebuttal to the critique that such a projection of external existence is not justified *phenomenologically*, from the limits of what is given in experience itself.

the problems with Johnston's reading and accords with Hegel's critiques of epistemological theories that posit an independent object external to yet represented by consciousness. Indeed, Rockmore's argument resonates with Hegel's critique of the "sophistry" of perception,[43] which ends in a dualism between consciousness and an external objective cause. This dualism cannot discern what belongs to the object as it is externally to consciousness versus how consciousness transforms the object in its being *for it*. To investigate nothing but consciousness's *own* contents and activities—including how objects appear in, through, and as their structured unity—resolves this problem definitively.

For my concerns, it is less of a problem whether Hegel takes natural kinds to exist independently of their relation to consciousness or whether they are only *experienced* as objectively existing from within the constructivist framework.[44] Rather, it is more important to examine how certain determinations could be judged within experience as essentially and objectively belonging to natural phenomena, regardless of their 'actual' status outside of conscious experience.

Following Falkenburg and Thomas Posch, I argue that Hegel offers two standards for making such a justification. First, Hegel demonstrates a commitment to preserving phenomena in their qualitative distinctiveness, such that one should not attempt to reduce distinct qualitative levels of nature to an underlying sameness. As Falkenburg emphasizes, Hegel is concerned with doing justice to the phenomenological structures of experience "of increasing degrees of complexity, to which quite distinct conceptual structures apply."[45] This attitude is evinced in Hegel's critique of the physics of his day to regard "magnetism, electricity and chemism" as "one and the same thing" over and against their qualitative differences.[46] What holds validly and essentially for one kind of phenomenon may not for another or otherwise require a more complex reformulation reflecting

[43] PS ¶130.
[44] Whenever I use the words 'exist' or 'existing,' it is with this qualification in mind.
[45] Brigitte Falkenburg, "How to Save the Phenomena," p. 98.
[46] EPN §240A.

qualitative difference in nature (including, for instance, the levels of mechanism, chemism and organics and the distinct phenomena falling under each). Moreover, for Hegel, the essential determinations of these qualitatively distinct phenomena hold regardless of further discoveries (e.g. there is no life without sensibility, irritability, and reproduction, by the very definition of life; there is no mater without gravity, by the very definition of matter; and so on). Second, and more importantly for my concerns, Hegel's phenomenological analysis indicates that only what is observable in sense perception can be justified as objective. I thus interpret Hegel as rejecting the validity of positing unobservable causes or structures behind the appearing of phenomena.

These two standards for the objective validity of scientific laws and concepts are not unproblematic. First, Hegel may be charged with begging the question with regard to the observation of qualitative distinctions in nature. For example, is there still not the threat of misrecognizing the organic realm as teleological, over and against a mechanistic view? Perhaps distinguishing these qualitatively distinct layers of nature is justified in the systematic development of the philosophy of nature itself; yet, if the philosophy of nature depends for its content on these empirical concepts, this solution is circular.[47] Perhaps Hegel intends his logical science, with its sections on mechanism, chemism and teleology and life, to prove the necessity of distinguishing these layers.[48] Finally, perhaps the phenomenological justification for distinguishing qualitative differences is precisely *its own*, given by the "test" of experience. In this case, what appears cannot be fully or adequately described through qualitative

[47] EPN §246A. As I consider in the conclusion, how one understands Hegel's philosophy of nature as either *a posteriori* or *a priori* may confound this problem.
[48] In view of my concerns with observability below, one might look to Hegel's assurance that the animal has feeling as one place where problematic inference to the unobservable takes place. However, feeling is part of the determination of life as outlined in the pure science of logic (SL p. 683), thus seeming to allow this inference in the study of nature. The target of critique would move to the justification of this logical principle and its application. The same would go with the application of other logical concepts and their determinations to the study of nature.

reduction, leaving something left unsaid that is more adequately articulated through these distinctions. Thus, for example, even if certain organismic processes *can be* understood mechanistically or chemically when taken in isolation, the very structure of their working together presents itself differently than mere self-externality. Defending Hegel's non-deflationary account of life, James Kreines underscores that the parts of the organism cannot themselves exist and be reproduced over time without an interconnectedness allowing for the activity of assimilation and species-reproduction.[49] This more holistic account emblematizes Hegel's concern with understanding a phenomenon in all of its complexities.

A second, more serious problem with the criteria for the validity of scientific concepts and laws is that what it means to 'save' phenomena may be contentious under different conceptions of observability. Hegel's lack of specificity on what counts as observable is particularly problematic for certain entities like atoms, which may be argued to indirectly appear according to abductive reasoning, or which may be argued to exist as merely theoretical constructs, opening the problem of underdetermination. It is necessary to emphasize the gap in Hegel's work around the question of observability and how different criteria may enable different accounts of a contemporary Hegelian philosophy of nature. Nevertheless, I argue that the problem of observability can be approached through Hegel's treatment of Kepler and Newton, which provides paths for considering contemporary debates.

Hegel on Scientific Theory and the Unobservable

Hegel's discussions of Kepler and Newton span across his dissertation *De orbitis planetarum*, the *Philosophy of Nature*, the *Science of Logic*, and his

[49] James Kreines, *Reason in the World: Hegel's Metaphysics and its Philosophical Appeal* (Oxford: Oxford University Press, 2015), pp. 77-109.

lectures on the history of philosophy.[50] His narrative across these texts is relatively consistent,[51] with Kepler serving as an exemplar of the proper methodological boundaries of empirical science and Newton serving as a warning against the speculative excess of scientific theory. As Rockmore writes, Hegel considers the difference between Newton and Kepler to be one between "causal analysis" and "phenomenological description."[52] While Kepler provides "phenomenological laws" for particular celestial phenomena,[53] Newton substitutes these with "laws of forces,"[54] which Posch emphasizes emerge out of a unified theory deriving "several classes of motions."[55] Indeed, as K.N. Ihmig writes, Hegel seeks to establish "mechanics on purely kinematical grounds," focusing on observed motion alone.[56] Because Newton's unified theory moves beyond phenomenological description to the forces lying behind phenomena, he loses the basis for the objective validity of his laws in a way Kepler does not.

