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PLANCK'S 'SHORT STEP' ARGUMENT FOR DIVINE REASON IN PHYSICS

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Abstract

One standard argument for a role for divine reason in Physics is that appeal to God is necessary to explain why there are laws of Physics and Mathematics governing the physical universe at all. My own proposal is not a metaphysical proposal of this sort. Rather, I propose that the application of the laws encounters a problem within Physics itself when: (1) the laws are what I will call 'optimization-type laws' of the sort present in the Principle of Least Action or, in its modern mathematical formulation, the Variational Approach to Physics; (2) we assume a postulate: All fundamental principles in a fundamental physical theory must be explanatory and be explanatorily complete for the relevant domain; (3) we assume that the Variational Approach is fundamental vis-à-vis the alternative, Laws-of-Motion Approach; and (4) the relevant domains are those of Classical Physics and The General Theory of Relativity. The problem is due to the backward-looking nature of least-action explanations of motion: you have to know where a ray of light is going to end up as part of the 'boundary conditions' setting up the set of possible paths, but you then do not have an explanation of why the ray of light gets to that end point. Since this latter explanandum is a part of the explanatory domain of Classical Physics and the General Theory of Relativity, this makes a physics confined to a variational explanatory style incomplete for the relevant domain. But if this style of explanation is incomplete then, I argue, it is not fundamental, contrary to our assumption. By considering the mode of application of the optimization principle to be one, not of immanence-in-nature, but of rational-agent-selects-optimal-possible-world-guided-by-rational-use-of-laws application, then, as required, you do get a complete explanation that falls fully within the variational explanatory style. The argument has both historical (Leibniz and Planck) and systematic dimensions.

Keywords: God, Principle of Least Action in Physics, Planck, Leibniz, Science and Religion

1. Max Planck on the fundamentality of the Principle of Least Action

Modern science, in particular under the influence of the development of the notion of causality, has moved far away from Leibniz's teleological point of view.

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Science has abandoned the assumption of a special, anticipating reason, and it considers each event in the natural and spiritual world, at least in principle, as reducible to prior states. But still we notice a fact, particularly in the most exact science, which, at least in this context, is most surprising. Present-day physics, as far as it is theoretically organized, is completely governed by a system of space-time differential equations which state that each process in nature is totally determined by the events which occur in its immediate temporal and spatial neighbourhood. This entire rich system of differential equations, though they differ in detail, since they refer to mechanical, electric, magnetic, and thermal processes, is now completely contained in a single theorem, in the principle of least action. As we can see, only a short step is required to recognize in the preference for the smallest quantity of action the ruling of divine reason, and thus to discover a part of Leibniz's teleological ordering of the Universe.

Physics… is inclined to view the principle of least action more as a formal and accidental curiosity than as a pillar of physical knowledge… On this occasion everyone has to decide for himself which point of view he thinks is the basic one, and must also ask which approach will eventually be more successful.

Thus it has been even more surprising that this principle, originally viewed by Leibniz and Maupertuis as a mechanical theorem, was found by Hermann von Helmholtz to be valid, without any restriction, throughout the entire physics of his time. Recently, David Hilbert, by employing Hamilton's version of the theorem, has established it in Einstein's general theory of relativity. The more complicated circumstances become, the less likely it is that the dominance of such a simple law could be a mere accident [1].

2. Passages from Leibniz - Discourse on Metaphysics

2.1. If mechanical rules depended only on Geometry without Metaphysics, the phenomena would be entirely different

I even find that several effects of nature can be demonstrated doubly, that is, by considering first the efficient cause and then by considering the final cause, making use, for example, of God's decree always to produce his effect by the easiest and most determinate ways, as I have shown elsewhere in accounting for the rules of catoptrics and dioptrics; I shall say more about this soon [2].

2.2. Reconciliation of two ways of explaining things, by final causes and by efficient causes…

…I find that the way of efficient causes, which is in fact deeper and in some sense more immediate and *a priori*, is, on the other hand, quite difficult when one comes to details… But the way of final causes is easier, and is not infrequently of use in divining important and useful truths which one would be a long time in seeking by the other, more physical way…. I also believe that Snell, who first discovered the rules of refraction, would have waited a long time before discovering them if he first had to find out how light is formed. But he apparently followed the method which the ancients used for catoptrics, which is in fact that of final causes. For, by seeking the easiest way to lead a ray from a given point to another point given by reflection on a given plane (assuming that this is nature's design), they discovered the equality of angles of incidence and angles of reflection, as can be seen in a little treatise by Heliodorus of Larissa, and elsewhere [2].

3. The Principle of Least Action

In its most simple formulation *Action* is defined as *mass x distance x velocity* [3]. The *Principle of Least Action* in the form given to it by Maupertuis (1745) is stated thus: *Nature always minimizes action.* A modern statement of the Principle of Least Action can also be given for potential energy in the form of two principles:

(1) The stable equilibrium states (that is, states of rest) of a physical system are characterized by the condition that, in such a state, the potential energy of the system is less than it would be for any possible (or virtual) close-by state of the system.

