Einstein's Big Break

The Archaeology of a Scientific Revolution

By

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Honors Thesis
Submitted in partial fulfillment of the requirements for the degree of Bachelor of Arts in Modern Critical Philosophy
At Brown University

April 12, 2010

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ACKNOWLEDGMENTS

This honors thesis is truly the capstone of my Brown education, bringing together my two concentrations in physics and modern critical philosophy. I could not have made it through the two years I spent on this project without the generous help and relentless encouragement of my friends, family, and teachers. Special thanks are due to Wendy Hui Kyong Chun, my thesis advisor, who put up with my hardheadedness and verbosity despite never having met me before I approached her with an honors thesis proposal. Had she not pushed me to start writing in September, this thesis might never have been completed. Throughout the process, her comments pushed me to think harder about how I was approaching this difficult topic. After teaching me quantum mechanics, Brad Marston helped me wade through century-old physics text. I couldn't have written seriously about the underlying physics and mathematics without his patient help. Elizabeth Weed has been my most valuable advisor at Brown, but more importantly, she taught me how to read. It is not an overstatement to say that her continuing guidance has made into the reader, writer, and thinker I am today. I started researching Einstein's *annus mirabilis* while writing my final paper for John Michael Silverman's seminar on Althusser. I thank Professor Silverman for encouraging me to take on this challenging topic, which was initially too intimidating for me to broach.

I must thank my friends and family, who put up with my incessant talk about my thesis for two years. Without their support, I surely would have lost my mind. I am particularly grateful to Jeffrey Knowles and Nicholas James Dolan Greene, whose curiosity and intelligence I exploited to the fullest in discussing my research and writing. I thank my grandmother, Rhoda Selvin, for being the most loyal reader of my work. And finally, I extend my deepest gratitude to my family, Craig, Barbara, Andy, and Laura, for their love and encouragement.

Nick Werle
April 12, 2010

INTRODUCTION: WHAT IS OUR KNOWLEDGE WORTH?

Scientific thought is a development of pre-scientific thought. As the concept of space already played a fundamental role in the latter, we must begin with the concept of space in pre-scientific thought. There are two ways of regarding concepts, both of which are necessary to understanding. The first is that of logical analysis. It answers the question: How do concepts and judgments depend on each other? In answering it, we are on comparatively safe ground. It is the certainty by which we are so much impressed in mathematics. But this certainty is purchased at the price of emptiness of content. Concepts can only acquire content when they are connected, however, indirectly, with sensible experience. But no logical investigation can reveal this connection; it can only be experienced. And yet it is this connection that determines the cognitive value of systems of concepts.

For example, suppose an archaeologist belonging to a later culture finds a textbook of Euclidean geometry without diagrams. He will discover how the words "point," "straight line," "plane" are used in the propositions. He will also see how the latter are deduced from each other. He will even be able to frame new propositions according to the known rules. But the framing of these propositions will remain an empty word-game for him, as long as "point," "straight line," "plane," etc., convey nothing to him. Only when they do convey something will geometry possess any real content for him. The same will be true of analytical mechanics, and indeed of any exposition of a logically deductive science….

> *Regarding the problem of the nature of the pre-scientific concepts in our thinking, we are almost in the position of that archaeologist. We have, so to speak, forgotten what features in the world of experience caused us to frame those concepts, and we have great difficulty in representing the world of experience to ourselves without the spectacles of the old-established conceptual interpretation. There is the further difficulty that our language has to work with words, which are inseparably connected with those original concepts. These are the obstacles that confront us too when we try to describe the nature of the pre-scientific concept of space.1*
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> *-Albert Einstein, 1934*

Nineteenth century physics was a proud discipline. By 1900, physicists had produced a compelling and unified theoretical edifice, in which all physical phenomena were taken to be the fully determined effects of interactions between fundamental particles. Although technological improvements permitted the detection of the atom, and then the electron, by the end of the century, the reigning mechanical view could assimilate these discoveries without too much trouble. There are two fundamental physical categories for the mechanical view: matter and force. Combining particles and central forces (e.g. gravity, electricity, and magnetism) in a baroque assemblage of equations and natural philosophy, classical physicists could describe their whole world according to the same laws. Indeed, this universality was Sir Isaac Newton's fundamental insight and the philosophical meaning of the parable in which he realizes that the same attractive force is respon-

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1 Albert Einstein, "The Problem of Space, the Ether, and the Field in Physics" (1934) in *Beyond Geometry.* ed. Peter Pesic (Mineola, NY: Dover, 2007), 187-8.

sible for both the fall of the apple and the elliptical orbit of the Moon. This coherent explanation for all phenomena is what gives his Principia such lasting power. It lays out an ironclad system of cause and effect, which governs the force-mediated interactions of bits of matter, on the inert stage of an absolute space and proceeding according to an independently flowing, absolute time.

Classical physics, then, achieved its scientific raison d'être in the pursuit of the natural laws responsible for these interactions. It aspired to a sort of divine omnipotence, since tabulating the simultaneous positions and momenta of all matter would be theoretically sufficient to know the world's past and future in their entireties. As the nineteenth century drew to a close, physicists perceived this absolute knowledge to be a more real possibility than ever before, even if the necessary measurement remained a practical impossibility. During the preceding one hundred years, many more phenomena, once incompatible with the mechanical view, were assimilated into its logic. In 1801, Thomas Young conclusively demonstrated that light is not a ray of corpuscles but a wave, apparently settling a debate that began in the 1600s between Newton and Christiaan Huygens. But this presented physics with a problem: If light is a wave, what is doing the waving? Just as sound waves require a medium, usually air, for their propagation, light waves required an elastic medium if they were to both traverse the vacuum of space and retain consistency with the mechanical view.