Before examining the problem with Newton's theory in greater depth, let us consider the objection that Kepler's laws are less phenomenologically adequate than Hegel portrays. First, mathematical models are only approximate in nature—something Hegel does not problematize sufficiently. Thus, with new instruments, might there be a need to reformulate the laws with greater accuracy, perhaps revealing

[50] For an extensive examination of Hegel's engagement with Newtonianism, including precise engagements with the mathematical formalism of Newton and Kepler, see: *Hegel and Newtonianism*, ed. by M. J. Petry (New York: Springer, 1993). My brief analysis focuses on the question of observability and does not touch on the myriad of important topics in the Hegel-Newton relationship.

[51] However, Rockmore notes slight differences between the earlier and later critiques; for instance, the early complaint in the dissertation that "Newton does not prove his theory of gravitation by deducing it from the phenomena" is absent. See: Tom Rockmore, *German Idealism as Constructivism*, p. 129.

[52] Tom Rockmore, *German Idealism as Constructivism*, p. 129.

[53] Thomas Posch, "Hegel and the Sciences," in *A Companion to Hegel*, ed. by Stephen Houlgate and Michael Baur (Malden, MA: Wiley Blackwell, 2011), pp. 177-202 (p. 193, original emphases).

[54] Hegel quoted in Thomas Posch, "Hegel and the Sciences," p. 193.

[55] Thomas Posch, "Hegel's Criticism of Newton's Physics. A Reconsideration."

[56] K.N. Ihmig, "Hegel's Treatment of Universal Gravitation," in *Hegel and Newtonianism*, ed. by M. J. Petry (New York: Springer, 1993), pp. 367-381 (p. 379).

minute changes previously unaccounted? Even if so, however, the laws can be understood *as approximate* articulations of phenomena that correspond to this objectivity in the very mode of approximation; moreover, the conceptual determinations of the phenomena themselves can still be discerned through these models. Second, the Humean might charge that these laws cannot be known to always hold and thus lack objectivity. What if, for instance, the planets were to change course? To this, note that *phenomenological* laws are meant only to rearticulate observed phenomena as they so appear; even if these laws were somehow no longer to apply, it means not that the laws were not objective or true but that the phenomenon *itself* changed. The same goes with other natural kinds.

In contrast, *theoretical* laws move beyond the mere appearing of phenomena. The problem with Newton's universal laws is not that they are empirically inadequate or false *per se* within the classical frame. However, as Falkenburg writes, Hegel takes it to be the domain of philosophy to criticize physics "whenever the preliminary concepts of that science do not denote natural kinds but unobservables."[57] Once again, the 'unobservable' is what is not or cannot be perceived sensuously *as itself*; rather, it is or can only be theoretically inferred *from* the observed effects that it is postulated to cause or structure. This includes entities or structures that have no empirical verification but are merely hypothesized to exist, especially from within a scientific theory. Falkenburg claims that this critique of the unobservable is "in the spirit of Hegel's own *phenomenological* attitude towards *physics* itself," which bars inference from what is observable to what is unobservable or merely hypothesized.[58] Newton's laws make such an inference by explaining motion via centripetal and centrifugal forces that are, Hegel claims, conceptually incoherent when taken independently of one another.[59] For Hegel, gravity, inertia, impact, and fall are essential

[57] Brigitte Falkenburg, "How to Save the Phenomena," p. 130.
[58] *Ibid.*, p. 99, original emphases.
[59] EPN §270R. As he writes, "[n]o enquiry is made into how an independent force […] is able, of its own accord, to make itself subordinate to the other, and then to make itself predominate, to get the other force to allow this, and to follow this up by cancelling this predominance again, or allowing it to be cancelled."

determinations of matter yet not under the Newtonian paradigm of forces.[60] This is because, Ihmig writes, Newton models these forces as "external causes" of matter and motion, rather than the essential determinations of matter's unity with motion.[61] Indeed, Hegel charges that these forces are conceived as "implanted in matter" and thus "originally external to it."[62] As such, they gain a *separate* existence as distinct, unobservable entities from the "sensuous events" that they are inferred to cause.[63] The problem of observability haunts Newton elsewhere.[64] As Falkenburg writes, Hegel especially criticizes Newton for having made reference to unobservable atoms "and their primary qualities (and their interactions with an immaterial substance, the ether or absolute space)."[65]

According to Hegel, Newton's treatment of mathematics leads him to posit the existence of these unobservable, theoretical entities. As Rockmore writes, part of Hegel's rejection of Newtonian dynamical laws lies in how "natural science employs unclarified metaphysical categories based on mathematics, rather than thinking about the conception of the object."[66] By confusing mathematical figures with physical entities, Newton "conflates the *a priori* and the *a posteriori*" and "depends more on a mathematical approach than on the empirical data by slighting the phenomena."[67] Although Newton claims to have an inductive method grounded in empirical observation,[68] Hegel charges Newton with

[60] EPN §262-268.
[61] K.N. Ihmig, "Hegel's Rejection of the Concept of Force," in *Hegel and Newtonianism*, ed. by M. J. Petry (New York: Springer, 1993), pp. 399-414 (pp. 413-414). Ihmig warns that Hegel's critique of *Newtonian* forces does not equate to a rejection of the category of force, which appears elsewhere in the *Philosophy of Nature* without speculation to the unobservable (p. 402).
[62] EPN §261R.
[63] *Ibid.* §261R.
[64] For further references on the unobservability of Newtonian force, see also: Thomas Posch, "Hegel and the Sciences," p. 193.
[65] Brigitte Falkenburg, "How to Save the Phenomena," p. 107.
[66] Tom Rockmore, *German Idealism as Constructivism*, p. 130.
[67] *Ibid.*, p. 125.
[68] Tom Rockmore, *Cognition: An Introduction to Hegel's* Phenomenology of Spirit (Berkeley: University of California Press, 1997), p. 54.

