Physics and Fundamentality

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8/30/17

1. Introduction

What justifies the allocation of funding to research in physics when many would argue that research in the life and social sciences may have a more immediate and beneficial impact in transforming our world for the better? At a time when financial support for research in physics (and more generally for basic research with less immediate and obvious ties to medical or defense applications) is by percentages decreasing, this is a crucial question for the physics community to address in order to avoid facing an existential threat to research programs.[1] Here, philosophical work can be useful in providing a clear articulation of the sense or senses in which the sort of knowledge physics provides is special and worthy of support.

To see the sort of aid philosophical analysis may provide, consider first the sort of justifications the physics community themselves make in defense of funding their research programs. Physics organizations like the American Physical Society (APS) and American Institute of Physics (AIP) are alike in appealing to two primary justifications

[1] A stark indication of the present threat to physics funding is U.S. President Donald Trump's 2018 proposed budget. This includes a decrease of 18.4% to the Department of Energy's high energy physics program and a cut of 19.1% to nuclear physics. The budget slashes funding of basic science at the National Science Foundation (NSF) by 13%. These cuts are part of a trend away from funding purer research in basic science and toward research with medical or defense applications. The National Institutes of Health's (NIH) budget increased to $17.2 billion in 2000, and to $31 billion in 2010. By contrast, the NSF budget grew from $1 billion in 1983 to $6.87 billion by 2010, but then only grew to $6.9 billion in 2013. The Trump budget is unusual in its proposing even larger cuts to NIH spending (22%) than to spending in basic research;. http://www.sciencemag.org/news/2017/05/what-s-trump-s-2018-budget-request-science

for funding projects in physics.[2] First, an appeal is made to the significant cultural value of possessing an understanding into the deep natures of the things that make up our universe. For example, the APS notes in a public statement that such research "extends and enriches our lives, expands our imagination and liberates us from the bonds of ignorance and superstition."[3] And a statement by the director of the AIP cites the quantum physicist Victor Weiskopf who wrote:

> Fundamental research creates the intellectual climate in which our modern civilization flourishes. It pumps the lifeblood of ideas and inventiveness not only into the technological laboratories and factories, but into every cultural activity of our time. The case for generous support for pure and fundamental science is as simple as that.[4]

Weiskopf is no doubt correct: the impacts on western civilization of Copernican astronomy or Newtonian physics would be difficult to overstate. Although the intellectual impact of some of the most important developments in twentieth century physics, quantum mechanics in particular, may presently be stymied by lack of a clear interpretation of those theories, one may expect future historians to note a similarly significant cultural shift.

In addition to the cultural benefits, physics organizations also make an explicit appeal to the value of research in physics in providing the knowledge needed to develop new and useful technologies. Often, when trying to illustrate the instrumental value of

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[2] British organizations like the Institute of Physics (IOP) tend to place the focus more on economic benefits. See note 6 below.
[3] Statement 99.6 "What is Science?" https://www.aps.org/policy/statements/99_6.cfm.
[4] "Reminding Congress that basic research pays off" https://www.aip.org/commentary/reminding-congress-basic-research-pays.

basic research in physics for providing the knowledge base for technologies, it is noted that only an understanding of quantum mechanics or general relativity could have allowed development of such things as lasers, cell phones, and GPS devices. An MIT report, "The Future Postponed," illustrates the many ways in which basic research, including research in physics, is essential to the development of several new technologies that enhance civilization and how the decrease of funding may lead to societal harms.[5]

Although one may praise the technologies that physicists typically have cited in making a case for the funding of physics (though the value of cellphones is debated), I would argue that the appeal to just a handful of technologies may be too weak to justify the very high expenditures needed to fund today's basic research in physics. Are the technologies physics has provided for us really so useful that we should take money away from other scientific endeavors? Cellphones and GPS are very nice, but what is the use of having a way of navigating to the nearest Starbucks if one is dying of malaria? Given the limited funding overall that is earmarked for scientific projects, one might argue one should fund the sciences with impact for the technologies that really matter. This is not to say one cannot make a strong argument for funding physics based on the technological development it may facilitate. But a stronger technology-based case for funding physics comes not from a mere listing of examples, but rather from the premise that *whatever* sort of technologies one is interested in, physics may provide the knowledge relevant to their development. Indeed, basic research in physics has repeatedly demonstrated its use for the development of superior medical technologies, the most obvious examples being tools

[5] https://dc.mit.edu/sites/default/files/Future%20Postponed.pdf

for medical imaging such as positron emission tomography (PET) and magnetic resonance imaging (MRI).