To fill this void, physicists turned to the luminiferous ether, a substance that was supposed to fill the universe and transmit light waves. This was certainly not the first suggestion than an ethereal substance pervades all space, but the convincing evidence that light is a wave stemming from Young's diffraction experiments made its presence a theoretical necessity. As increasingly sensitive equipment became available, physicists elaborated an ever more complete wave theory of light. This movement reached its apex in 1864 with James Clerk Maxwell's dynamical theory of the electric field, which showed electricity, magnetism, and light to be manifestations of the same fundamental phenomenon and transmitted by one and the same ether. Undoubtedly the pinnacle of classical physics, Maxwell's system of four equations describing the electromagnetic field united the most resistant phenomena and brought them firmly in the mechanical fold. By the end of the century, some physicists declared that all that remained for the discipline was to refine measurements and explain a few stubborn phenomena.

Perhaps the two most obstinate problems at the turn of the twentieth century were related to blackbody radiation and the failure to detect the luminiferous ether. But even these were eventually taken care of. Max Planck and Hendrick Antoon Lorentz, two of the most prominent German physicists of their day, published explanations that seemed to work, even though they were confusing. And though their equations remain in today's physics contemporary physics textbooks, their logical justifications were thoroughly classical. In retrospect, their theories' oddities might seem to be omens of an impending theoretical crisis, but there is no evidence of any panic on the part of their contemporaries.

Radical change and the end of classical physics were, however, only a few years away. In 1905, an unknown clerk at the patent office in the Swiss city of Bern, reading and writing in his spare time, published a set of four papers that touched on nearly every area of active physics research. During this so-called annus mirabilis, Albert Einstein introduced new approaches to the calculation of molecular dimensions and the mathematical description of Brownian motion. But what made 1905 a genuine revolutionary moment were his radical theories of space, time, and light. Although they presented no new experimental results, "On a Heuristic Point of View About the Generation and Conversion of Light" and "On the

Electrodynamics of Moving Bodies" represent a fundamental break with the logic of classical physics, even as they merely read previous theories.

These two papers contained several revolutionary theories. The first suggested that treating light as composed of discrete energy quanta rather than continuous waves made previously insoluble problems – the energy distribution of blackbody radiation, the photoelectric effect, and the ionization of gases – appear to be simple. The second did what decades of "failed" experiments could not: Force physics to abandon Newton's absolute space and time, and along with it any reliance on the luminiferous ether. Starting from two clearly defined postulates and a new form of scientific rigor, Einstein produced a theory of relativity, in which space and time are tied to a given observer by pulses of light. Physics was no longer a means to divine omniscience, but a system of thought grounded on a set of irreducible conventions. In a phrase, Einstein showed physicists what their knowledge is worth.

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Einstein's annus mirabilis is a quintessential scientific revolution. Although many mathematical relationships seem to have survived this scientific break, they formed radical new theories as their classical objects were replaced with modern ones. On the strength of fresh logic, these old equations were transformed to fit new theories. Drawn to its concept of the paradigm shift, many philosophers of science turn to Thomas Kuhn's Structure of Scientific Revolutions to understand the implications of this historical rupture. Although Kuhn's text does a wonderful job of explaining how a science shifts from one period of normal scientific practice to another, this thesis argues that it is insufficient to understand the full epistemological implications of a scientific revolution. Writing in the

1950s, Kuhn had only one developed epistemology to which he could turn: analytic philosophy's empiricist conception of knowledge as true justified belief. This philosophy seeks to test the correspondence between scientific models and the real world, accessed through neutral experience, as a guarantee of its truth.

For Kuhn, whose philosophical project is at root historical, analytic philosophy's timeless test of truth does not work. In its place, this thesis proposes we turn to the ideas of Louis Althusser (1918-1990) and Michel Foucault (1926-1984). By viewing knowledge as the result of a historically determinate process of production, carrying on according to a given mode and with certain means, Althusser's epistemology enables us to understand the radical nature of Einstein's annus mirabilis papers. In the following pages, I aim to explain how these papers constructed a new problematic for modern physics, one that recognizes the fundamental power of convention, imagination, and human thought. For Althusser, the problematic is a historically specific, epistemological structure peculiar to a given science; the latter "can only pose problems on the terrain and within the horizon of… its problematic, which constitutes [the science's] absolute and definite condition of possibility."2 The problematic also defines the way in which a science produces the objects of its knowledge, thereby setting limits on what is visible to the science and establishing its self-avowed relation to the real things in the world. Thus, the philosopher seeking to understand the epistemological foundations of a science should analyze its problematic. This thesis argues that such a generalized Althusserian epistemology works well alongside Kuhn's theory of scientific revolutions, and attempts to elaborate a coherent philosophy of science from this intersection.

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2 Louis Althusser, "From *Capital* to Marx's Philosophy," in *Reading Capital.* trans. Ben Brewster. (London: Verso, 1997), 25.

Although Kuhn's study is historical, it lacks a fully theorized methodology for constructing a history. He rails against the traditional approach to chronicling the history of science, which works retrospectively and views "out-of-date theories… [as] in principle unscientific because they have been discarded…. Rather than seeking the permanent contributions of an older science to our present vantage, [he] attempt[s] to display the historical integrity of that science in its own time."3 In doing this, he works to construct periods of normal science, punctuated by scientific revolutions. However, this strategy requires him to track continuous lines of thought through decades, and once a science has settled into a stable paradigm, it's treated rather monolithically until the next revolution comes along.

Althusser's epistemology also requires a specialized historical methodology, one that privileges ruptures and discontinuity. But he does not articulate such an approach in any depth. Rather, he gestures to the work of his student, Foucault, as examples of the sorts of historiographies his epistemology requires. This thesis works to theorize the relationship between Althusser's epistemology and Foucault's method of archaeology, a connection that receives relatively little notice from either side. In archaeology's pure analysis of discourse, we find the way of accruing material on which to deploy Althusser's epistemology. And finally in Althusser's philosophy, we find the epistemological structures that explain why archaeology functions the way it does.