conflating the physical and mathematical by deducing physical entities from mathematical formalism. In *De orbitis planetarum*, Hegel challenges Newton for using terms like "attraction," "impulse," and "propensity towards a centre" in an "indiscriminate" and "interchangeable" way for both physics and mathematics, despite Newton's own claim that these terms refer to mathematical models rather than actual physical entities or structures.[69] Accordingly, Hegel warns that "we must beware of confusing pure mathematical grounds with physical ones […] we may not mix that knowledge typical of the secure and formal manner of mathematics with physical relationships by attributing physical reality to what only has reality in mathematics."[70] This attitude is consistent in Hegel's later writings. In the *Philosophy of Nature*, Hegel writes against Newton that mathematical analysis "should be sharply distinguished from whatever is supposed to have a physical reality."[71] He claims that centripetal and centrifugal forces are "only mathematical lines."[72] Instead, empirical science must be measured by the "physical worth and physical significance of its determinations and procedure."[73] The confusion of ontologizing unobservable, theoretical entities emerges in their being referenced in theoretical laws.

Although subjective explanation is ineliminable to the activity of empirical science, *causal-theoretical* explanation exceeds the boundaries of phenomenological justification. As Gerd Buchdahl writes, Hegel opposes theory and hypothesis in empirical science for "going beyond experience" and "transcend[ing] the phenomena."[74] Theoretical speculation provides causal explanations 'behind' phenomena that are thus inessential—or that involve a lack of empirical evidence to be judged as

[69] Hegel quoted in Tom Rockmore, *German Idealism as Constructivism*, pp. 127-128.
[70] Hegel quoted in Tom Rockmore, *German Idealism as Constructivism*, p. 127.
[71] EPN §270R.
[72] *Ibid.* §270A.
[73] *Ibid.* §270R.
[74] Gerd Buchdahl, "Conceptual Analysis and Scientific Theory in Hegel's Philosophy of Nature (With Special Reference to Hegel's Optics)" in *Hegel and the Sciences,* ed. by Robert S. Cohen and Marx W. Wartofsky (Boston: D. Reidel Publishing, 1984), pp. 13-36 (p. 20).

essential—to the appearing of the *phenomenon as phenomenon*. In other words, positing unobservables in causal or theoretical explanation moves explanation beyond what is given with certainty; it engenders the problem of assenting to the existence of what is not or cannot be perceived sensuously from within the limits of this experience itself. As such, it cannot be known whether the contents of these theories and hypotheses refer to the essential determinations of the objects themselves or are empty products of subjectivity. This lack of certainty manifests in the problem of underdetermination, as multiple causal frameworks can explain the same phenomenon by extending beyond mere phenomenological description. Differences in what are posited as underlying causes may take the form of contemporaneous theories, or they may indicate historical paradigm changes, based on data falsifying theories.[75] In principle, one may invoke the problem of alternative theories, ranging from the plausible to the absurd (Descartes' evil demon?), to underscore the underdetermination of even the most entrenched theories positing unobservable causes or structures to explain phenomena. Many scientific realists are satisfied with strong plausibility as a way of cancelling out other possible theoretical explanations. However, for Hegel, the essential determinations of a phenomenon as phenomenon are given insofar as they appear in sense perception; what is given theoretically or hypothetically cannot, by its very nature, attain this kind of phenomenological necessity—regardless of how empirically adequate in modeling observations it may be.[76]

All of this is not to say that Hegel does not recognize the role of theory and hypothesis in empirical science's attempt to explain

[75] For example, while gravity is an essential determination of matter, the shift from understanding it as Newtonian force to understanding it as the curvature of space-time in general relativity shows how the same phenomenon can fall under incompatible theories.

[76] Unobservable *historical* phenomena (e.g. big bang theory, the original emergence of life from non-life, etc.) may also fall under this critique, though I will not explore the complications of this historical dimension here.

"everything."[77] I would add the value of their predictive powers and practical implications as well; in the realm of practical application, the empirical adequacy of theories goes far. However, for purely epistemological reasons, Hegel may be understood as an anti-realist about scientific theories for extending beyond the strict boundaries of phenomenological explanation. The general nature of contemporary debates over realism and anti-realism in its metaphysical, epistemological, and semantic variants is too extensive to engage here.[78] However, as Harald Wiltsche writes succinctly, scientific realism—at least in its epistemological valence—"implies that science provides us with methods to determine the truth-values of our theories," especially including the unobservable.[79] In contrast, he continues, scientific anti-realism is characterized by the view that "observation and experiment are the only ways to find out about the truth or falsity of scientific statements."[80] Accordingly, Rockmore characterizes Hegel's view of scientific theory as "fallibilist," in the sense that theories that posit what is unobservable in principle "are not and can never be proven, and hence are never beyond the possibility of refutation" with new data.[81]

However, it is necessary to examine, with greater specificity, what it means for something to be observable in nature. As Rockmore writes, part of Hegel's phenomenological analysis of empirical science involves interrogating how the subject actively "shapes what it observes or experiences."[82] In empirical science, there is a mediation between this activity (including experimentation) and the concepts through which the

[77] EPN §270A. Hegel also notes here that "philosophy need not be disturbed if the explanation of each and every phenomenon has not yet been completed."
[78] For an extensive discussion of the realism/anti-realism debates in contemporary philosophy of science, see: Matthias Egg, *Scientific Realism in Particle Physics: A Causal Approach*, (Berlin: De Gruyter, 2014), pp. 8-10.
[79] Harald Wiltsche, "Review of Lee Hardy's *Nature's Suit: Husserl's Phenomenology of the Physical Sciences*," *Husserl Studies*, 31.2 (2015), 175-182 (p. 181).
[80] Harald Wiltsche, "What Is Wrong With Husserl's Scientific Anti-Realism?" *Inquiry* 55.2 (2012), 105-130 (p. 106).
[81] Tom Rockmore, *German Idealism as Constructivism*, p. 123.
[82] Tom Rockmore, *Cognition*, p. 86.

subject approaches objects as observable at all. From a phenomenological perspective, these concepts must be interrogated and corrected—so as to discover which are natural kinds—by 'testing' the appearing of phenomena to the subject's experience of this appearing.