So there are two primary motivations for funding research in physics: (i) that insight into the deep natures of things has wide-sweeping (presumably positive) cultural impacts on civilization and (ii) that it has the potential to cause the development of an especially wide range of important technologies.[6] As I will demonstrate, both of these rely on an assumption taken on as obvious by many, namely that physics has a special status among the sciences: that it is fundamental.[7] The goal of this paper is to offer an articulation of the sense in which physics is fundamental, one that may serve to underwrite these justifications for the allocation of funding to research in physics. At least in the philosophical literature, there are some relatively standard accounts of what it would be for physics (or some branch(es) of physics) to be fundamental that may underwrite the justifications for funding just noted. However, as I will argue, these are both scientifically unmotivated and overly ambitious. Indeed, it is so easy to show that physics does not satisfy these standard accounts of fundamentality, it is dangerous to

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[6] Although this will not be so relevant for the work I wish to accomplish in this paper, physics organizations do appeal to other justifications for funding their research. When addressed to sources of government funding, appeals are also made to the values of achieving gains in national security and dominance. Historians of physics (e.g. Riordan 2000) have documented the Reagan administration's enthusiastic support for the doomed Superconducting Supercollider project as a means of establishing U.S. dominance in particle physics. In addition, physical societies often appeal to the benefits of supporting researchers in universities who will train a nation's scientists and engineers, thus ensuring a strong national workforce and economy. The British Institute of Physics (IOP), for example, issued several statements in 2017 on "the role of physics in supporting economic growth and national productivity."
http://www.iop.org/publications/iop/2017/page_69224.html

[7] This is more immediately obvious, I realize, for the first motivation than the second. I return to this in Section 5.

continue to promote them at the risk of undermining the case for the financial support of research in physics.

Before beginning, I should acknowledge that what I have said is obvious to many, that physics, or some branch of physics, is fundamental, is by no means universally accepted. In fact, this view has been forcefully rejected by many, both inside and outside of the philosophical community. I won't be engaging with these criticisms here, important though they are. My project will rather be to take on board the assumption that physics has a special status among the sciences, that it is fundamental, and see how best to spell out the sense in which this may be so.

2. Completeness Conceptions

To say that physics is fundamental is to say that it has some kind of special status; what this special status amounts to is the topic of this paper. One point worth emphasizing at the outset is that I will not be entertaining the idea that the sense of fundamentality that is at issue and should be used to justify the allocation of resources to research in physics is one of relative importance. When considering the claim that physics or a specific branch of physics is a or the fundamental science, I am considering a metaphysical claim. This metaphysical claim may then be used to motivate a value claim, but it is not itself a value claim. I understand there are colloquial uses of 'fundamental' where the word simply means important. And some old-fashioned notions of reduction, e.g. that developed by John Kemeny and Paul Oppenheim in the 1950s, may have encouraged this reading, as these accounts of reduction implied that reduced sciences should be replaced by the ones they are reducible to.[8] This certainly suggests a sense in which those sciences that may be shown to be reducible, and therefore nonfundamental, are relatively less important than physics in that they can be dispensed with. But this is not the sense of fundamentality I am exploring here. I have no interest in defending the idea that other sciences should be eliminated, that they are dispensable, or that physics is more important than biology or any of the life or social sciences in any sense. Although it will be clear below that I am sympathetic to a form of reductionism, this version should not be taken to have the eliminativist implication of older conceptions.

The metaphysical conceptions of physics (or certain branches of physics) as fundamental in which I am interested have tended to tie physics's fundamentality to its ability to provide a complete picture of the world in some way or other. There are two primary kinds of completeness thesis that have been offered and I will discuss them both. The first is ontological or constitutive, the second, causal or dynamical. These are the conceptions alluded to in the first section, that I take to be on the right track, yet problematic for reasons that will be explained in the following sections.

2.1. Ontological or Constitutive Completeness

The first sense in which physics is taken to be fundamental cites its ontological, or more broadly constitutive metaphysical completeness. For example, Ted Sider writes, "completeness seems definitive of fundamentality… All fundamental matters "boil down to" or "derive from" or "hold in virtue of" fundamental matters" (2011, pp. 105-109). We will return to Sider's conception of fundamentality as metaphysical completeness below,

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[8] W.V. Quine's (1960) proposed reductions of mind and language were explicitly eliminative as well in this respect (pp. 264-265).

but let's first discuss what is an older, perhaps more influential understanding, one that is often taken as a critical target by those who would argue against the fundamentality of physics. This classic picture of physics as an ontologically complete, fundamental science appears in Oppenheim and Hilary Putnam's 1958 "Unity of Science as a Working Hypothesis." Oppenheim and Putnam view the sciences as arranged into a hierarchy of levels ordered by relations of mereological decomposition. Each science in the hierarchy comes with a proprietary domain (organisms, cells, molecules, atoms, etc.) with the entities of each science mereologically decomposable entirely into entities within the domain of each of the sciences below. Physics provides the fundamental science at the base of this hierarchy in virtue of the fact that it is out of the entities of physics that the entities of all of the other sciences are composed. Physics thus enjoys ontological completeness: all entities are either physical or composed out of physical entities.

Today's philosophers of science, even to the extent that they are sympathetic to some sort of unity of science doctrine, have offered several reasons to be skeptical of Oppenheim and Putnam's particular approach to explicating the ontological fundamentality of physics. I will cite just two sources of disagreement. First, there is skepticism that the domains of individual sciences mark out a neat partition of entities into levels in the way Oppenheim and Putnam proposed. Scientific explanations often cross-cut domains of entities in ways that problematize the levels picture. Neuroscience in particular provides numerous examples: explanations of a single phenomenon will routinely appeal to brain areas, cells, chemicals, and individual ions (Craver 2007). Second, there is some implausibility to the claim that the relationship linking phenomena across the various sciences may or may always be the simple one of mereological composition/decomposition. This may naively sound plausible when one thinks of the neat drawings of atoms and molecules one learned in one's first chemistry classes, but the picture is strained significantly by the details of actual scientific reductions. It is simply inaccurate that reductive explanatory accounts of the superconductivity of metals, memory consolidation, or social networks, say, will involve the supposition that they are built up out of basic physical parts in the way that a house may be built out of bricks.