Working with statements, archeology seeks to assemble an archive. Dispersions are intrinsic to this type of assemblage, and for Foucault, they are not to be covered over as traditional histories do with such continuities as cause and effect. This is an aspiration that would help strengthen Kuhn's philosophy,

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[3] Thomas Kuhn, *The Structure of Scientific Revolutions*. 2nd ed. (Chicago: Chicago UP, 1970), 1-3.

which, as we have said, has a tendency to suture historical ruptures beyond revolutions. By bringing these two discursive fields into conversation, this thesis proposes for Kuhn a more fully theorized historical strategy. Moreover, this exchange should introduce distinctions between the Foucauldian discontinuity and the Althusserian break, and in doing so explain why every scientific revolution does not require the production of a fundamentally new problematic.

As archaeology is the appropriate historical method for both Althusser and Kuhn's philosophies, it is the one attempted here. In assembling archives of classical and Einsteinian physics, I aim to mobilize these discourses for the reader. In addition, I hope to disperse the tightly wound standard annus mirabilis narrative, which takes quantum and relativity physics as strokes of personal genius on Einstein's part. In our approach, Einstein's radical vision is not the result of heroic sightings of objects others had missed. Instead, the epistemological break he initiates emerges from a historically determinate conjuncture of existing physical theory, technical prowess, and philosophical criticism. Further, the new objects visible after his 1905 critiques are not properly his, but rather belong to the new problematic itself, which defines the limits of the visible with its internal structure.

As the paradigm example of the scientific revolution, much ink has been spilled on Einstein's annus mirabilis. This thesis was hardly composed in isolation. I am particularly indebted to Peter Galison, whose brilliant book Einstein's Clocks, Poincaré's Maps was an immense help in analyzing the relationship between Einstein's thought and that of Poincaré. These two texts are not, however, identical in their aims. Galison's book describes how the technical backgrounds of the two men – Einstein's evaluation of patent applications for time coordination devices and Poincaré's position at the French Bureau des Longitudes – influenced their ideas about the nature of synchronized timing systems, simultaneity across long distances, and absolute Newtonian time. In contrast, this thesis takes both Poincaré and Einstein's experience in the patent office as elements of the conjuncture from which the epistemological break into modern physics emerged. Insofar as it traverses similar terrain, it does so from a far more abstractly philosophical perspective.

Similarly, one might hear echoes of Galison and Lorraine Daston's Objectivity or The Invisible Century by Richard Panek in my ongoing discussion of scientific vision. However, because this thesis works mostly on an epistemological level, it deals with vision primarily as a part of the familiar visual metaphor for knowledge. While this analysis could certainly be extended to discuss the ways that vision plays into changing notions of scientific knowledge at a more material level as those books do, that is beyond the scope of my current project.

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This thesis begins with an analysis of classical physics. We will study the mechanical view, which dominated science in the nineteenth century by arguing that all physical phenomena are the result of the interaction of matter and forces. In doing so, we will find it necessary to explore a pair of concepts – Kuhn's paradigm and Althusser's problematic – that will be the basic units of epistemological analysis going forward. In analyzing the problematic of classical physics, I will argue that it was a thoroughly empiricist discipline, which took itself to be in the business of discovering the universal laws of nature.

In the third chapter, we will explore the historical conjuncture in which Einstein was working. Following the reading list of the Olympia Academy, the modest philosophical discussion group of which Einstein was elected president, we will evaluate physics' cutting edge in the years before

Einstein's annus mirabilis. Along the way, I will introduce the Althusserian notion of symptomatic reading, the means by which I see Einstein effecting an epistemological break. We will also examine analytic philosophy's traditional problem of knowledge and see why it cannot handle the epistemological rupture of a scientific revolution. Finally, I will introduce Foucault's archaeology as the historical method necessary for our philosophy of science.

In the fourth chapter, we will undertake our own symptomatic reading of two of Einstein's annus mirabilis papers, "On the Electrodynamics of Moving Bodies" and "On a Heuristic Point of View About the Generation and Conversion of Light." This is the core of the thesis, for it will show how our philosophy of science uniquely handles the challenge of the annus mirabilis by identifying the truly revolutionary character of Einstein's physics. At this point, our philosophy will coalesce around the notion of the epistemological break, with a series of arguments intended to show the intellectual power that comes from combining Foucauldian archaeology's pure analysis of discourse with Althusser's understanding of knowledge as the result of a process of production.

In the fifth chapter, I will conclude by articulating the coherence of our philosophy of science, showing how the theories of Althusser, Foucault, and Kuhn benefit from their combination.

Finally, I have included a pair of historical appendices. While I have tried to write this essay in a manner that will be accessible to both physicists and philosophers, I believe some readers might appreciate an overview of the relevant physics. These appendices narrate the transformation of classical physics into quantum mechanics and general relativity, reviewing the important characters: not only people but also important theories and experiments. I urge the reader to take these with caution, and to bracket, as much as possible, the continuity they foist on the fundamentally discontinuous history of physics.[4] The attentive reader will immediately recognize how they violate nearly all the tenets of Foucault's archaeology, which seeks to break down the enforced coherence of standard historical narratives. Aside from these appendices, I have tried to construct the body of this thesis according to the dictates of the archaeological method by producing an archive of physical knowledge. I hope that my attempt to aid the mathematically disinclined reader does not undermine that archaeological effort.

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[4] I offer these appendices of continuous history in the same way that Roland Barthes provides a "tutor text," Balzac's complete *Sarrasine*, at the end of *S/Z*. That said, my offer comes with the same plea: "We must further accept one last freedom: that of reading the text as if it had already been read. Those who like a good story may certainly turn to the end of the book and read the tutor text first; it is given as an appendix in its purity and continuity, as it came from the printer, in short, as we habitually read it. But for those of us who are trying to establish a plural, we cannot stop this plural at the gates of reading: the reading must also be plural, that is, without order of entrance: the 'first' version of a reading must be able to be its last, as though the text were reconstituted in order to achieve its artifice of continuity.... Rereading, an operation contrary to the commercial and ideological habits of our society, which would have us 'throw away' the story once it has been consumed ('devoured'), so that we can then move on to another story, buy another book, and which is tolerated only in certain marginal categories of readers (children, old people, and professors), rereading is here suggested at the outset, for it alone saves the text from repetition (those who fail to reread are obliged to read the same story everywhere)."