More problematically, the precise boundary between the observable and the unobservable may be taken as a matter of historical and technological context. Although Hegel does not provide an exhaustive treatment of the role of instruments in mediating observation, he passingly mentions telescopes[83] and light microscopes[84] at different moments in the *Philosophy of Nature* and seems to have no problem with their usage in enabling observations. After all, Kepler could not have discovered his phenomenological laws without instrumental supplementation. Nor would the qualities of chemical elements, electricity, or magnetism be discernible without specific instruments or measurement apparatuses. Thus, on the one hand, one can expand observability with technologies in order to discover new entities or qualities of entities *as they so appear as themselves* through the augmentation of perception. In these cases, what was 'unobservable' without technological mediation can be made observable. On the other hand, one can record and characterize data as the effect or trace of entities (or their qualities) that cannot in principle, by their very posited nature, be observed perceptually in that way.[85] These unobservable entities are inferred to cause the appearing of perceptual data. For instance, there are entities that are posited to be too small to see with light yet are inferred from photo images visible by the subject; this includes the detection of ions in cloud chambers and atoms with electron microscopes.[86] In these cases,

[83] EPN §279A.
[84] *Ibid.* §320A.
[85] Compare the distinction I draw here with: Edmund Husserl, *Ideas: General Introduction to Pure Phenomenology*, trans. by W. R. Boyce Gibson (New York: Routledge, 2012), §52.
[86] This is why we *still* could not observe atoms directly, even if we augmented our eyes with electron microscopes: the images that appear via electron microscopes always appear as sensuously grasped with light itself. The relation is thus always inferential. On this point, see: Harald Wiltsche, "What is Wrong With Husserl's Scientific Anti-Realism?" pp. 116-117.

what appears presents itself with reference to what is unobserved or unobservable to explain *what* the appearing is. For future analysis, these examples also bring to question how positing theoretical or unobservable entities *in the functioning of the instrument itself* may problematize judgment on what appears through it.

Given Hegel's lack of engagement with the nature of observability, it may be open to debate how Hegel would treat various technological possibilities. On the one hand, it seems that Hegel would problematize—wherever it may be judged—the existence of theoretical causes, structures, or models that cannot be given except as causes 'behind' sensuously observed effects, or otherwise as unobservable postulates explaining observation. With purely hypothesized entities or structures that have no discernible verification in experience (e.g. string theory), this position is unproblematic. On the other hand, one may argue that certain unobservables appear indirectly through instrumental mediation, such that the term 'unobservable' is itself a misnomer.[87] This mode of argumentation may support a dissolution of the observable/unobservable distinction altogether. However, such a perspective must reckon with the rebuttal that the appearing of only some entities involves, in principle, a direct contradiction of their sensuous appearing with their own posited unobservability through the sensible medium in which they are brought to observation. Most generally, only some entities are postulated as non-perceptual or distinct in kind from the observed effects that they are theoretically modeled, inferred, or hypothesized to cause. As warned above, this includes unobservable, theoretical entities that are ontologized from mathematical formalism (e.g. Newtonian forces and electromagnetic fields). Judging particular cases according to these standards may engender debate, informed by technological advances and the philosophical investments touched upon above.[88] Whatever one's position on these

[87] One might argue that these entities are *directly* observable; however, it is unclear how one could reject an irreducible need for inferential reasoning to what cannot *in principle* be observed yet whose results must be recorded sensuously.

[88] I also bracket the problem of possible vague cases/examples that problematize

contentious issues, I note that making these judgments will influence how one reads Hegel's philosophy of nature for today: on the one hand, denying the philosophical relevance of much contemporary empirical science; on the other, reconciling Hegel's criticisms of scientific theory with inference to unobservables.

On this latter point, perhaps one may attempt to distinguish between realism about scientific theories and realism about certain unobservable entities. Ian Hacking and Nancy Cartwright posit versions of "entity realism" that both seem incapable of maintaining this distinction coherently. Hacking explores the "home truths" about entities, abstracted from what is common to multiple theories, while Cartwright fails to distinguish what makes causal explanation via unobservable entities different than causal explanation through theories and theoretical laws.[89] Matthias Egg claims to fare better in his use of inference to the best explanation [IBE] under the criteria of non-redundancy, material inference, and empirical adequacy.[90] Discussing the atomic hypothesis, Egg claims that knowledge of unobservable atoms "does not come from a fundamental theory, but from what is experienced in the laboratory."[91] Yet, inferring what is experienced (or manipulated, in Hacking's case) is precisely the problem at hand, rather than its solution. The same problematic form of making an explanatory leap from observable data to underlying causes

distinguished observable and unobservable and how best to characterize them according to the standards discussed here. My analysis is only meant to introduce the theme of (un)observability in Hegel's work, rather than definitively characterize or resolve all issues with it. Perhaps this vagueness could be critically engaged to become part of a reflection of nature and the imperfections or limits of empirical knowledge. Moreover, the observable/unobservable distinction remains valuable even in view of possible vagueness; as Wiltsche writes, the distinction holds "so long as clear cases exist on both ends of the continuum" (Harald Wiltsche, "What Is Wrong With Husserl's Scientific Anti-Realism?", p. 128 fn. 5). The examples given in this essay are clear cases.

[89] Egg discusses Hacking's and Cartwright's work in depth, and my description accords here with his. See: Matthias Egg, *Scientific Realism in Particle Physics*, pp. 19-32.

[90] Matthias Egg, *Scientific Realism in Particle Physics*, p. 32.

[91] *Ibid.*, p. 102.

arises even in Egg's example, regardless of whether a hypothesis ascends to the status of a well-articulated theory in its content. One would be burdened with engaging the seemingly irreducible gap from *best* explanation to judgment about the *necessity* of underlying natural kinds. More plausibly, perhaps Hegel's purely logical science, with its sections on mechanics, chemism, teleology, and life, proves the necessity of distinguishing these layers of objective being. If one accepts that this jump to necessity cannot be made non-arbitrarily yet asserts the belief that these entities are real, then accepting entity realism is as problematic as accepting full-fledged theory realism. Perhaps one may attempt to reconcile Hegel's philosophy with realism about certain theories or hypotheses beyond the problems he finds in Newtonianism. Yet, if so, it is unclear how the problem of underdetermination can be avoided, leading to a merely tentative account of natural being (or, rather, one that can never prove *necessary* from experience itself), over and against what I interpret as Hegel's concern with its indubitably essential determinations. An alternative reading of Hegel's project may find precisely such an implication non-problematic.