(2) The equilibrium states of a physical system are the stationary states of its potential energy.

Let's take a simple example to explain these rules. (This example and these rules are given in Hildebrandt and Trombo [3, p. 84-85].) Suppose we start with a valley and a ball is placed on one side. It will roll down the side until it comes to rest on the bottom. Why? One explanation has to do with a balance between the forces of gravity and the forces of resistance provided by the sides and floor of the valley. This is classical Newtonian physics. Another, which dispenses with the notion of force, relies on the fact that there is a certain point on the contour of the valley where potential energy of the whole system (ball and Earth) is at a minimum, and that is on the very bottom of the valley. The bottom of the valley is the stationary point mentioned in Rule 2 and, mathematically speaking, is the point on a horizontal line that runs tangent to the bottom of the valley. This point is mathematically discoverable by applying the differential calculus to the curve representing the contour of the valley. In general, when the possible states of potential energy of a system are represented by equations, the 'floor of the valley' is discovered by the differential calculus. It is Leibniz who invented this calculus in its modern formulation and put it to this use. We shall now see how he did so.

4. Leibniz's Optics in Tentamen Anagogicum (1697)

My example is Leibniz's derivation of the standard law of reflection: Euclid's Law [4]. (The angle of approach equals the angle of departure for a ray of light striking a reflecting surface. Here I follow McDonough's interpretation [5].)

To begin the derivation, Leibniz asks us to consider a surface represented on Figure 1 as line C1-C2.

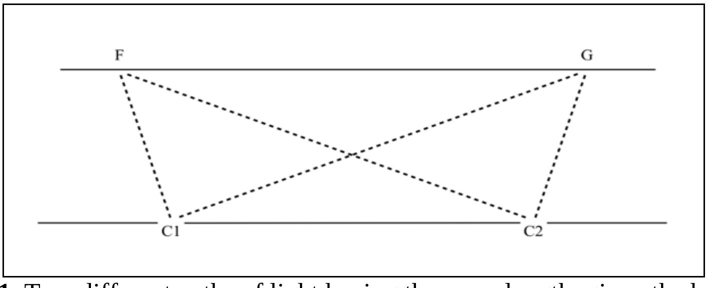

Figure 1. Two different paths of light having the same length, given the boundary conditions.

Suppose that we specify two points that a ray of light must pass through, illustrated in Figure 1 as F and G, on a line FG while also striking a point on another line - the ‘base line’ - below it: C1-C2. In general there will be at least two different paths that a ray of light can take between the same start and end points that are of equal length. These are illustrated by lines F-C1-G and F-C2-G. Suppose that in this case the length of line is 30 cm. In another possible case of twin lines the length may be 28 cm. We now construct an equation, graphed in Figure 2.

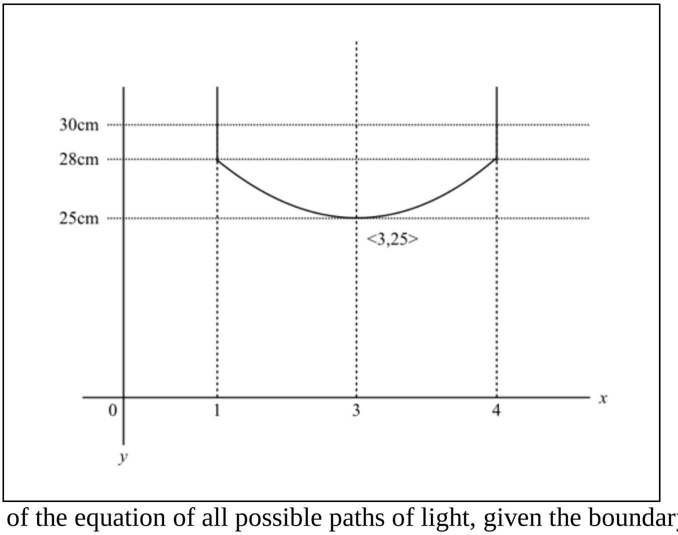

Figure 2. Plot of the equation of all possible paths of light, given the boundary conditions.

Here the y-axis represents the length of all possible lines starting at F on line FG touching the base line at some point, ending at a point G on FG. (These are the ‘boundary conditions’.) The x axis represents the location of points on the base line. For example, ‘3’ might represent the point 3 cm from the left-end of the base line. Leibniz is able to construct an equation represented by the plot in Figure 2. Each ordered pair of points in this equation determines a unique possible path that the ray can take given the boundary conditions. This plot shows that for any given length on the y-axis there are, with one exception, two different paths that a ray of light can take, passing through two different points on the base line, both starting and ending at the same points on line FG. For example one line of 28 cm would touch the base line at approximately 1 cm from the left end of the line, and another line of the same length would touch at approximately 4 cm. The one exception is represented by the point at the bottom of the curve where the horizontal tangent intersects it. (Recall the ball-at-the-bottom-of-the-valley example.) To mathematically determine such points, Leibniz has invented the differential calculus, which he uses here to determine the x and y values of this point. Since this point is the sole unique path among all the other twin paths, he calls this the 'most determinate path' and proposes a principle that light travels along the most determinate path; this is the Most Determinate Path Principle (MDPP). This principle then fixes a length for the path (25 cm in the diagram) and a point at which it strikes the base line (point 3 in the diagram). Leibniz then goes on to prove Euclid's law by standard geometrical reasoning [2, p. 483]. This is in accord with his description of method in Section 22 of the *Discourse on Metaphysics.*