-Roland Barthes, *S/Z*. trans. Richard Miller. (New York: Hill and Wang, 1974), 15-6.

THE EMPIRICIST PROBLEMATIC OF CLASSICAL PHYSICS

In every treatise that is to be scientific, Reason must not slumber, and reflection must be actively applied. To him who looks at the world rationally, the world looks rational in return. The relation is mutual…. The movement of the solar system follows immutable laws. These laws are its Reason. But neither the sun, nor the planets that revolve around it according to these laws, have any consciousness of them.[1]

-G.W.F. Hegel, 1840

Physicists didn't spend the nineteenth century searching for the elusive luminiferous ether just because a list of great men assured them there was something to find. As far back as Newton's *Opticks*, prescient scientists had doubted the reality of a substance that had to be not only 700,000 times more elastic than air to support high-frequency vibrations but also 600,000,000 times less resistive than water to allow planets to flow through unimpeded.[2] Indeed, revolutionary discoveries in chemistry, thermodynamics, and electromagnetism had already proven other supposedly fundamental fluids to be nothing more than convenient myths. By the time Michelson and Morley built their fated ether-seeking interferometer,

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[1] G.W.F. Hegel. *Introduction to The Philosophy of History*, trans. Leo Rauch. (Indianapolis: Hackett, 1988), 14.

[2] Isaac Newton. *Opticks*. (1730) 4th ed. (New York: Dover, 1952), 352.

Lavoisier's theory of combustion had banished phlogiston as the fluid of fire, Thompson had shown particulate motion – not caloric flows – to be the source of heat, and Maxwell had established that electromagnetism was not the result of effluvia flows. These failures threw suspicion on a substance alleged to fill the whole universe without leaving a trace.

Despite these doubts, however, belief in the ether actually grew in strength during the 1800s. At the start of the nineteenth century, there had not seemed to be a theoretical need for such a substance. Since the beginning of a rivalry between Newton's corpuscular theory of light and Huygen's undulatory theory, the former had gained a decisive advantage. While Newton entertained both possibilities in his *Opticks*, he decided that light's straight-line paths, reflection, and refraction made sense only if light were composed of rays of particles speeding from its source. Huygen's explanation relied – many argued too heavily – on an analogy with sound waves. He suggested that diffraction and other phenomena implied that light propagates in waves through a universal, luminiferous ether.

So it was truly shocking when a British polymath named Thomas Young stood before the Royal Society on November 12, 1801, and announced that he had decisive evidence that light propagates by undulations. In the lecture, he hewed closely to the system Newton laid out in the last two books of *Opticks*, which Young argued was not as much of a polemic for crepuscularism as was usually assumed. He went back to the master's text and studied the rings of "inflexion," which we now know as diffraction. On this basis, Young formulated four hypotheses:

1. *A Luminiferous Ether pervades the Universe, rare and elastic in a high degree.*
2. *Undulations are excited in this Ether whenever a Body becomes luminous.*

> 3. *The Sensation of different Colours depends on the different frequency of Vibrations, excited by Light in the Retina.*
>
> 4. *All material Bodies have an Attraction for the ethereal Medium, by means of which it is accumulated within their substance, and for a small Distance around them, in a State of greater Density, but not of greater Elasticity.*[3]

The key to Young's discovery was the characteristic interference pattern resulting from diffraction in his famous double-slit experiment. While one would expect corpuscles of light to travel through the slits in a straight line, producing two bright spots directly behind the openings, diffraction produces a wide, complex pattern of light and dark fringes. Young appealed to his previous work on sound, easily identifying the distinctive pattern as the product of waves.

Young's resurrection of the wave theory of light couldn't have been a result forced along by desire, as he was met with "hostility, even vilification." Even though Young "went far out of his way to give full, even undue, credit to Newton, he still incurred the wrath of Newtonian orthodoxy for his irreverence."[4] The interference Young observed in his diffraction experiments could not be the product of corpuscular light; if two streams of light particles were to hit a screen at the same location, common sense dictated that the combination could only be additive. By its essential nature, matter could not annihilate other matter. Only multiple waves striking a surface out of phase with each other are capable of producing the kind of destructive interference responsible for the dark spots in the characteristic diffraction pattern. Young explains:

> Since every particle of the medium is affected by each undula-

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[3] Thomas Young, "The Bakerian Lecture: On the Theory of Light and Colours," *Phil. Trans. R.S.* 92: 14, 16, 18, 21 (1802).

[4] Loyd Swenson, *The Etherial Aether: A History of the Michaelson-Morley-Miller Aether-Drift Experiments, 1880-1930*. (Austin: Texas UP), 16.

> tion, wherever the directions coincide, the undulations can proceed no otherwise than by uniting their motions, so that the joint motion may be the sum or difference of the separate motions, accordingly as similar or dissimilar parts of the undulations are coincident…. it is well known that a similar cause produces in sound, that effect which is called a beat.[5]

These easily replicated demonstrations quickly convinced experimental physicists that light had to be composed of waves. Choosing one or the other form of matter was an implicit obligation of any theory that aspired to be counted as proper physics. When investigating the cause of light, Huygens constrained himself with the rule that "it is inconceivable to doubt that light consists in the motion of some sort of matter…. In the true Philosophy… one conceives the causes of all natural effects in terms of mechanical motions."[6]

In his lecture, Young worked strenuously to match his wave theory of light with contemporary ideas about the nature of matter and to expose connections that would unite light with other physical phenomena. For example, an undulatory theory connected light and heat by way of Thompson's mechanical theory of particulate vibration. Young judged it "highly probable that light differs from heat only in the frequency of its undulations or vibrations."[7] The lecture's most striking moment for the modern reader must surely be the adjustment of an erroneous experiment bestowing light with a quantity of momentum. He attributed this result to a poor experimental design that mistook the rising pressure of heated air on the illuminated side of a thin copper plate for the light corpuscles' combined momentum.[8] In response, he cited

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[5] Young, "Bakerian Lecture," *Phil. Trans. R.S.* 92: 34 (1802).