These concerns are not themselves devastating for the view that physics might possess some form of ontological or constitutive completeness. But it is reasonable to look beyond the Oppenheim and Putnam picture to fill in the details of what an account of this completeness might look like. First, the claim of completeness should not require the sciences carve out a neat hierarchy of levels. Instead, we might only ask that physics enjoy a special status with respect to the rest of the sciences and that it provide the ontological basis for the other sciences, however overlapping and untidy their ontologies may be. Second, it would be better to allow for more flexibility in the sort of relations that may obtain between what is described by the various sciences and physics. One currently dominant model sees the physical sciences as providing mechanistic explanations for those of other scientific theories, causal explanations which describe how the latter phenomena may arise out of the former in specified conditions (Machamer, Darden, and Craver 2000). In metaphysical circles, several frameworks have been proposed, including ones based on notions of ground (Fine 2001, Schaffer 2009, Dasgupta 2014), truthmakers (Heil 2012), scrutability bases (Chalmers 2012), and metaphysical semantics (Sider 2011), all at a level of abstraction adequate to allowing that individual reductive explanations may vary in the way they view the relationship between physical ontology and special science phenomena. The metaphysicians who make these proposals aspire to formulate a claim that some theory provides a complete metaphysical basis for all phenomena and thus may be viewed as a fundamental theory.[9] For example, working within the grounding framework, Shamik Dasgupta (2009) explores a version of grounding physicalism, the view that physics may provide metaphysical explanations or grounds for all true claims in the other sciences, i.e. explanations that state in virtue of what these nonphysical phenomena occur. David Chalmers (2012, Chapter 8) considers (and rejects) the claim that physics may provide a complete scrutability base for all truths. And so on.

It is worth noting that physicists also think of the fundamentality of their theories in terms of their capacity to provide a powerful class of constitutive explanations. In *Dreams of a Final Theory*, Steven Weinberg defended the special character of fundamental physics partly on the basis of what such theories could allow us to achieve in explanatory power, in showing us in virtue of what all other truths obtain. Fundamental physical theories have this status because, he argues, they are the theories that lie at the convergence of these arrows of explanation. To illustrate this feature, in his chapter "A Piece of Chalk," he shows how if we start from any fact we might want to explain, including the color or makeup of a piece of chalk, we can continue to ask a series of explanatory questions that will ultimately lead to an explanation in the terms of fundamental physics. If we want to know in virtue of what the chalk is white, this will lead us to an explanation in terms of the wavelengths of light that are reflected by the surface of the chalk. If we want to know what makes it the case that these wavelengths

[9] This is not so for those promoting mechanistic accounts, and so I will not focus on these in what follows.

and not others are reflected, we will be led to an explanation in terms of the molecular structure of the surface. If we want to know why surfaces with this molecular structure reflect light of these wavelengths, we will be lead to quantum theories. And similarly with any other explananda we might have started with.

> By tracing these arrows of explanation back toward their source, we have discovered a striking convergent pattern – perhaps the deepest thing we have yet learned about the universe. (1992)

Weinberg expresses optimism in the possibility of a final theory, one to which we can ultimately trace all arrows of explanation downward to. But this isn't an essential feature of the model. More fundamental theories may exhibit greater clusters of explanatory convergence. This is something we will come back to when we consider alternatives to completeness models of fundamentality.

2.2 Causal/Dynamical Completeness

Another form of completeness thesis one encounters in order to distinguish physics as fundamental states not that physics may provide a complete set of ontological or constitutive explanations, but rather a complete set of causal explanations. For example, Jaegwon Kim (1998) and David Papineau (2001) have influentially argued that physics, in contrast with the other sciences, exhibits a form of causal completeness. What Kim calls 'the causal closure of the physical domain' and Papineau calls 'the causal completeness of physics' is the principle:

> (CC) Every physical event that has a cause has a physical cause,

or better:

(CCT) Every physical event that has a cause at some time t has a physical cause at t.[10]

In his paper, "The Rise of Physicalism," Papineau argues that the accumulation of microphysical causal explanations for a diverse range of phenomena over the past centuries especially since the development of quantum mechanics and molecular biology provides inductive support for this principle, CCT. In light of the fact that so much of the behavior of complex, living creatures is capable of explanation without appeal to nonphysical, vital, mental, or "occult" causes, but just in terms of a small number of basic physical forces and principles, we have good reason to think that all will.

Kim (2010) argues that by satisfying such a principle, physics distinguishes itself from the other sciences. Although the complete causal explanation of physical effects does not ever require the postulation of nonphysical causes, it is always the case that a complete causal explanation of chemical or biological or social effects requires an appeal to physical causes. To cite some terribly mundane examples: fires, heart attacks, and mass rallies all require the influx of oxygen. And all effects, when the demand for explanation is traced out far enough into the past, find nothing other than explanation in terms of early physical features of the universe.