5. Leibniz's philosophy of Physics in Tentamen Anagogicum

To begin our discussion, I note that there is an important similarity between the treatment of physics in the *Discourse on Metaphysics* and *Tentamen Anagogicum*: both texts discuss two realms in Physics. Here is a text from *Tentamen Anagogicum*: "…I usually say that there are, so to speak, two kingdoms in corporeal nature… the realm of power, according to which everything can be explained mechanistically by efficient causes, and the realm of wisdom, according to which everything can be explained architectonically, so to speak, *or by final causes*…" [4, p. 478-479] Leibniz says that the MDPP is an 'architectonic' principle. ("This principle of nature, that it acts in the most determinate ways which we may use, is purely architectonic in fact…" [4, p. 484]) But there is also an important difference between the two treatments. The examples of the final-cause principles that Leibniz discusses in the earlier work are minimizational principles (light takes the shortest path) but in the later work the topic is a new principle, one which "supersedes the preceding one" [4, p. 479], namely the MDPP (light takes the unique path). Elsewhere I consider the significance of this difference [6].

Leibniz also says that the MDPP is 'anagogical', that is, it is something "that leads us to the supreme cause" [4, p. 484-485]. But how can something that is *defined* as a God-applied principle 'lead us' to God in a non-trivial way? I shall call this 'the triviality puzzle' and deal with it below. There is also the question of what 'leads us' might mean. One possibility is that it means 'gives us the basic proof' of the existence of God, whose existence is otherwise epistemically problematic. Another is that, while God's existence is not epistemically problematic it is epistemically problematic which of the principles in nature are

God's special principles. What would be special about these principles is that they are the ones God uses directly to choose the actual world: that would then be the meaning of calling them 'architectonic principles'.

The latter alternative is the one that I adopt here as a working hypothesis. (For an alternative treatment of architectonic principles in Leibniz see [7]. On this alternative, we know that the most determinate-path principles are God's special principles in selecting the actual world because the most determinate path principle is a kind of physical optimization, and physical optimization is a kind of perfection, so Leibniz figures that these are the principles that a being seeking perfection in His choices would use as the primary basis for choosing the actual world.

So, this is Leibniz' picture as I am understanding it. God has available to him a set of principles (including the MDPP) that he uses in a rational (architectonic) application to select the optimal world which he will actualize. In this application these principles have explanatory force: they are used as part of a process to *create* the actuality of the selected possible world. *Within* the world thus selected the optimization principles are expressed as true empirical regularities, but without explanatory force, the case for which I make elsewhere [6]. However, from these principles mechanistic laws can be derived that do have explanatory force. This is the solution to the Triviality Puzzle raised earlier.

6. How optimization principles are 'fundamental' - Leibniz vs. Planck

If I am right about the characterization of the Science and Metaphysics in Leibinz's theory of optimization principles (at least around 1697), then Leibniz' theory and Planck's in the 'Address' are not consistent: contrary to Leibniz, Planck regards optimization principles as explanatorily fundamental, hence as explanatory, in the natural order.

Underlying this difference is a difference in the sense in which Leibniz and Planck take optimization principles to be fundamental. For Leibniz, optimization principles would be fundamental because they are *architectonic principles*: they are the principles God uses in a rational application to choose the actual universe. So any characterization of optimization principles as *fundamental* for Leibniz could not serve as a premise in a proof for divine reason in Physics - by definition, the characterization presupposes divinity; but, for Planck, this characterization of the optimization principles does provide the key premise in such a proof, so he must have a different understanding of what it means for optimization principles to be fundamental. I begin the next section with a consideration of what that might be.

7. Planck and the case for the fundamentality of the Principle of Least Action in Physics

Planck finds in Leibniz's thought an appeal to divine reason underlying the Least-Action approach to Physics, an appeal which he endorses. There are grounds for wondering whether Leibniz does indeed endorse the Principle of Least Action as a fundamental principle of Physics but I will not make an issue here of the historical accuracy of this supposition. I will, however, suppose that for Planck the appeal to divine reason by Leibniz should be understood on the agent-selector model for physics-principles. The primary grounds that *Leibniz* has for positing an agent-selector for the universe are metaphysical and *a priori*. What grounds could *Planck* have? Planck argues that the Principle of Least Action is a *fundamental principle* of physics rather than a 'curiosity' that really doesn't fit into mainstream physics. I think that Planck is pointing here to grounds that lie within physics.