[6] Christiaan Huygens, *Treatise on Light,* trans. Silvanus P. Thompson. (Chicago: Chicago UP, 1912), 3. Accessed from Project Gutenberg e-Book, http://www.gutenberg.org.

[7] Young, "Bakerian Lecture," *Phil. Trans. R.S.* 92: 34 (1802), 47.

[8] Helmholtz's criticism of the experimental design would, in fact, be verified

a Mr. Bennett, who "repeated the experiment, with a much more sensible apparatus, and also in the absence of air; and very justly infers from its total failure, an argument in favor of the undulatory system of light."[9]

As the century wore on, the ether became increasingly essential to physicists' view of the universe. Every experiment or theoretical refinement that supported the notion that light travels in waves simultaneously reinforced the necessity and fine-tuned the details of the ether. Very simply, the ability of light waves to carry energy across the vast emptiness of space required that there be some substance that could be doing the waving. Moreover, theory required that the light energy reside in some substance during its finite travel time from a star to the Earth. An undulating ether filled this need. Although theory required the same apparently contradictory characteristics of the ether that had struck Newton as unrealistic centuries before, physicists used their creativity to get around the doubts of stubborn intuition. The concept of the ether was rooted in their understanding of matter's essential nature; it *had* to exist. So when Michelson and Morley's vaunted interferometer failed to detect the ether wind created by the Earth's motion through absolute space, the response was to develop a cogent theoretical explanation of the results, not to dispense with the entire concept. Nineteenth-century physicists recognized this infamous failed experiment as just another problem to be solved, not the first shot of an impending revolution.

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by later results. This erroneous *radiometer effect* – in which an illuminated, reflective surface experiences a pressure from heated gas – was the result of performing the experiment in poor vacua. Only with a vacuum better than 10^{-6} torr can the radiometer effect be minimized enough to detect the light's *actual* momentum, known as *radiation pressure*. The first precise measurement of this radiation pressure did not occur until 1923, by which time vacuum technology had sufficiently advanced.

-A.P. French, *Special Relativity*. (Boca Raton, FL: CRC Press, 1968), 14.

[9] Young, "Bakerian Lecture," *Phil. Trans. R.S.* 92: 34 (1802), 46.

> *Any object or problem situated on the terrain and within the horizon, i.e., in the definite structured field of the theoretical problematic of a given theoretical discipline, is visible. We must take these words literally. The sighting is thus no longer the act of an individual subject, endowed with the faculty of 'vision' which he exercises either attentively or distractedly; the sighting is the act of its structural conditions, it is the relation of immanent reflection between the field of the problematic and its objects and its problems. Vision then loses the religious privileges of divine reading: it is no more than a reflection of the immanent necessity that ties an object or problem to its conditions of existence, which lie in the conditions of its production. It is literally no longer the eye (the mind's eye) of a subject which sees what exists in the field defined by a theoretical problematic: it is this field itself which sees itself in the objects or problems it defines – sighting being merely the necessary reflection of the field on its objects.*[10]
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> *-Louis Althusser, 1965*

As long as a hard science is consistently producing results, there doesn't seem to be much need for the sometimes-tortured interventions of philosophy. While practitioners of the so-called "human sciences" must constantly defend the integrity of their disciplines, the physical scientists enjoy the easy benefits of working on the register of the empirical. During this period of *normal science*, discoveries flow smoothly from one to the next, facts build up to form a communal store of objective knowledge, and scientists' gazes penetrate more and more deeply into Nature. For practitioners of a firmly grounded discipline, such a period is characterized by a clear under-

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[10] Louis Althusser, "From *Capital* to Marx's Philosophy" in *Reading Capital*, 25.

standing of the world. They are happy, productive, and largely untroubled by philosophical timidity. Despite the continual frustrations of inconclusive experiments and the never-ending hunt for resources, normal science guarantees researchers not only an overarching sense of purpose but also a clear understanding of what they are doing and what they are doing it to.

Thomas Kuhn ascribes this sort of confidence in a discipline to the existence of a successful and unchallenged *paradigm*. When a science is dominated by a particular paradigm, its members share a certain worldview, which prescribes the proper tools and topics of research. A given paradigm is not restricted to a single individual; rather, it is a diffuse set of coherent beliefs about the world, and rules for the practice of a science. Its adoption permits a more or less frictionless exchange of ideas among far-flung laboratories. Particular paradigms gain acceptance "because they are more successful than their competitor in solving a few problems that the group of practitioners has come to recognize as acute." A paradigm need not explain everything about the world; if it did, then there would nothing left to research. Instead, its acceptance is based on "a promise of success discoverable in selected and still incomplete examples."[11]

Supported by the strength of a successful paradigm, scientists have a set of common methods and shared knowledge that they use to push their discipline forward. Only in this state can there be a period of normal science, which "consists in the actualization of [the paradigm's] promise, an actualization achieved by extending the knowledge of those facts that the paradigm displays as particularly revealing, by increasing the extent of the match between those facts and the paradigm's predictions, and by further articulation of the

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[11] Thomas Kuhn *The Structure of Scientific Revolutions*, 23.

paradigm itself."[12] This was precisely the situation in which nineteenth century physicists found themselves. Despite the many puzzles (such as the precise character of the ether) that remained to be solved completely, their mechanical theories grew increasingly secure. Judged by its ability to explain the problems of the day – celestial mechanics, optics, thermodynamics, and electromagnetism – physics appeared to be nearing completion.

Perhaps the most important effect of a paradigm's success is the necessary repression of vexing philosophical questions. When normal science reigns for a discipline, questions about its existence or purpose are replaced with the concrete facts and figures of research. The rules of normal scientific practice make lugubrious metaphysical debates unnecessary, freeing researchers' minds to focus on the puzzles of the day. The existence of a functioning paradigm, though likely invisible to its adherents, is evidence that these questions have been decisively answered.