Before moving on, it is worth noting another form of causal/dynamical completeness, although today it is not commonly raised in the context of discussions of the fundamentality of physics. This is completeness not with respect to the facts about an

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[10] This second principle is introduced to rule out cases in which there is a sequence of events of the form P1→N→P2, where a physical event at t_1 causes a nonphysical event at t_2 which then causes another physical event at t_3. Here, P2 has a physical cause, but not at each time at which it has a cause. An explanation of the immediate or proximate causing of P2 would in this case be forced to appeal to nonphysical events.

event's causes, but completeness with respect to the facts about an event's effects. Physical determinism is a thesis stating that the complete physical state of the universe at a time together with the physical laws provides the resources for a complete account of what will happen in the future. In this way, one might construe determinism as another form of causal completeness thesis, and one that may provide an account of the fundamentality of physics. Although I will set such a thesis aside for the bulk of the paper to keep the discussion relatively compact, I will return to this interpretation of the completeness claim later in this paper. For now, I will simply note that to get a causal or more broadly dynamical completeness claim of this form, that physics may provide a complete account of physical effects (as opposed to physical causes), one need not require determinism. One might also take physics to provide a complete specification of the probability of any event's occurrence. This suggests a form of forward-looking causal completeness compatible with indeterminism.

So we see two senses in which physics may be claimed to be complete: completeness in the sense of providing a complete set of ontological, constitutive or reductive, explanations, and completeness in the sense of providing a complete set of causal explanations. At least prima facie, these senses of completeness do seem to underwrite the key motivations for pursuing research in physics.[11] A complete set of metaphysical explanations tells us the deep nature of all things, which will then affect how a civilization conceptualizes the world around it. A complete set of causal explanations tells us what will be able to produce desired effects as well as what effects to expect from

[11] I return to the issue of whether this is really so in Section 5.

our technological manipulations. As discussed at the start of this section, it is also worth emphasizing that by claiming physics satisfies these notions of completeness, there is no implication that other sciences cannot also provide an important class of explanations, causal and constitutive, explanations that possess their own distinctive virtues. The claim is only made that the explanations physics provides may have the special feature of being complete in one or another sense.

3. The Failures of Causal and Metaphysical Completeness

Although arguably construing the fundamentality of physics in terms of its constitutive and/or causal completeness answers to the two motivations for funding research in physics outlined in the first section; unfortunately, it is also pretty clear that no real physical theory is complete in either the constitutive or causal sense. As I will argue in this section, these claims of completeness are all of them scientifically unmotivated. So at the risk of undermining the case for the allocation of resources, financial and otherwise, to research projects in physics, we would do well to develop an alternative account of what the fundamentality of physics amounts to. Actually, as we will see in a later section when I outline my preferred interpretation of the fundamentality of physics, the completeness interpretations are more ambitious than they need to be anyway to do the work they need to in underwriting the arguments for funding. I'll run things in the reverse order of the previous section here: first describing my concerns with causal completeness claims before turning to my concerns about metaphysical completeness. In both cases, as we'll see, my concern is not with physics's ability to (causally or constitutively) explain the features of macroscopic or living things, but rather with its limitations in what is typically seen as its own domain.

3.1 Against Causal Completeness

Recall the causal completeness claim at issue is:

> (CCT) Every physical event that has a cause at some time t has a physical cause at t.

Defenses of physicalism argue that this claim receives inductive support from a history of successful microphysical causal explanations for a diverse range of phenomena. However, this may be called into question by what has come to be almost a received view in the philosophy of physics that causal notions do not sit well with our most fundamental microphysical theories. Following Russell (1912); Field (2003), Norton (2003), and others have noted that certain features essential to causal explanation such as the localization in space and time of causes and effects as well as the time-directedness of the causal relation, require grounding in features we find lacking in fundamental microphysics. The most basic microphysical laws link only global world states, not the kind of spatiotemporally localized events we ordinarily single out as causes and effects. Moreover, microphysical laws appear all to exhibit time-reversal invariance preventing the objectivity of any distinction between causes and effects that we expect in causal explanations. And so, it is suggested that microphysics does not have the required structure to ground any causal facts.

Although the absence of these features has been felt by many to undermine the validity of causal notions in microphysical explanations,[12] the needed features do appear when we move to the macrophysical domain. The second law of thermodynamics brings with it the time-directedness of causal processes as well as the resources for singling out local causes among total global world states (see Papineau 2013). And so although the general (CCT) principle may appear problematic and unjustified[13] when applied to all physical events, the more narrow (macro-CCT) does not:

> (macro-CCT) Every macrophysical event that has a cause at some time t has a macrophysical cause at t.

Indeed, the sort of cases that Papineau (2001) alludes to supporting the causal completeness of physics are overwhelmingly cases involving macrophysical causes and effects. What Papineau primarily appeals to as cases in his inductive argument for causal completeness are successes in physical explanations across chemistry, biology, and the life sciences enabling us to understand the processes involved in chemical reactions and those allowing organisms to grow and reproduce.