When Planck says that the Principle of Least Action is a fundamental principle - 'Planck's Postulate' as I will call it - I will take that as meaning that it is a fundamental principle in a *fundamental physics*. What is a 'fundamental physics' for Planck? Here I want to distinguish between this question - a question of what 'fundamental physics' *means* - and the question what are the *grounds* for claiming that a certain physics has this property.

Dealing with the second question first, I offer two alternative grounds for thinking that a certain physics is fundamental:

1. If there are several distinct physics-theories (or parts of physics-theories), PT, whose fundamental laws can be deduced from the fundamental laws of another physics theory, PT*, such that the laws of PT* are more simple overall than those of the other theories, then PT* is a fundamental physics-theory with respect to the other 'competitor' theories. (In this case the 'competitor theories' are the branches of Classical Physics and General Relativity). This holds even if the application of the laws of PT and PT* are mutually deducible.
2. If all of the laws of a Physics-Theory PT can be deduced from the laws of a Physics Theory PT*, but not vice versa, then PT* is fundamental to PT.

I take Planck's assertion that the Principle of Least Action is a fundamental principle (in a fundamental physics) to be based on the first rationale. Notice that the first ground relies on the concept of comparative theoretical simplicity. How does one tell that one theory is simpler overall than another? Ultimately, this is something that has to be left to the intuitive judgments of people who work professionally with these theories.

I now turn to the first question: what does the word 'fundamental' in the phrase 'fundamental physics-theory' mean or, rather, what *should* it mean, given Planck's purpose in making the claim? (Planck himself leaves the notion unexplicated in the text we are working with, quoted at the outset.)

One way to give the meaning of the notion of fundamentality is by way of a full philosophical analysis of the concept into necessary and sufficient conditions. This is an ambitious task that I do not need to accomplish for the purpose of argument-reconstruction, and will not attempt here. For these purposes it will be sufficient to provide a necessary condition.

It is controversial whether modern physics employs a notion of causality, but it is not, I hope, controversial that modern physics is *explanatory*. (Denied for example, by Carroll: "…if you open…a textbook on quantum field theory… for example words like that ['cause'] are nowhere to be found. We still, with good reason, talk about causes in everyday life, but they are no longer part of our best fundamental ontology." [8]) It explains how and why things in the physical world are as they are, how and why things that happen, happen as they do. So I am going to posit a necessary condition on the concept of fundamentality that embodies the idea of *explanatory completeness*.

7.1. Planck's condition on the fundamentality of Physics theories

A physics-theory PT* is fundamental with respect to another physics-theory or set of physics-theories, PT, only all of the things in the domain(s) of explanation of PT can be *directly explained* by PT*, that is, *explained in the explanatory style of PT** without essential reliance on explanations in the style of PT, even if the explanations of a given phenomenon E afforded by PT are entailed by the explanations of E afforded by PT*.

Let me explain the qualification. Suppose that you and I are in a room together and that I admire you. You are the tallest person in the room and I admire you *because* you are the tallest person in the room. This is the 'because' of cause and sustains counterfactual inference: whoever is the tallest person in the room would be the object of my admiration. In this case *being the tallest person in the room* is, *per se*, the explanation why I admire you. By contrast, even if you happen to be six feet tall, even if, somehow, the circumstances showed that the tallest person in the room *had* to be six feet tall, that would still not make being six feet tall, *per se*, the cause for my admiration: it would only be a necessarily accompanying property.

Let's apply this distinction to a case that we have already considered: Leibniz' derivation of the MDPP (the Most Determinate Path Principle). Consider again Figure 2. The curve represents a set of possible paths that a ray of light might take given the stipulations of start and end points and a constraint: the ray must strike an intervening surface with certain characteristics. The possible paths are represented as points on the curve consisting of an ordered pair <x,y>. For example, the pair <1,30> represents the path that a ray of light will take with a total length of 30 cm, striking the intervening surface at a point designated 1. Now, in Least-Action Physics the actual point is determined by a 'critical point' on the curve. In the case illustrated in Figure 2, the y-value is taken at its minimum (25 cm), thus determining a specific point on the curve <3,25>. This determines a specific path which Least-Action Physics would select as the actual path. But the notion of a minimum contains two ideas: that of a unique point and that of a point that bears the 'less than' relation to other quantities. Even though the minimum point and the unique point are the same, that is, they are mathematically equivalent in this context, if we assume that the properties of this point provide the explanation why the ray of light takes the path it actually does, then we still may ask which is the explanation *per se* and which the necessarily accompanying property. That is, is the minimization-explanation the explanation *per se* (in which case its' uniqueness is only accompanying) or is the unique-point explanation the explanation *per se* (in which case minimization is only accompanying)? With Leibniz' MDPP, it is uniqueness *per se* that affords the explanation rather than the minimal property (in Least-Action Physics it would be the minimal property *per se* that offers the explanation). Here is the passage from Leibniz:

This makes us see, finally, that the rule of the unique path or the path most determinate in length of time, applies generally to the direct and the broken ray… without distinguishing in the process whether the time is the longest or the shortest, "*though it is in fact the shortest*…" [4, p. 483] (Here Leibniz is talking about the more generally applicable least-time property rather than the shortest-distance property, which applies only in the case of reflection ('the direct ray').)