Yet the fact that normal scientific practice occludes philosophical pondering does not imply that these researchers are pushing forward without a determinate philosophy of science. The philosophy has merely disappeared from view. Instead, they "'spontaneously' recognize the existence of philosophy," though this "recognition is generally unconscious…. It remains enveloped in the *forms* proper to unconscious recognition: these forms constitute the 'spontaneous philosophies of scientists.'"[13] These philosophies manifest themselves in the day-to-day practice of the scientists. Every time a physicist measures the spacing of diffraction fringes or a chemist tabulates the energy profile of a chemical reaction, his automatic interpretation and understanding betrays a litany of

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[12] *Ibid.,* 24.

[13] Louis Althusser, *Philosophy and the Spontaneous Philosophy of the Scientists*, trans. Gregory Elliott. (London: Verso, 1990), 109.

congealed theoretical commitments. In a 1967 lecture given as part of a "Philosophy Course for Scientists" at the École Normale Supérieure, Louis Althusser concluded that "inside every scientist, there sleeps a philosopher."[14]

Althusser focused his attention on the production of knowledge, and the most fundamental element of his epistemology is the *problematic*. Without trying to force a comparison between two independent theoretical structures, we might venture to understand the problematic in relation to Kuhn's more familiar concept of the *paradigm*. Whereas the paradigm is "a nest of commitments proved to be both metaphysical and methodological," the problematic is a far more subtle epistemological structure.[15] Both terms refer to structures that exist in thought and provide a coherent ground on which to ask properly formed research questions and erect a cogent theoretical edifice. A functional paradigm provides this stability to a science with a (possibly unspoken) set of rules that maintain a certain standard of normal scientific practice. In contrast, Althusser is concerned with "a fact peculiar to the very existence of science: it can pose problems on the terrain and within the horizon of a definite theoretical structure, its problematic, which constitutes its absolute and definite condition of possibility, and hence the absolute determination of *the forms in which all problems must be posed*, at any given moment in the science."[16] The problematic is not a set standard that ideas must reach in order to count as scientific. Rather, it is the absolute limit of comprehensibility for any idea at all.

Althusser builds the problematic by teasing apart the ubiquitous metaphor of knowledge as vision, its theoretical structure unraveling the stubborn visual metaphor. "Any ob-

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[14] *Ibid.,* 71, 111.

[15] Thomas Kuhn. *The Structure of Scientific Revolutions,* 41.

[16] Louis Althusser, "From Capital to Marx's Philosophy," in *Reading Capital*, 25.

ject or problem situated on the terrain and within the horizon, i.e., in the definite structured field of the theoretical problematic of a given theoretical discipline, is visible," he writes. "It is the field of the problematic that defines and structures the invisible as the defined excluded, *excluded* from the field of visibility and *defined* as excluded by the existence and peculiar structure of the field of the problematic."[17]

Every linguistic term, every line of math, every object of study is represented on and restricted by the terrain of a science's problematic. These elements all connect in a complex web of "necessary relations," which provide the coherence and intelligibility of the science's worldview. These elements have meanings only in virtue of their existence in the field of the problematic. Try to disengage them (for Althusser, a futile aspiration), and there would be nothing more than a thought without a mind or – even better, for the mathematically inclined reader – a tensor without a manifold. Similarly, Kuhn denies the possibility of doing science without any paradigm whatsoever. An existing paradigm is only abandoned in favor of a legitimate replacement.[18] The same rule applies to the problematic in Althusser's philosophy. Thus, the best way to understand a science, the only way to see what it sees, is to read the topography of its problematic.

> *Science regards the phenomena of the exterior world according to two processes of abstraction: in the first place it looks upon them as simple existences, without regard to their action upon our organs of sense or upon each other; in this aspect they are named matter. The existence of matter in itself is to us something tranquil and devoid of action: in it we distinguish merely the relations of space and of quan-*

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[17] *Ibid.*, 25-6.

[18] Thomas Kuhn. *The Structure of Scientific Revolutions,* 77.

> *tity (mass), which is assumed to be eternally unchangeable. To matter, thus regarded, we must not ascribe qualitative differences, for when we speak of different kinds of matter we refer to differences of action, that is, to differences in the forces of matter. Matter in itself can therefore partake of one change only – a change which has reference to space, that is, motion. Natural objects are not, however, thus passive; in fact we come to a knowledge of their existence solely from their actions upon our organs of sense, and infer from these actions a something which acts. When, therefore, we wish to make actual application of our idea of matter, we can only do it by means of a second abstraction, and ascribe to it properties which in the first case were excluded from our idea, namely, the capability of producing effects, or, in other words, of exerting force. It is evident that in the application of the ideas of matter and force to nature the two former should never be separated: a mass of pure matter would, as far as we and nature are concerned, be a nullity, inasmuch as no action could be wrought by it either upon our organs of sense or upon the remaining portion of nature. A pure force would be something, which must have a basis, and yet which has no basis, for the basis we name matter. It would be just as erroneous to define matter as something, which has an actual existence, and force as an idea which has no corresponding reality. Both, on the contrary, are abstractions from the actual, formed in precisely similar ways. Matter is only discernible by its forces, and not by itself.*[19]
>
> *-Hermann von Helmholtz, 1847*

From medieval observatories to nineteenth century laboratories, classical physicists took their science's *raison d'être* as the ability to explain the past and predict the future. Beginning with the motions of celestial objects, researchers

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[19] Hermann von Helmholtz, "On the Conservation of Force," in *Scientific Memoirs*, ed. John Tyndall and William Francis. (London: Taylor and Francis, 1853), 115-6.

sought out physical phenomena in order to make them intelligible. In an 1847 lecture, read before the Physical Society of Berlin, Hermann von Helmholtz argued that the goal of physics is to determine how physical phenomena are governed by a set of general laws of nature, and how one leads to the next. The science tackles this charge with a simple division of labor and a straightforward principle: "The finding out of these [phenomena] is the office of the experimental portion of our science. The theoretic portion seeks, on the contrary, to evolve the unknown causes of the processes from the visible actions, which they present; it seeks to comprehend these processes according to the laws of causality. We are justified… by the conviction that every change in nature *must* have a sufficient cause."[20] Regardless of the particular explanations in vogue at any moment in history, this ethic ensured a more-or-less steady production of knowledge from Galileo to the turn of the twentieth century. Those minor crises that did arise were taken care of and the offending results assimilated.