Again, I do not pretend to resolve all of the difficulties presented in appeals to observability, nor again to provide a definitive Hegelian response to these problems, including the potential malleability of his views in our current historical situation. Perhaps what is more important is to recognize how the problem of observability emerges, for Hegel, through the tension between providing a phenomenological analysis of empirical science and striving to discover objective determinations of natural being. If Hegel were not concerned with phenomenological evidence, his philosophy could be reconciled with realism about contemporary scientific theories yet would lose the rigorous criteria for discerning natural kinds. Exploring these stakes has relied on interrogating the nature of Hegel's commitments to observability and objectivity.

Hegel and the Quantum Unobservable

Thus far, I have given a more general analysis of Hegel's phenomenological account of empirical science in relation to the problem of theory realism. If Hegel's critiques of Newton are taken as paradigmatic of his treatment of empirical science, then all contemporary scientific theories also fall under his critique. However, the theory[92] of quantum mechanics is particularly interesting because it directly thematizes the role of observation and measurement in the constitution of phenomena.[93] Moreover, recent work by Slavoj Žižek has brought attention to the ways in which the Hegelian dialectic may be rearticulated in relation to certain theoretical interpretations of quantum mechanics.[94] Given the superseding of the classical Newtonian framework to which Hegel responds, anyone engaging the continued relevance of Hegel's philosophy of nature must address the development of quantum mechanics. Thus, far from an arbitrary annex to the concerns in the first sections of this essay, the theory of quantum mechanics provides one locus for examining the continued relevance of Hegel's phenomenological analysis of empirical science.

Rather than provide an overview or thorough analysis of the history, theory, or mathematical formalism of quantum mechanics, I seek only to

[92] I take the *theory* of quantum mechanics to lie in its positing of unobservable entities and their properties and activities as causes of observational data, while there are many *interpretations* of the theory that posit distinct underlying ontologies (or not). These interpretations may be considered their *own* theories or hypotheses *of* quantum mechanics. Note, however, that some philosophers of science like Tim Maudlin object to labeling quantum mechanics as a *theory* given the unclarity of this underlying ontology. For Maudlin, quantum mechanics is a "predictive receipt" *in search of a theory* (rather than interpretation *of* the theory). See: Tim Maudlin, *Philosophy of Physics: Quantum Theory* (Princeton: Princeton University Press, 2019), p. xi. I reject Maudlin's terminology because it presents quantum mechanics as if neutral description rather than as already theoretical in form, in the sense of its positing of unobservables.

[93] I do not engage quantum field theory here. Note, however, that even in the expanded purview of quantum field theory, the measurement problem and interpretation of the wavefunction, on which I focus my analysis below, are not resolved.

[94] Slavoj Žižek, *Less Than Nothing: Hegel and the Shadow of Dialectical Materialism* (London: Verso, 2012), pp. 905-961.

consider quantum mechanics in relation to Hegel's concerns with scientific theory and observability. The previous sections of this essay ground my warning to avoid capture by metaphysical speculations that pervade the popular reception of quantum mechanics.

Yet, the extent to which one might engage quantum mechanics in relation to these criteria depends on how one justifies the existence of natural kinds in relation to observability. The most conservative reading of observability from a Hegelian lens—one tied to the critiques of theory and entity realism—would reject that quantum mechanics reveals anything valid about the objective determinations of natural being. On this reading, the proper Hegelian response to quantum mechanics, as a scientific theory, is to critique how it posits the existence of atomic and subatomic unobservables that causally explain the appearing of experimental observations. On the other hand, if one attempted to reconcile Hegel with realism about these quantum entities—something that must be taken with suspicion, given the problems examined above—it would be necessary to provide a more detailed examination of what quantum phenomena are understood to be. Most importantly, regardless of whether one accepts this latter view, the multiplicity of realist interpretations that attempt to explain why and how they act must be submitted to critique for failing to present empirical evidence and failing to overcome the problem of underdetermination. As such, I argue that examining the details of quantum mechanics provides opportunities for a more nuanced Hegelian critique. For the sake of clarity alone, I speak of atomic and subatomic particles and their qualities *as if* they were real in order to provide this critique.

With quantum mechanics, the relationship between the mathematical "formal structure" and the semantic "empirical interpretation which *fixes* the meaning and reference of the formal structure"[95] is particularly fraught with uncertainty.[96] As Peter Lewis writes, quantum

[95] Brigitte Falkenburg, "How to Save the Phenomena," p. 102.
[96] Peter Lewis, *Quantum Ontology*, (Oxford: Oxford University Press, 2016), p. 26.

mechanics seems to reveal that "physical explanation has limits."[97] The phenomena of entanglement (whereby pairs of particles seem to be inextricably and immediately connected across space and time), wave-particle duality (based on the apparent capacity of quantum particles to also act as waves),[98] quantum superposition (whereby certain values are presented as indeterminate or probabilistic pre-measurement), and quantum indeterminacy (based on the incapacity for all qualities of a quantum system like position/momentum, energy/duration, and spin of different axes to be known determinately *at the same time* and thus ever completely) present significant problems for interpretation. The problem lies in that these phenomena do not seem explicable from the tools of the formalism. For instance, wave-particle duality "can't be explained via waves and it can't be explained via particles—so what kind of physical entity does quantum mechanics postulate behind the phenomena? Entanglement can't be explained via spin properties of individual electrons—so what kind of property does quantum mechanics postulate behind the observed correlations?"[99] Similarly, it is unclear to what quantum superposition and indeterminacy refer, particularly whether these reflect an objectively existing probabilism or indeterminacy in nature itself. For Lewis, it is as if "we have no idea what we are talking about, because we have no idea what (if anything) the basic mathematical structures of the theory represent."[100]