8. Forward-looking and backward-looking physics

Leibniz has identified two approaches to physics, that 'by final causes' and that 'by efficient causes'. Both are represented in theories of reflection in antiquity.

The earlier theory, due to Euclid around 300 BC, states that a ray of light travelling in a straight line from a point A that is reflected from a surface at point B is reflected away from B at the same angle with which it strikes that point. This principle can be used not only to explain why rays of light behave as they do but can be used to predict the path a ray of light will take prior to its reflection. It is because the events governed by this principle proceed forward in time that we can say that part of the explanation of the path the light takes when it leaves point B is the angle it takes when it strikes point B. Moreover, since this principle involves only the concepts of motion and geometry, it counts as a mechanistic principle. The term 'mechanism' in connection with physics is sometimes used to describe a physics of matter in motion that contrasts with 'dynamical': the latter employs a metaphysically robust notion of force, the former does not. That is the use here. However, Leibniz also uses the term 'mechanistic' to describe his own physics where it describes the principles governing efficient causation [2, p. 478] which, of course, is a dynamical physics. When Leibniz wishes to talk about physical principles that do not involve forces, he calls them 'geometrical principles' [4, p 478]. Henceforth, I will follow Leibniz's usage. We shall call a physical principle of this sort 'causal/mechanistic' and the physics in which it occurs 'forward-looking physics'.

The later theory, due to Heron around 100 AD, states that a ray of light starting at point A, striking one surface and being then reflected to another surface at point C, takes the shortest distance between points A and C. In the language of natural (Aristotelian) teleology we would say that it *seeks* the shortest distance between points A and C and the reflecting surface. This principle differs from the causal-mechanistic principle in that it uses teleological concepts ('seeks'), does not posit that light travels in a straight line and does not explain the behaviour of the path of light in terms of the size of angle the ray takes when striking or leaving the surface. The only notion involved is the minimization of distance travelled: all other properties of the ray, its' straight-line path, where it strikes the mirror and the angle of approach and departure from that point, are derived from this one principle. When expressed in teleological language, I shall call principles of this sort 'teleological-minimization principles'. Notice that the statement of this principle requires that we are first given point C, the place where the ray of light eventually ends up. So I will call a physics having this property in general (whether expressed in teleological language or not) a 'backward-looking physics'; in this case it is a backward-looking teleological physics.

8.1. A problem for backward-looking physics

I can't undertake here a thorough discussion of teleological physics in general, so I will briefly make a few points. Consider, as an example, Aristotle's notion of the tendency of fire to move upwards. This tendency, to be activated, requires that the fire be somehow responsive to, hence somehow detect, the direction *up.* In no other way could the *tendency* for fire to move up explain the *actuality* of fire moving up. But now we encounter a difficulty for a minimizing-telos to explain the path the ray of light takes from A to C via an intervening surface. The difficulty is that it seems impossible for the ray of light when at A to detect, hence to be responsive to, the 'shortest distance between A and C via an intervening surface' because, to do so, it has to detect, hence be response to, point C. But this is just what it can't do because it hasn't arrived there yet! Now consider a different example. A cowboy is heading westward back to the ranch after a long day on the range and wants to take the shortest path home, but his horse needs watering. The nearest source of water is a river some miles to the south (Figure 3). (The example and diagram is based on one from [3, p. 50].)

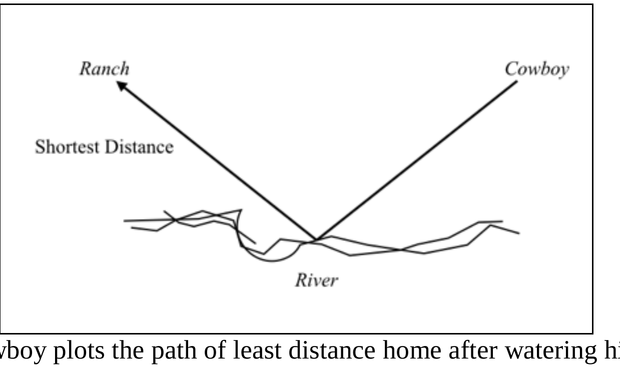

Figure 3. A cowboy plots the path of least distance home after watering his horse at the river.

The cowboy can figure out what direction to take to the river by some seat-of-the-pants calculating in order to take the shortest path home via the river. This does not require that he has to be able to detect or be responsive to the location of the ranch as such, but it does require that there be a *mental representation* of the location of the ranch, the river and his current location. Here there is a genuinely explanatory, and genuinely teleologically-explanatory, employment of the shortest-distance property accounting for why the cowboy arrives at the ranch. But the ray of light does not possess the requisite mental-representational and calculational capabilities. Since there are only two options - the detection-of-point-C option and the mental-representation-of-point C option - and neither is possible, no minimizing telos can explain why the ray of light ends up at point C. At least not by itself.