But this goal – a complete description of nature – cannot account for the far-reaching success of physical science alone. The real engine of discovery was a foundational belief about existence and causality known as *the mechanical view*, which held that "force and matter [are] the underlying concepts in all endeavors to understand nature."[21] The results of these "two processes of abstraction"[22] form an indissoluble pair of fundamental concepts along a familiar axis: noun, verb; presence, action; cause, effect. Alone, neither term is ponderable, but between them is the source of all knowledge of the physical world. Any physical system, no matter how complex, could be reduced to a superposition of individual

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[20] *Ibid.* p. 115

[21] Albert Einstein and Leopold Infeld, *The Evolution of Physics*. (Austin: Touchstone, 1967), 52.

[22] Hermann von Helmholtz, "On the Conservation of Force," in *Scientific Memoirs*. 115-6.

matter and forces. This conceptual pair captures the natural essence that the mechanical view ascribes to anything existing in the world.

Powered by the innovations of the Industrial Revolution, nineteenth-century technology grew increasingly refined; this permitted physicists to achieve an unprecedented degree of experimental precision. These results brought more and more evidence that motion is at the root of all phenomena. The kinetic theory of heat, which replaced the idea that heat was a fundamental fluid called "caloric," was the mechanical view's most compelling result. It suggested that gases are composed of an enormous number of particles in constant motion, with a characteristic range of velocities defined by temperature. Kinetic theory easily explained many experimentally observed behaviors of gases by means of straightforward mechanical logic. Pressure became the result of the constantly occurring collisions between gas particles and the wall of a container. Heat was no longer a special form of energy; rather, it was another manifestation of the familiar kinetic energy, known as *vis viva* to nineteenth century physicists.

Particulate motion proved a convenient way of connecting apparently disparate fields of physics, and whenever a theory accomplishes this sort of unification, it counts heavily in favor of correctness on all sides. Indeed, Young appealed to the smooth integration of the wave theory of light with kinetic theory of heat as evidence for the former: "The affections of heat may perhaps hereafter be rendered more intelligible to us; at present, it seems highly probable that light differs from heat only in the frequency of its undulations or vibrations."[23] This unity was soon extended further to include electromagnetism. In 1821, Fresnel had shown that light waves carried by the ether must be transverse (as opposed to longitudinal waves, like sound), accounting for its bi-directional polariza-

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[23] Young, "Bakerian Lecture," *Phil. Trans. R.S.* 92: 47 (1802).

tion. Later, Hertz observed that Maxwell's electromagnetic waves shared the same propagation speed and polarization properties as visible light. This suggested that the same type of wave caused these two phenomena. Consequently, these undulations shared the same medium: The luminiferous ether and the electromagnetic ether were declared to be identical. This was not a speculative result. While this ethereal unification was both aesthetically and ontologically pleasing (for it reduced the number of necessary objects), this unification was the result of rigorous analysis of the physical evidence.

Of course, physics was not entirely complete once the mechanical view united these disparate physical problems under the banner of molecular motion. Physicists still had to calculate these motions, and that meant extracting the essential data quantifying the matter and forces behind every vibration. According to Helmholtz, this success in the realm of theory left the science with a clear mission. Thanks to the mechanical view, "we discover the problem of physical natural science to be, to refer natural phenomena back to unchangeable attractive and repulsive forces, whose intensity depends solely upon distance. The solvability of this problem is the condition of the complete comprehensibility of nature."[24] With motion as the complete basis for everything, physics' ultimate goal of complete knowledge of the universe was within theoretical reach; only the practical difficulty of measurement remained. Considering the astonishing improvement in technology during the eighteenth century, the challenge of fully tabulating these data must have seemed eminently manageable.

The mechanical view serves as our way into classical physics' problematic, since the stipulation that all phenomena are the result of molecular motions precisely defines "the form

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[24] Hermann von Helmholtz, "On the Conservation of Force," in *Scientific Memoirs*. 117.

in which all problems must be posed."[25] Paradoxically, this problematic is both infinite and limited. It is infinite insofar as it contains everything, covers the world totally: Everything is physical; everything is mechanical; everything is motion. But simultaneously, the problematic is a fundamentally limited space. When everything is motion, nothing escapes the laws of mechanics, which are both symmetrical in time and tied to a given and meaningful coordinate system. (Among the many symptoms of this definition of the physical as mechanical was Planck's inability to *see* the fundamentally statistical nature of entropy, and thus explain why certain chemical reactions are irreversible.) The paradox of the problematic "is that it is an *infinite* because *definite* space, i.e., it has no limits, no external frontiers separating it from nothing, precisely because it is *defined* and limited within itself, carrying in itself the finitude of its definition, which, by excluding what it is not, makes it what it is."[26]

Despite the spatial metaphor, it is never an issue whether a particular object, concept, or question is inside or outside the field of a given problematic. Returning to the customary visual metaphor of knowledge, Althusser rejects the idea that the problematic has an inside/outside boundary in favor of a distinction between the visible and the invisible. This latter relation is neither mappable to the former nor simply demarcated on its own:

> In the development of a theory, the invisible of a visible field is not generally *anything whatever* outside and foreign to the visible defined by that field. The invisible is defined by the visible as *its* invisible, *its* forbidden vision: the invisible is not therefore simply what is outside the visible (to return to the spatial metaphor), the outer darkness of exclusion – but the *inner darkness of exclusion*, inside the visible itself because defined by its structure. In

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[25] Louis Althusser, "From Capital to Marx's Philosophy," in *Reading Capital.* 25.