The formalism of quantum mechanics raises two problems involving the question of observability. First, in accordance with Hegel's warning not to confuse mathematical structure with physical reality, physicist Niels Bohr raises the problem that the formalism of quantum mechanics relies

[97] *Ibid.*, p. 25.
[98] Note Hegel's treatment of light in EPN §276R, in which he claims that the mechanical concepts of wave and corpuscle (particle) are not qualitatively appropriate descriptors of the phenomenon of light's simplicity and indivisibility. Might Hegel's critique that light is never given *phenomenologically* as either wave or particle, but rather is only modeled and causally explained as such from observational results, be one resource with which to critique the theory of quantum mechanics more broadly?
[99] Peter Lewis, *Quantum Ontology*, p. 22.
[100] *Ibid.*, p. 23.

on imaginary numbers. For instance, the formalism of the Heisenberg uncertainty principle and Schrödinger's wavefunction equation posit the imaginary number i that does not seem to have any real significance, ontologically speaking.[101] As Jan Faye writes, the nature of this mathematical formalism leads Bohr to take the wavefunction to have "only a symbolic meaning" rather than to represent anything real.[102] The modeling of quantum phenomena with complex vector spaces—complex because they use i—as Hilbert space is particularly problematic if taken as "a direct representation of the spatial structure of the world."[103] This is because it would indicate that "the world has many, many more spatial dimensions" than what is directly observed in experience.[104] Moreover, the formalism of complex vector space is not phenomenologically valid but rather merely predictive. Thus, second, there is a more serious problem with the probabilistic nature of the formalism of the complex vector spaces as it relates to determinately measured values. Before measurement, we can represent with these complex vectors "the potential possibilities but not the actual values of our measurements," as physicist Leonard Susskind and Art Friedman write.[105] While the wavefunction equation is deterministic as it involves the state-vectors themselves, "even if we know the state-vector exactly, we don't know the result of any given measurement."[106] In other words, even if a range of results can be predicted probabilistically, uncertainty is built into the mathematical formalism as it relates to actual, determinate measurements.

Let us consider in greater depth why. Summarizing Bohr's anti-realism, Faye lists four mediations involved in the appearing of any

[101] Jan Faye, "Copenhagen Interpretation of Quantum Mechanics." *The Stanford Encyclopedia of Philosophy*. https://plato.stanford.edu/entries/qm-copenhagen/.
[102] Jan Faye, "The Copenhagen Interpretation of Quantum Mechanics."
[103] Peter Lewis, *Quantum Ontology*, p. 163.
[104] *Ibid.* Lewis also discusses several ways to avoid this implication, for instance in Bohm's theory and GRW theory, which I will not examine in this essay.
[105] Leonard Susskind and Art Friedman, *Quantum Mechanics: The Theoretical Minimum*, (New York: Basic Books, 2014), p. 39.
[106] Leonard Susskind and Art Friedman, *Quantum Mechanics: The Theoretical Minimum*, p. 126.

quantum phenomenon, which problematizes grasping what exists pre-measurement: first, "the need of classical concepts for the description of measuring results;" second, "the entanglement of the system and the measuring instrument;" third, "the contextual nature of the measurements of complementary properties;" and fourth, "the symbolic character of the quantum formalism."[107] The probabilistic nature of the mathematical formalism relates directly to the problems of measurement with the "measurement problem." Under the classical paradigm, it is relatively unproblematic to assume that what is observed through experimentation and observation are the processes and dynamics that occur independently of scientific measurement itself. This is not so with quantum mechanics. Under its theoretical presuppositions, the very act of measurement affects or changes the quantum system due to the scale of analysis—that is, what is observed is so small that any act of recording or measurement interferes with what is given. Because to observe and measure is always already to fix values, what belongs to the quantum system pre-measurement cannot be discerned, with certainty, from the determinate measurement results themselves. The problem of the unknowability of what exists pre-measurement holds for many of the problems of quantum mechanics. Entangled properties that are modeled probabilistically pre-measurement cannot be known to have been already determinately valued or not. Indeterminately modeled properties of a quantum system can never be measured directly without fixing them. Indeed, the superposition of the wavefunction cannot be known directly because to measure it is, again, to fix it. Thus, the question becomes whether the wavefunction refers to something objective, and if so, whether it has an underlying wave, particle, or wave-particle ontology, and whether this ontology is deterministic.

In response to the measurement problem, some deny that quantum mechanics reveals anything discernible about what really exists pre-measurement. For example, QBism takes the probabilism of the mathematical formalism to indicate nothing more than *subjective belief* about a quantum system, which leads this position to suspend judgment on

[107] Jan Faye, "The Copenhagen Interpretation of Quantum Mechanics."

any direct ontological implications.[108] On the other hand, a number of realist interpretations attempt to fill the explanatory gap built into the formalism of quantum mechanics. Lewis exemplifies the realist pathos in writing that it is the "business of science to describe the world" outside of subjective measurement and observation.[109] For quantum mechanics, this means postulating the underlying causal conditions of measurements, as they are pre-measurement. Dustin Lazarovici, Andrea Oldofredi, and Michael Esfeld characterize quantum mechanics as necessitating a "provisional, hypothetical" ontology in order to do so.[110]

There are several "provisional, hypothetical" ontologies in quantum mechanics—all of which I cannot examine in any depth here—that attempt to describe the quantum system pre-measurement. Each posit unobservable entities or structures beyond what is directly observed in experimentation, based on philosophical or methodological commitments external to what is actually observed (including, for instance, preserving determinism or locality). I follow Lewis in characterizing some of these interpretations. For example, the Everett Interpretation maintains the determinism and locality of quantum systems by arguing that quantum superpositions are not probabilistic. Rather, "every outcome of a measurement actually occurs"[111] because reality itself branches out into many worlds that correspond with each of the superimposed quantum states of the formalism. While "there are no collapse and no hidden variables," meaning this interpretation may be viewed as parsimonious adding nothing to the evolution of the Schrödinger equation itself,[112] it makes an entirely unfalsifiable claim about other worlds to which we have no phenomenological access, from our experience of observing only *one*