Even if it might not have the full generality of the principle (CCT) that Papineau, Kim, and many others in the philosophy of mind have discussed, a macroscopic completeness principle such as (macro-CCT) is quite powerful and can support the conclusion that a great deal if not all mental phenomena may be explainable in physical terms. Nonetheless, (macro-CCT) arguably does not suffice to underwrite the sense of

[12] Although it is not entirely straightforward that it does. See Ney (2009) and Frisch (2014) for further discussion.
[13] Let me be clear about the status of CCT if it is only within macrophysics, not microphysics alone, that there may be causal facts. The problem is not that CCT will then turn out to be false, nor even vacuous. The problem is rather that we cannot understand CCT as supported by an inductive basis consisting of microphysical causal explanations.

completeness metaphysicians are after when they take some theory or class of theories to be fundamental. But if principles involving causal notions are problematic when applied to the microphysical domain, we might ask whether there is some alternative, general dynamical principle we might adopt, one perhaps stripped of causal notions to avoid the problems noted above. In recent work, Alyssa Ney has proposed that a natural place to start would be to replace the notion of causal completeness with one of nomic sufficiency (2016). For example:

> (NS) For any physical fact, there is some other physical fact that, together with the laws, logically entails it.[14]

Here, the thought is that physics provides us with principles that allow the derivation of facts about the occurrence of any physical fact, or at least those that may be taken to have some dynamical explanation. Physics may thus have a claim to provide a complete set of nomic explanations in the physical domain.

The difficulty is that the motivation for this principle rests on a caricature of what our best physical theories offer. One might point to Einstein's field equations or the Schrödinger or Dirac equations in an attempt to cite laws that appear to cover all possible domains, however there are two flaws even with these examples. First, each of these laws, and any others we might cite, hold only in a limited regime. Of the quantum laws, the Schrödinger equation is for nonrelativistic systems, the Dirac equation for relativistic fermions. There is neither a general equation holding for all relativistic systems nor for all types of free particles, let alone particles that interact, nor a patchwork of principles we might stitch together to cover all regimes. The Einstein field equations are the central

[14] Or, in the case of indeterministic physical laws, entails the chances of the fact's obtaining.

principles of general relativity, which is a classical i.e. nonquantum theory of gravity. One hopes these may be recovered even in situations in which gravity is quantized, but this is not clear. And there is no straightforward recipe for getting from these laws to something that would hold more generally. Second, even in the regimes where it is reasonable to apply one or another of these laws, knowing how to model a system in order to generate solutions is an art, not something for which there is a general recipe. For example, it is possible to use the Schrödinger equation to model systems like a particle in a box or a harmonic oscillator, but there is no rule for how to apply the law to generic situations. In short, although we may grant that there are cases in which physical principles and ingenuity allow physicists to predict how some systems will behave from one time to the next, to take the inductive leap from the existence of nomic explanations in some physical contexts to the existence of explanations in all is simply not justified. This isn't to say that physicists don't have the ability to explain and predict a lot. Of course they do, and the extraordinary power of their methods and principles is revealed repeatedly, for example in the stunning recent discoveries of the Higgs boson and gravitational waves. But it is certainly a leap to go from such successes to the conclusion that physics has anything like the tools to provide a complete nomic/dynamical account of the behavior of all physical systems.

3.2 Against Constitutive Completeness

As was the case with causal completeness, it is useful to break the claim of constitutive completeness into two parts and ask first, is it plausible that physics gives us the resources to constitutively or reductively explain all macroscopic phenomena and facts, and then second, is it plausible that physics has the resources to provide a constitutive understanding of everything within its own domain, all microphysical facts.

Here again, while the answer to the first question is arguably, "yes," the answer to the second is quite obviously, "no." I recognize that this turns the standard way philosophers think in the context of debates about physicalism on its head. The challenge for physics's achieving completeness (and physicalism as it is standardly construed) is typically thought to come from macro-level phenomena – minds, consciousness, and the like – not from "below" in physics itself. But this is mistaken. For just as in the causal case, we have good inductive reason for thinking that all macroscopic phenomena will receive explanations, in this case, microphysical constitutive explanations, in light of the diverse kinds of successful microphysical explanations that have already been achieved. The kinds of macroscopic phenomena encapsulated in this universal claim are similar in relevant respects to those that have already been explained and so there is no clear threat to their receiving similar kinds of constitutive explanations.

The real question is whether physics has the resources to constitutively explain all other types of phenomena, in particular all microphysical phenomena. Again, the answer is that it has the ability to explain a lot, but certainly not everything. Dark matter is one phenomenon that although there is excellent reason to believe it exists, physics has no accepted account of. It is not clear whether present physics has the resources to explain what it is, or whether revisions to physics will be required to explain it. In addition, it is not clear at the moment whether current physics has the resources to provide a quantum theory of gravity or what such a theory ought to look like. There are several mutually incompatible proposals for the basic principles that should be used to guide the development of such a theory all positing very different fundamental ontologies including loops, strings, and causal sets (Smolin 2001). And so the metaphysical completeness of physics breaks down even before physical theories begin to be applied to the complex domains of the macroscopic.

4. No Salvation in Future Physics

I've argued that completeness theses of the kind that might serve to explicate the sense in which physics is a fundamental science fail to be satisfied by any of our current physical theories. Nonetheless, one might argue that when it is claimed that physics is fundamental, this does not presuppose that any current physical theory is complete, rather only that physics as a discipline has the resources to achieve such a complete theory at some time in the future.