But perhaps we can appeal to a *division of explanatory labour*: the forward-looking account, whether teleological or not, explains why the ray arrives at point C, the backward-looking account, whether teleological or not, explains why it takes the shortest path. I argue in the next section that if the principle of Least Action is the fundamental principle in a fundamental physics - as Planck maintains - then even this possibility is ruled out. This is because a physics that is fundamental in relation to some alternative physics must be a *complete* physics and a complete physics must explain *in its' own explanatory style* all that the alternative physics explains. Since the alternative physics is a laws-of-motion physics and *it* explains why the light ends up where it does (given initial conditions) this is what the backward-looking, least-action physics must also explain in its own style. That is just what the division-of-labour proposal denies, and that is why it is ruled out for our purposes. From this follows the 'short step' to Planck's final conclusion: the need for postulating divine reason in Physics.

9. Planck's 'short-step' argument for divine reason in Physics

Before proceeding with the argument, I want to deal with an objection to the possibility that the set of least-action laws (optimization laws) in Physics could, even in principle, be fundamental *vis-à-vis* the set of mechanistic laws. The objection depends on the fact that these two sets of laws are mathematically inter-derivable. If you start with a problem formulated within the least-action laws you can derive the corresponding mechanistic law, and vice versa. (As mentioned by Planck, *Address*. Proven in the modern-day version of the Principle of Least Action, the Variational Calculus [9, 10].) The objection derives from the principle that if A and B are mathematically equivalent in the way in question here, then they are simply alternative formulations *of the same phenomenon*. "The principle of least action (+suitable definition of action) is… a completely equivalent re-statement of the equations of motion. It is just phrased in a different form, which is more mathematically convenient for certain purposes, such as finding conserved quantities or looking at perturbations. There is no particular magic behind it- the action is chosen precisely such that is has this property… If you accept the equations of motion as a valid description, it is just a mathematical exercise to re-formulate the theory in terms of a least-action principle, and vice-versa." [A. Davis, https://www.quora.com/Why-does-least-action-principle-work-Hamiltons-least-action-principle] In this case, of course, one could not in principle be explanatorily more fundamental than the other. I do not accept the principle. Here's why.

In modern physics there are two main approaches to understanding and predicting physical phenomena: the 'Variational Approach' and the 'Laws of Motion' approach. The latter is the familiar approach in which initial conditions are specified and paths of motion to end points are determined via deterministic laws. This is the approach which Leibniz calls 'the mechanistic approach'. The former corresponds to what Planck has been calling the Principle of Least Action: it selects from a set of possible paths or actions the path or action that is at a minimum. The Variational Approach is based on a 'Variational Schema' consisting of 5 main elements:

1. A configuration space Q,
2. Initial and final boundary data + some constraint,
3. A space P of paths between the boundary data,
4. A function S on the path space P,
5. The actual path is a critical point of S [N. Teh, *Teleology and the Variational Schema*, Teleology Within Physics?, Workshop, Harvard University, April 01, 2016].

As noted, the Laws of Motion for both Classical Physics and General Relativity - I am leaving Quantum Theory out of the scope of this discussion - can be deduced from the Variational Approach, of which element 3 asserts the existence of a 'space P of paths'. The space in question is a space of *possibilia*, merely possible paths. That is what the term 'variational' means in the term 'variational calculus'. So the equation (the 'function S' of element 4) has an ontological commitment to a set of *possibilia*. This is not the case for the laws of motion themselves: their ontological commitments are only to actualities. It is true that from a law of motion we can also deduce the action, which is at a minimum. So we might think that the ontological commitment of the laws of motion do indeed contain mere possibilia, since, we might think, what is minimized must be described as actions among a set of all possible actions understood as *possibilia*. This is not quite right. Consider the derivation of the shortest-distance property of a ray of light from Euclid's Law, as shown in Figure 1. We suppose Euclid's Law and then prove the following proposition (1): *If l is the length of the path taken by the ray ABC, then ~ [there is a path meeting the operative boundary conditions and constraints with length l* such that l* < l]*. This latter statement gives the meaning of 'l is the shortest path that a ray of light can take meeting the boundary conditions and constraints'. But this statement is itself equivalent to (2): *If l is the length of the path taken by the ray ABC, then, for all paths, if they meet the operative boundary conditions and constraints and have a length l* , then l < l*.* Statement (2) is a universally quantified statement and, on the standard 'if-then' rendering of a universally quantified statement, (2) does not make an ontological commitment to *possibilia*, that is, does not entail the existence of merely possible paths meeting the boundary conditions and constraints: these paths enter the picture only conditionally, as the antecedent in such statements. So the phenomena are fundamentally different. The oddity is that they coincide in the actual outcome.