[108] See, for instance, Hans Christian von Baeyer, *QBism: The Future of Quantum Physics*, (Cambridge, MA: Harvard University Press, 2016), pp. 129-184.
[109] Peter Lewis, *Quantum Ontology*, p. 43.
[110] Dustin Lazarovici, Andrea Oldofredi and Michael Esfeld, "Observables and unobservables in quantum mechanics: How the no-hidden-variables theorems support the Bohmian particle ontology," *Entropy* 20.5 (2018), 116-132 (p. 131).
[111] Peter Lewis, *Quantum Ontology*, p. 63.
[112] *Ibid.*, p. 62.

measurement result. Second, the "hidden variable" interpretation of Bohm and de Broglie, which posits a dual ontology in which particles move on a "wave-like field that pushes them around" deterministically,[113] also takes there to be no collapse of superposition into determinate values; rather, determinate values are of the particles that are pushed by the wavefunction itself.[114] This interpretation overcomes the problem of indeterminacy of position of quantum particles. Yet, this interpretation supplements the mathematical formalism by adding coordinate positions of point-particles as unobservable variables, hence its namesake.[115] Nothing from the experiments themselves justify the positing of these hypothetical structures, nor can they ever be verified directly because the initial positions of entities that supposedly evolve deterministically cannot be known due to the disturbance of measurement. Other hidden variable hypotheses rely on this same unobservability, whether they choose to violate locality or, as in the case of the retroactive causality hypothesis,[116] claim that effects precede causes in time. Such a claim seems not to be metaphysically coherent. Finally, versions of spontaneous collapse theories take the underlying ontology of quantum mechanics to be "wave-like" and indeterministic according to the wavefunction;[117] for these interpretations, the wavefunction exists objectively and "collapses" into determinate values according to entanglements that particles form with others in a system. Aside from positing the existence of an indeterminacy that can never be directly observed, these interpretations suffer from the seemingly *ad hoc* introduction of the fundamental constants of "the frequency of hits and the width of the hit function."[118] They too pose problems for locality.

For my purposes, it is less important to examine each of these interpretations and their permutations in depth than it is to note how they

[113] Peter Lewis, *Quantum Ontology*, p. 108.
[114] *Ibid.*, p. 57.
[115] *Ibid.*, p. 56.
[116] Lewis notes that no "retrocausal hidden variable theory has been constructed" (*Ibid*. p. 104).
[117] *Ibid.*, p. 180.
[118] *Ibid.*, p. 160.

are vulnerable to Hegel's phenomenological critique of theory realism. The realist pathos must be submitted to a more fundamental, phenomenological critique of causal-theoretical explanation, grounded in the inability to discern objective determinations from mere subjective speculation. Each of the realist interpretations fall into this problem because they provide causal explanations structured according to theoretical motivations external to the results of observation and measurement. Although these realist interpretations claim to describe what is "really" observed, these descriptions are not phenomenologically valid; each supplements the appearing of observational results with underlying conditions and causes not given by the phenomenon itself. For instance, the Everett Interpretation supplements the phenomena observed by claiming that what is *really* registered as the determinate values of quantum states is a branching off of reality into multiple worlds; the Bohmian interpretation claims that what is *really* observed are only particles moving on a deterministic wave; spontaneous collapse theories claim that what is *really* observed is the "collapse" of an actually existing wavefunction into determinate values.

Yet, one might ask: could it not be that any one of these things are being observed always and already—just that we are not aware of it? Thus, even if these theories are only hypothetical today, might one be proved as true in the future? Again, as with all causal theories that rely on inference to unobservable causal principles, none of these theories can ascend to necessarily objective truth of the things themselves. As Thomas Seebohm writes, in contrast with classical physics, for which "there are no serious problems in principle for the ontological interpretation of the theoretical entities of classical mathematical formalism,"[119] the problem facing incompatible interpretations of quantum mechanics is that "there is no possibility to find any mathematical or empirical justification for one of them together with the rejection of the other."[120] Realist interpretations uptake certain assumptions about the quantum system pre-measurement

[119] Thomas Seebohm, *History as a Science and the System of the Sciences: Phenomenological Investigations*, (New York: Springer, 2015), p. 222.
[120] *Ibid.*, p. 225.

that already frame how any new data is to be interpreted. Depending on the interpretation, the nature of (non)locality, (in)determinism, the wavefunction, and so on are hypothetical presuppositions that lead to other posited unobservables, *ad hoc* assumptions, or intuitively empty claims that reflect these pre-established commitments. Experimental results are subsequently made to fit their framework. Given the nature of quantum formalism in relation to measurement, post-measurement empirical data has not been able to refute any of these hypotheses or commitments from within quantum mechanics itself. For this reason, even interpretations that may be open to entity realism must criticize the arbitrariness—at least the lack of necessity—of adhering to one realist interpretation over another, as measured against the data itself. Finally, even if one *were* to narrow the interpretative field based on external philosophical commitments, any one interpretation can never ascend beyond hypothesis to what cannot, in principle, be perceived in experience. One could never discern the natural structures that lie outside of perceptual experience *or not*.[121]

As such, it seems that nothing definitive can be said about the determinations of nature at the quantum level, prior to measurement. Yet, having problematized these realist interpretations, there is a certain anti-realist temptation that must also be addressed. Uncertainty over the underlying causes of quantum phenomena does not translate to the view that what appears in the frame of experimentation has no connection with what exists 'in itself,' even if there may be challenges to whether and what natural kinds can be attributed to this appearing. On the one hand, with a more restrictive view of observability, it makes as little sense to speak of what does not apply to an actually existing 'quantum realm' as what does:

[121] One exception may be if a theory or interpretation posits something conceptually self-contradictory or metaphysically incoherent. There seems to be nothing *a priori* about space preventing about non-locality, about causality preventing natural indeterminism, or about reality preventing the existence of multiple worlds. I leave for future work whether any of these concepts contradict Hegel's own views on space, causality, and world. However, note that Hegel writes of these concepts as they appear and function *in our perceptual experience*, so that any seeming contradiction may be from within this frame alone.

this 'quantum realm' cannot be judged to exist objectively in either case, since it is unobservable. On the other hand, this problem remains even with a more expansive view allowing for indirect observability or IBE. Just as the realist interpretations are problematic for making a projection to what cannot be observed, so too would an anti-realist interpretation that projects a quantum realm disconnected from its own appearing. Such a position would reproduce the kind of theoretical projection that plagues realist causal theories. In other words, neither can it be said definitively that the quantum system "has no particular property or character *until* we make the measurement,"[122] as if it were otherwise devoid of determinations pre-measurement and only gains them in the subjective frame of experimentation.[123] While the measurement problem restricts what can be known in quantum mechanics, asserting what the pre-measured quantum realm *is not* ontologically turns out to be as speculative as the realist theories that attempt to discern what it *is*.