But there fails to be good justification for the claim that physics as a discipline (whatever that is supposed to mean) has the ability to achieve completeness in the future. One might argue that we may simply run an inductive argument of the kind I have already endorsed. Above, I agreed that these constitute inductively sound arguments:

Causal Macro-completeness:

1. Many macrophysical effects have received macrophysical causal explanations.

Therefore,

2. All macrophysical effects will receive macrophysical causal explanations.

Metaphysical Macro-completeness:

1. Many macrophysical phenomena have received physical constitutive explanations.

Therefore,

2. All macrophysical phenomena will receive physical constitutive explanations.[15]

So, the question is, why shouldn't one similarly endorse the following arguments:

Causal Micro-completeness:

1. Many microphysical phenomena have received microphysical dynamical explanations.

Therefore,

2. All microphysical phenomena will receive microphysical dynamical explanations.

Metaphysical Micro-completeness:

1. Many microphysical phenomena have received physical accounts of their basic features.

Therefore,

2. All microphysical phenomena will receive physical accounts of their basic features.

The answer is: because the class of macrophysical phenomena is well-understood and unified in a way the class of microphysical phenomena is not. So there is a good basis from which to justify the former inductions. It is reasonable to believe that other macrophysical phenomena will receive causal and constitutive explanations in terms of

[15] One commentator has objected that the recalcitrance of consciousness to physical reduction undermines these two arguments. This misconstrues the dialectical situation. Physicalists use arguments like these in order to motivate the pursuit of physical reductions of consciousness and other seemingly recalcitrant natural phenomena. The defenders of arguments like these generally grant that we as yet have no widely accepted physical account of phenomenal consciousness, however she appeals to such inductions in order to motivate the pursuit of such of such accounts as well as a sense of optimism that such accounts will be found.

macro- or microphysical phenomena respectively because we know that they are similar kinds of phenomena to those for which we already have explanations: these other macroscopic phenomena are simply further arrangements of the same kind of basic matter in various configurations. Thus, their explanation will not require new science. As J.J.C. Smart noted in 1978:

> I concede that there are sure to be revolutionary changes in physics, but I deny such changes are likely to be relevant to the philosophical problem about mind and its relation to the physical world … Cosmology apart, revolutionary changes in physics are likely to occur only at the sub-atomic level: to put it crudely, whatever happens to physics, a hydrogen atoms will contain one proton and one electron, and water will still be H_2O. (p. 339)

It is reasonable to expect physics already has the resources to explain the macroscopic phenomena we don't presently have causal or constitutive explanations for.

By contrast, when new microphysical phenomena appear, they tend to be of novel kinds with unexpected features that are not simply arrangements of things we already understand. And so there is no basis for an inference from what has been true of the kinds of microphysical phenomena for which we already have an understanding to those for which we do not.

5. Fundamentality Without Completeness

Given that there fails to be justification for claims of the causal/dynamical or ontological/constitutive completeness of physics, we will need to look elsewhere if we would like an account of the sense in which physics, or some branches of physics, are fundamental sciences. Recall, we are looking for a concept of fundamentality that may allow us to underwrite the claims that:

> (1) Physics provides us with the sort of insight into the deep natures of things which has the potential for transformative cultural impacts, and
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> (2) Physics provides us with the knowledge of how things work that facilitates the development of a wide range of useful technologies.

The ontological/constitutive completeness of physics would entail that it can provide metaphysical explanations for everything there is, thereby providing insight into the deep natures of everything there is. The dynamical completeness of physics would tell us for any thing how it is brought about. And, supplementing this with a forward-looking dynamical completeness principle like physical determinism, physics could tell us how anything is determined or likely to behave in all environments or based on any manipulation conditions.

But even if the constitutive and dynamical completeness theses could provide a basis for underwriting (1) and (2), these theses are rather stronger than what is needed. For (1) and (2) to obtain, physics needn't be constitutively and dynamically complete, it only needs to capture a great deal of insight into the basic natures of things and provide understanding of how systems behave in a wide variety of circumstances. This is good, because as I have argued, physics is neither constitutively nor dynamically complete.

Some principles one might try out in order to capture a weaker sense of the fundamentality of physics are the following:

> Physics provides a lot of causal/dynamical and metaphysical explanations.
>
> Physics gets pretty close to causal/dynamical and metaphysical completeness.

Either would do a decent enough job on its own of supporting (1) and (2). However, one can make a stronger case in defense of physics funding if it can be shown that physics has some privileged status within the sciences. A principle of fundamentality can do that job, yet neither of the above principles succeeds in capturing such a notion. For fundamentality is a maximal notion that claims formulated with 'a lot' or 'pretty close to' don't succeed in capturing. Another flaw with using these weaker principles to describe the sense in which physics is fundamental is that they fail to support another role this fundamentality concept plays, namely to formulate comprehensive metaphysical positions.

I'll return to this in greater detail in the following section, but what I especially have in mind are positions like physicalism and its rivals. Physicalists take physics alone to provide a fundamental characterization of reality. But if this is interpreted as meaning that physics provides a lot of causal and constitutive explanations, or is pretty close to providing a complete set of causal and constitutive explanations, then this is something even dualists can agree with. The standard property dualist position of e.g. Nagel (1974), Jackson (1982), and Chalmers (1996) allows that physics provides very many explanations, even that it provides explanations of almost everything. It only denies that physics provides explanation of the qualitative features of experience.