Now to the argument. Planck is working within a perspective in which the fundamental law of physics is an optimization principle, in this case, The Principle of Least Action. This is Planck's Postulate. As mentioned above, the optimization principle in its natural-law form is a principle in a backward-looking physics. Like Leibniz, let us also say that there is another form of optimization principle, the architectonic form, in which it figures as a rational principle used by an agent-selector to select the optimal world. Contrary to its natural-law version, an optimization principle used in this way is not backward-looking - the normal order of causality is preserved. This will prove to be of critical importance to the argument. However, unlike Leibniz (on my reading), I shall not deny to the natural-law form of optimization principles, at least in principle, the status of explaining events in the physical order. In what follows, 'natural-law optimization principles' are to be understood in an explanatorily potent sense.

On the other hand, mechanistic laws (and laws governing teleological processes immanent in nature) are forward-looking. (What matters for the purposes of this argument is not the distinction between these two kinds of laws but the fact that they are forward-looking. In this way I can avoid the metaphysical thickets and concentrate on giving the reader a clear and simple reconstruction of Planck's 'short-step' argument.)

Planck's Condition on Fundamentality asserts that fundamental principles are explanatorily *complete*. If we can show that there is an explanatory *incompleteness* in the natural-law optimization principles for *explananda* in the domains of Classical Physics and the General Theory of Relativity, then the only fundamental form of optimization principles remaining would be those applied architectonically by an agent-selector. And we *can* show that there is an explanatory incompleteness for the natural-law interpretation of optimization principles, in this case, the Principle of Least Action.

Take the case of the reflection of a beam of light discussed above. I have observed above that any backward-looking physical principle cannot *by itself* explain why something, in this case a ray of light, takes a path that terminates at point C. This is because termination at C is part of the *boundary conditions* for this style of explanation. This would not be problematic as long as we accept that such a physics has only a *partial role* to play in explaining why the ray takes the path from A to C via the intervening surface - it explains why the path is shortest. The job of explaining why, given certain *initial conditions*, the ray ends up where it does, would then fall to a forward-looking physics - a nice division of labour we might think. But on Planck's approach, any physics employing the Principle of Least Action is not a partial or derivative physics, it is a *complete* physics explaining the full domain of phenomena explained by traditional mechanistic physics, including the path from A to C taken by our ray of light. No division of explanatory labour between theories expressed in alternative explanatory styles is allowed for complete physical theories; all the required explanatory power must come from one explanatory style, in this case, the explanatory style of the

Principle of Least Action. But *in its natural-law formulation*, the Principle of Least Action is part of a backward-looking physics. As such, it cannot explain some of things that need to be explained. This shows that the Principle of Least Action, understood as natural law, would not be part of a *complete* physics, hence, by Planck's Condition of Fundamentality, not part of a *fundamental* physics. However, according to Planck's Postulate, the Principle of Least Action *is* a principle in a fundamental physics, and it must take whatever form is needed to satisfy this condition. So we are in a quandary.

The quandary can be avoided for Planck if, but only if, he chooses the architectonic form of the Principle of Least Action. On this approach there are laid out for a divine agent all the possible cosmological tableaux (all the possible worlds), all of which are spatio-temporally determinate possible worlds. It follows that, in any unique possible world, the start and end points of the beam of light are uniquely determined - call them S and E, respectively - so in selecting a unique possible world (the physically 'optimal' world) to actualize, the agent-selector *thereby* selects S and E as the start and end-points of the ray of light, respectively. This is possible because the rational application of the Principle of Least Action is not backwards looking, unlike its naturalistic counterpart.

To sum up. If you ask Planck (as I have reconstructed his argument) why the beam of light starts at point S and ends at point E after striking an intervening surface, his answer is: *because there is a single, spatio-temporally determinate, physically-optimal possible world, in that world there is a beam of light that starts at S and ends at E after striking an intervening surface, and the divine agent-selector makes that world actual*. So we now have an explanation falling fully within a Least-Action-Principle explanatory style not only of why light takes a certain path given certain specified boundary conditions, but why those particular boundary conditions actually obtain. In this way we have an explanation that *matches* the explanatory scope of the mechanistic-law explanations of Classical physics and the General Theory of Relativity in accounting for why the ray of light ends up where it does, without departing from its characteristic explanatory style. This is just what we do not have in the case of Least-Action Physics interpreted as natural law. That is why, on the present reconstruction of Planck's reasoning, the appeal to divine reason rationally applying optimization law, rather than a natural application of optimization law, is mandatory in Physics.

10. Leibniz, Plank and modern-day Physics

The argument for divine reason that I have just outlined seems to me to be plausible for the conception of physics it depends on. But things have changed in the landscape of theoretical physics since 1922. Quantum Mechanics as Planck developed it has changed with the incorporation of Heisenberg's Uncertainty Principle. Whole new approaches to physics have emerged, for example, the probabilistic, path-integral approach of Richard Feynman. The teleological approach to Physics is, if anything, even more of an outlier to standard physics-theories than it was in Planck's day. Moreover, my impression from modern-day working physicists is that they are little interested in questions of ontological fundamentality. Their main concerns are pragmatic: what physics-approach works best for a given theoretical or experimental problem. So we may well wonder how much of the relevance of Planck's argument for Divine Reason in Physics survives into the modern day?