Instead, attention must be given to how the 'in itself' appears. Hegel's critique of the noumenon is not based on the presupposition that we have a 'view from nowhere' of natural being, nor does Hegel claim that we can 'exhaust' all empirical knowledge or that there are not things that may be unknown at different times. Rather, attention must be paid to how objectivity appears in different ways in its various relations—including, I would add in view of contemporary physics, those relations formed with observational instruments and measurement apparatuses. As Stephen Houlgate writes, for Hegel, "nothing can avoid asserting its own determination in its relations with others, but equally nothing can avoid being constituted in ways that are beyond its control by other things that surround it."[124] Thus, Hegel argues for a more nuanced perspective that questions what *of* the 'in itself' appears—or, to reverse perspectives phenomenologically, how the 'in itself' is intended as objective in sense

[122] Patrick Heelan, *The Observable: Heisenberg's Philosophy of Quantum Mechanics*, (New York: Peter Lang Publishing, Inc., 2016), p. 84.
[123] Some attribute this view to Bohr. See: Patrick Heelan, *The Observable*, p. 108.
[124] Stephen Houlgate, *The Opening of Hegel's Logic: From Being to Infinity*, (Lafayette, Indiana: Purdue University Press, 2005), p. 349.

perception—so as to prompt the need for amending our understanding of the objective determinations of nature. Whether this dialectical overturning supports the isomorphism emphasized by Johnston or the constructivism emphasized by Rockmore, nature must be treated in its *own* phenomenal appearing.

However, on this point, we return to the heart of the problem of a Hegelian interpretation of quantum mechanics: precisely *what* is observed in those experiments and observations that claim to reveal the nature of the 'quantum' world? Even if the experiments of quantum mechanics reveal *something* about how nature appears, does it enable knowledge of certain 'quantum' natural kinds *more specifically*, based on the criteria of validity discussed above? As I interpret Hegel, one would have to suspend judgment about causal claims outside of the appearing of the phenomena themselves—even if this means not being able to subtract measurement itself from the experience of this appearing. Yet, if we must suspend causal theories in empirical science, we have strong reason to deny that these observations say anything about 'quantum' natural kinds or entities at all. Given that quantum mechanics is a theory that explains measurement results from entities that cannot be observed perceptually (and whose very ontology is subject to debate), there is an irreducible 'gap' in attributing 'quantum' natural kinds to it in a way that guarantees that what is explained is necessarily objective and valid rather than merely hypothetical. If so, is Hegel's lesson that the *uncertainty* about what these observations actually entail emerges from the problems of moving beyond what is perceptually given and into the realm of the theoretical or hypothetical?

Conclusion

In view of the questions above, the way we develop a contemporary Hegelian philosophy of nature may be informed by two issues. First, as I have emphasized in this essay, it will be necessary to make judgments about the ways in which objects can be said to be given in perceptual

experience. This may include judging the limits of observability and whether Hegel's philosophy can be reconciled with IBE or some forms of theoretical speculation—including what we would lose of his project, under my interpretation, if we attempt such a reconciliation. In any case, these judgments must directly thematize the epistemological limitations of empirical science in attaining to the same kind of apodicticity as pure philosophical logic—including the role of the 'middle term' of subjective interpretation and explanation required to articulate the essential determinations of natural being.

Second, a contemporary Hegelian philosophy of nature may depend on how we understand the connection between empirical science and the philosophy of nature more generally. As Houlgate writes, there are differing readings as to whether the philosophy of nature is meant as a "flexible conceptual framework" in view of the scientific discoveries of the day, or whether the different divisions of the philosophy of nature are determined *a priori*.[125] Edward Halper's formulation of the philosophy of nature exhibits an ambiguity between the *a priori* and *a posteriori* in Hegel's account, which Halper writes "does not aim to produce new scientific results but to deduce already established results by dialectical, *a priori* argument."[126] Regardless of where one stands on this debate, it is necessary to note that many of the developmental stages of Hegel's philosophy of nature rely on historically and technologically mediated observations of natural kinds. This includes the concepts of acid/base and positive/negative electricity and also Kepler's laws. Even if the general conceptual trajectory of the philosophy of nature is established, it would appear open to the addition of other natural kinds based on this character of its other contents. If so, whether this additional data might be reduced to or subsumed under a previous division or concept, or whether it might require establishing new divisions or determinations previously

[125] Stephen Houlgate, "Introduction," in *Hegel and the Philosophy of Nature*, ed. by Stephen Houlgate (Albany: SUNY Press, 1998), pp. xi-xxvii (pp. xiii-xiv).
[126] Edward Halper, "Hegel's Criticism of Newton," in *The Cambridge Companion to Hegel and Nineteenth-Century Philosophy*, ed. by Frederick C. Beiser (Cambridge: Cambridge University Press, 2008), pp. 311-343 (p. 316).

unarticulated, any supplementations must be judged in view of the first concern with epistemic justification.

Rather than stipulate how one must continue Hegel's legacy today, I end this essay by underscoring that one's attitude toward the two issues above will affect how one characterizes Hegel's contributions to current debates in the philosophy of science and empirical science. Yet, if Hegel's project is caught between a phenomenological analysis and concern for the true objectivity of natural kinds, as I have argued in this essay, it is precisely his concern with doing justice to both of these principles that makes his perspective so critical today.