My suggestion then is to reinterpret fundamentality in terms of a notion of explanatory maximality rather than explanatory completeness. For a theory to possess a maximal set of explanations is, I claim, for it to be a common source of explanations that possess the greatest degree of scope, accuracy, and precision over those that may be provided by any other theory that has been formulated. My claim is that physics is fundamental to the extent that it has the resources to provide a maximal class of explanations.[16]

This construal of the special status physics has vis-à-vis the other sciences in fact does a better job of supporting the funding of physics via (1) and (2) than does the more traditional completeness formulation. For, one might wonder, if physics is already explanatorily complete, then what is the purpose of funding new physical research? It might be worthwhile to fund the development of technological applications of this research or perhaps even philosophical work that connects this explanatorily complete physical theory with topics of cultural concern, but there is a question of why one should continue to fund physics research itself. This problem does not arise for the maximality interpretation, which does not claim physics to be explanatorily complete, only explanatorily better than its rivals. Under this interpretation, it will be worthwhile to continue to support physics research since such projects have had the best track record of providing the deepest and most extensive understanding of our world.

One may question whether our current physics, however, is maximal. Let me address one immediate concern with my proposal. I claim that the best physical theory, call it 'P,' is maximal with respect to its target class of explananda. And I have argued that physics does not have (nor is it reasonable to believe it ever will have) a complete theory. So there are some things that physics does not explain. Call 'P+' a theory that is just like P but adds explanations for at least some of what current physics does not

[16] As was the case for the proposed explanatory *completeness* of physics (and was illustrated by Weinberg's chalk example), there is no assumption that these explanations will always move directly from some target explanandum to a physical explanation. Most explanations of complex phenomena will rather involve chains of explanations down to some explanation in terms of physics.

explain. Then it would seem that it is actually P+, not P that is the maximal theory. And so, by my own account, physics is not fundamental.

Here is an example to illustrate the concern I have in mind. Our best current physics includes a Big Bang cosmology according to which the universe comes into being in a hot, dense state and there is no explanation for how or why this hot, dense state came about. Suppose P+ is a theory just like current physics but adds the claim that there is a God and this God caused the Big Bang. Then, since the explanations of P+ are broader in scope than those of P, it is P+, not P that is the fundamental theory according to my account.

I acknowledge this is a defect with the account as stated, one that, without saying more, gets the wrong result. But to address it, I simply need to say more about what I have in mind by a theory that is a common source of explanations with the greatest degree of scope, accuracy, and precision of all theories that have been formulated. The idea is that theories that are a common source of explanations have a certain degree of internal unification or systematicity, something that P+ will lack. The appeal to systematicity in an account of fundamentality is not new to my account. This is also a tacit element of Weinberg's model in which physics is the place where all explanatory arrows converge.

These comments lead to another question about my proposal, whether there is any such theory we may call 'physics' that is at the same time both maximal and systematized in the way I require. For, it is often claimed that the two main pillars of fundamental physics, quantum theory and general relativity, do not mesh well with one another, or that the two are inconsistent. However, this concern is overstated. Although there certainly remains a large open question about how *best* to achieve a unification of quantum theory and general relativity, or whether it may be possible to do so in a way that would serve as a final theory of everything, physicists do in practice know how to make general relativity and quantum theory work together. This semi-classical theory of gravity (e.g. Wald 1994) is questionable as a candidate for a final theory of everything, but constitutes a mathematically rigorous way of describing quantum fields in curved spacetime and as such demonstrates the systematization of current physics.

Finally, should one be skeptical that the sense of fundamentality I provide here is one that scientists would actually use, note that this is precisely the sense of fundamentality in play when theories are spoken of as fundamental in ordinary scientific contexts. Here, outside of the metaphysical context, fundamentality is always relativized to a target class of explananda. For example, the Bardeen-Cooper-Schrieffer (BCS)-theory is a fundamental theory of superconductivity. The theory of evolution by natural selection provides a fundamental theory of heredity. These theories are fundamental not because they are causally or constitutively complete. Arguably, they do not even provide complete explanations within their target domains. The BCS-theory of superconductivity provides illuminating explanations for low-temperature superconductivity, but fails to explain some high-temperature superconductivity in which the superconducting medium is not metallic. The neo-Darwinian theory of evolution by natural selection has of course been astoundingly successful, but faces limitations in accounting for some features which seem to be inherited on the basis of alternative selection processes, such as altered cell functioning in the offspring of groups subject to starvation. Nevertheless, the explanations these theories provide outrun the scope, accuracy, and precision of all competitor models and to this extent, it is reasonable to take them to be fundamental theories of their targets. When we move to the metaphysical context and take the target explananda to include absolutely everything, we may then say that a fundamental theory *simpliciter* will be a theory that outruns the scope, accuracy, and precision of all competitor theories.

That physics may provide a dynamically and metaphysically maximal set of explanations at this time certainly motivates the claims (1) and (2) that often appear in defenses of funding physics research. Moreover, it provides what is needed to avoid the problems for the weaker proposals above. Dualists do not agree with the physicalist that physics provides a set of explanations that is maximal in its scope, accuracy, and precision. And this, I argue, is a better explanation of their disagreement than that physics does not have the resources to provide a complete set of explanations. After all, it would be unreasonable for anyone, including the physicalist, to believe that physics is either dynamically or metaphysically complete.