My answer is: quite a lot actually! In particular, the explanatory incompleteness problem still arises for the Variational Approach in exactly the same way it did for the natural-law version of the Least-Action Principle as Planck understood it in 1922: the former also does not explain why the actual boundary conditions (think here especially of the point where the path actually ends) are as they are. For physicists interested only in pragmatic questions, this need not be a problem: when interested in where a particle ends up, use the Laws-of-Motion approach, when interested in the path a particle takes between start and end points, take the Variational Approach. But eventually ontological questions will catch up with you. When they do, there is available for your consideration Planck's Argument for Divine Reason in Physics in its modern, Variational-Approach form. (I call it 'The New Argument for Divine Reason in Physics'.)

11. The new argument for divine reason in Physics

This argument runs in parallel to Planck's Argument and I present it here in its formal version.

1. The Variational Approach to Physics is a fundamental physics with respect to classical Physics and the General Theory of Relativity (Planck's Postulate).
2. A physics-theory PT* is fundamental with respect to another physics-theory or set of physics-theories, PT, only if all of the things in the domain(s) of explanation of PT can be directly explained by PT*, that is, *explained in the explanatory style of PT** without essential reliance on explanations in the style of PT (Planck's condition on fundamentality).
3. The Variational Approach to Physics directly explains all the things in the domains of classical physics and the General Theory of Relativity without relying on the laws of either of these physics (logic: (1), (2)).
4. There are two possible correct interpretations of the Variational Approach to Physics: the natural-law interpretation and the agent-selector interpretation. (metaphysical premise).
5. Suppose, for purposes of *reductio,* that the correct interpretation of the Variational Approach to Physics is the natural-law interpretation (*Reductio* assumption).
6. The Variational Approach interpreted as natural law is a fundamental physics (logic: (5) and (1)).
7. The Variational Approach interpreted as natural law directly explains all the things in the domains of classical physics and the General Theory of

Relativity without relying on the laws of either of these physics (logic: (3), (6)).

8. The Variational Approach interpreted as natural law cannot explain at least one thing that is in the explanatory domain of classical physics and the General Theory of Relativity, namely, for a beam of light that starts at point S and ends at point E and strikes an intervening surface, why it starts at S and ends at E (substantive premise).
9. Lines (7) and (8) are contradictory.
10. Hence the assumption that the correct interpretation of the Variational Approach is the natural-law interpretation is false (*Reductio*, lines 5-9).
11. Hence the correct interpretation of the Variational Approach is the agent-selector interpretation (logic: (4), (10)).

QED.

12. Conclusions

I offer here two versions of a single argument for the existence of divine reason in Physics, that is, for the existence of God as Leibniz generally understood God. This argument, in both its versions, makes a critical assumption: it relies on the premise that the Principle of Least Action, as Planck understood it, or the modern Variational Approach to Physics is fundamental in relational to the Mechanism/Laws-of-Motion approach. Is Planck right about this? (Planck does not himself argue for this conclusion in his ‘Address’, but leaves it to “everyone to decide for himself which point of view he thinks is the basic one” [1]. Planck is speaking to people working professionally in the theoretical physics of his day, and I am not such a person, so I will designate Planck as my authority on this. Designating someone as an authority on a topic, when one is not an authority on the topic oneself, is a fraught business. However, I take Planck to have a unique, qualifying characteristic: as creator of the Quantum Revolution in Physics around the turn of the Twentieth Century - not this part of Physics or that part of Physics, but Physics as a whole - his intuitive understanding of the whole of modern theoretical physics is unsurpassed; and intuitive understanding is the kind most needed when making determinations of what is explanatorily fundamental in a theory and what is not. What I mean by ‘modern theoretical physics’ is a physical theory in which the equations of Einstein’s General Theory of Relativity and Schrödinger’s Wave Equation are accepted as fundamental physical principles. By the time of Planck’s paper in 1922 this was the case for the former. The Wave Equation is the adaptation of Hamilton’s Equation to the quantization of physical magnitudes represented by Planck’s own Quantum Theory. Hamilton’s Equation is one of two standard formulations of the Principle of Least Action, and was recognized as such by Planck in his address. Although Schrödinger did not formulate the Wave Equation until 1925, and Planck’s talk was given three years earlier, I take these facts to indicate that the Wave Equation was implicit in Planck’s physics of 1922. Consequently, and admitting that I am cheating a little bit, I take Planck's position in the 1922 paper to be based on modern physics in this sense.

However you answer the question this argument is not intended to compel your assent. If you do not think that the Principle of Least Action/Variational Approach is fundamental, and you do not believe in a role for divine reason in physics to begin with, then this argument gives you no reason to alter your opinion. If, on the other hand, you do think that the Principle of Least Action/Variational Approach is fundamental, and you do not believe in a role for divine reason in physics to begin with, you are also free to reject the conclusion, but with this important qualification: you must find one of the other premises to reject, of which there are three: (2), (4) and (8). However, if, upon reflection, you find that these premises *are* acceptable, then you *are* compelled to accept a role for divine reason in Physics.

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