6. Maximality and the Formulation of Physicalism

I have argued that it is not reasonable for anyone, including the physicalist, to endorse claims that physics is complete in either the causal/dynamical or ontological/constitutive senses. Physics leaves open many mysteries, mysteries we may hope that a future physics may resolve, but it is consistent even for a physicalist to believe that some of these may remain forever mysteries.[17] And so the best account of the fundamentality of physics lies in its explanatory maximality, not its explanatory completeness. This lesson helps us

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[17] See Ney (forthcoming) for discussion of this point and how best to interpret physicalism in its light.

resolve problems that crop up when philosophers have tried to put forward rigorous formulations of physicalism and other metaphysical positions.

In particular, Sider (2011) and Dasgupta (2015) have raised a problem for recent formulations of physicalism in terms of the notion of ground or metaphysical explanation, where physicalism is understood as the claim that all facts are physical facts or metaphysical explained (or grounded) in terms of the physical facts.[18] This is, of course, a completeness thesis, one of the kind that I have been criticizing.

The problem Sider and Dasgupta point to with such formulations of physicalism is best illustrated by considering an example of the kind of metaphysical explanation physics is being claimed to provide. For example, consider the fact that Shamik Dasgupta (SD) is conscious. Physicalism, interpreted in the way we are considering, will then entail that there is some physical fact that can explain the fact that SD is conscious. For example:

> (C) The fact that SD's brain is in physical state P grounds the fact that SD is conscious.

The problem Dasgupta raises is that physics does not seem to have the resources to explain (C). Physics alone cannot explain how physical facts may ground any nonphysical facts, since the latter are outside of the physical domain. As Dasgupta explains:

> (C) is not a purely physical fact, since it is not just about particle positions or field values or the like. Rather, it is in part a fact about consciousness – that is, about

[18] Sider's concern in his 2011, Chapters 7 and 8, is actually broader, about formulating any metaphysical thesis that some theory is fundamental in terms of a claim that it provides metaphysical explanations for everything.

> what grounds my being conscious. So the physicalist just characterized must say that (C) is also grounded in purely physical facts. And the problem (I will argue) is that this is implausible. If it is grounded in anything, it is grounded in facts about *consciousness*: it is because of something about consciousness that my being in state P grounds my being conscious. So if physicalism is formulated in terms of ground, it follows that it (physicalism) is false. (2015, p. 560)

Grounding facts, or facts about what metaphysically explains what are, to use Sider's locution, impure. They are not facts solely about what is claimed to be the fundamental domain, in this case physics (Sider 2011, p. 106). And if physics does not have the resources to explain impure facts, physicalism cannot be the view that all facts can be explained by the physical facts, or physicalism would be false. And more generally, for any set of facts F that might be claimed to be fundamental and capable of explaining some nonfundamental set of facts, if there are impure facts about the holding of grounding relations between F and what is nonfundamental, F too cannot be claimed to explain absolutely everything.

Although Dasgupta and Sider each have their own preferred ways of handling this issue for formulating physicalism and other fundamentality positions, I would argue the problem lies with understanding the fundamentality of physics in terms of a claim of metaphysical completeness. A reasonable physicalist (at least one living today or in the foreseeable future) shouldn't think that physics has the resources to explain all of the facts. She only need believe that physics has the resources to provide explanations that are maximal in scope, accuracy, and precision. Even if we may not use physics to explain the grounding facts, neither will we be able to use facts about qualia or vital forces or entelechies to do so. These facts fail to provide a challenge to the maximality of physical explanations.

7. Conclusion

The account of metaphysical fundamentality I've proposed in this paper achieves several things. First, it enables one to connect the metaphysical fundamentality of certain theories with the practically important issue of the justification of funding for research projects to advance those theories. And second, it does so in a way that is not more ambitious than what is needed to provide this motivation. It is an account of metaphysical fundamentality that is capable of applying to actual, current scientific theories. As a bonus, as I've argued in the previous section, it provides a notion of fundamentality that is helpful in formulating certain influential metaphysical positions like physicalism.

I can envision a critic who would argue that it is only those traditional notions of fundamentality framed in terms of completeness theses that have a genuine claim to be interpretations of metaphysical fundamentality. Theories that are merely maximal in the sense I describe in Section 5 may have virtues over their competitors, but this does not suffice to make them truly fundamental. My response is that it is not clear what the classical notion of metaphysical fundamentality does for us, one that perhaps cannot even be satisified by any actual theory. The notion I've outlined is one that can be satisfied by real theories and used to motivate funding for them. It is also a notion that can be used to formulate metaphysical positions like physicalism without creating insuperable problems. Following Sally Haslanger (2000), it is a good strategy when addressing metaphysical questions of the form ⌈What is X?⌉ to ask what good a concept of X may do for us. This goes for metametaphysical questions as well, such as "What is fundamentality?" I've argued there are narrow notions of fundamentality local to various explanatory demands and a broad, metaphysical notion. Both, to be useful and apply to real cases, ought to rely on a notion of maximality rather than completeness.

As I noted only very briefly above, some have argued that claims that physics is a fundamental science are pernicious – that such claims have been used to bolster patriarchal views about knowledge or that they may be used to drain funding away from more worthy projects in the medical or social sciences (Cartwright 1999, p. 18). My goal is not to weigh in precisely how research funding should be allocated nor to argue that it should all go to physics. But it is certainly my view that some should and it has been a goal of this paper to try to articulate the conceptual foundations of claims that it is important to continue to fund research programs in physics.

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