[26] *Ibid.*

> other words, the seductive metaphors of the terrain, the horizon and hence the limits of a visible field defined by a given problematic threaten to induce a false idea of the nature of this field, if we think this field literally according to the spatial metaphor as a space limited by *another space outside it*.... In other words, all its limits are internal, it carried its outside inside it.[27]

The infinitude of the problematic accounts for its complete applicability. In the case of classical physics, there was no subset of physical phenomena immune to the advances of the mechanical view; the view was precisely that *everything* was at bottom a mechanical process determined by the quantities of forces and matter.

In this sense, the mechanical view relied on the expressive totality of physics: that a single, essential set of mechanical laws governs the universe, applying to matter of any size, with forces of any magnitude. Indeed, the celebrated fable of Newton sitting under the apple tree relies on exactly this epistemological conceit, since his grand discovery was that the force pulling the apple to the ground is the same gravity that keeps the planets in their orbits. This expressive totality "has a type of unity in which each element of the whole... is never anything more than the presence of the concept with itself at a historically determined moment."[28] As nineteenth-century technology permitted physicists to see farther and smaller, this situation – "in which each part is *pars totalis*, immediately expressing the whole that it inhabits" – was extended accordingly. Distant astronomical objects and microscopic particles were both governed by the same laws, subject to the same Reason.[29]

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[27] *Ibid.*, 26-7.

[28] Louis Althusser, "The Object of Capital," in *Reading Capital*, trans. Ben Brewster. (London: Verso, 1997). 94-5.

[29] This is the epistemology properly undergirding Richard Panek's description of Galileo's brand of scientific vision in *The Invisible Century* (New York: Viking, 2004).

The theoretical necessity of an expressive totality is only one of the characteristics of classical physics' problematic that suggest it was mired in a pervasive *empiricism*. This empiricism is not restricted to the rules of the science itself, as any scientific analysis "merely reflects in its lessons and rules the real culprit: the conception of knowledge underlying the object of knowledge."[30] So what is classical physics' *object of knowledge*? What did nineteenth century physicists take themselves to be working *on*? As a first-order approximation, we might say that they were carefully working on empirical objects to formulate theoretical concepts.

According to Althusser, an empiricist problematic sees the world through an "expressive reading, the open and barefaced reading of the essence in the existence."[31] The most fundamental assumption of this reading is the (implicit) belief that scientists are looking for something that might be found "out there," in the real world:

> For the empiricist conception of knowledge, the whole of knowledge is thus invested in the real, and knowledge never arises except as a relation inside its real object between the really distinct parts of that real object…. The inessential part occupies the whole of the outside of the object, its visible surface; while the essential part occupies the inside part of the real object, its invisible kernel. The relation between the visible and the invisible is therefore identical to the relation between the outside and the inside, between the dross and the kernel. If the essence is not immediately visible, it is because it is concealed, in the strong sense, i.e., entirely covered and enveloped by the dross of the inessential…. Discovery should be taken in its most literal sense: removing the covering, as the husk is removed from the nut, the peel from the fruit, the veil from the girl, the truth, the god or the statue.[32]

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[30] Louis Althusser, "From Capital to Marx's Philosophy," in *Reading Capital.* 34.

[31] *Ibid.*, 35.

[32] *Ibid.*, 37-9.

For nineteenth-century physicists aspiring to "the complete comprehensibility of nature," this direct epistemological access, this empiricism, was a necessity.[33] With the goal of discovering the foundational laws of Nature, physicists parsed complex natural systems in order to alight on the essential relations from which the relevant measurements might be taken. Reducing composite quantities to their constituent mechanics was exactly this stripping away of the inessential. By arguing that temperature was really nothing more than the underlying molecular motions, kinetic theorists were uncovering the essential core of thermodynamics. This reduction of abstract phenomena to concrete motions and forces grounded their knowledge in the actual masses and velocities of the particles, eliminating the inessential aggregate quantity 'temperature,' which was merely an intermediate step to exposing the essential mechanical reality.

> *"The empiricist conception of knowledge presents a process that takes place between a given object and a given subject.... [It relies on] an operation of the subject called abstraction. To know is to abstract from the real object its essence, the possession of which by the subject is then called knowledge.... The essence is abstracted from real objects in the sense of an extraction, as one might say that gold is extracted (i.e., separated) from the dross of earth and sand in which it is held and contained. Just as gold, before its abstraction, exists as gold unseparated from its dross in the dross itself, so the essence of the real exists as a real essence in the real, which contains it. Knowledge is an abstraction, in the strict sense, i.e., an extraction of the essence from the real, which contains it, a separation of the essence from the real, which contains it and keeps it in hiding."*[34]
>
> *-Louis Althusser, 1965*

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[33] Hermann von Helmholtz, "On the Conservation of Force," in *Scientific Memoirs*. 117.

[34] Louis Althusser, "From Capital to Marx's Philosophy," in *Reading Capital*. 35-6.

Rather than viewing itself as producing knowledge from a collection of raw materials, an empiricist science aims to uncover the essential truths already existing in the world. In this view, the collection of knowledge is akin to resource extraction, a metaphor that maps smoothly onto classical physics. Experimental physicists were the prospectors; they scoured the land for signs that there was something to find and staked out a promising piece of the world to explore in detail. Mathematical physicists came second. They separated and refined the crude intellectual ore, carefully removing the inessential bits of error and grime so as to derive the greatest value from the plot. The laws that emerged from this processing were neither contrived nor purely descriptive; they were merely calculable formulations of what was already there: the true "Reason in nature," the *Geist* of the matter.[35]

We have just seen that "for the empiricist conception of knowledge, the whole of knowledge is… invested in the real, and knowledge never arises except as a relation inside its real object, between the really distinct parts of that real object."[36] But just because the knowledge was there to be found does not mean that it was easy to access. Newton himself was motivated to write his *Principia* by this difficulty. He begins his masterpiece with a famous scholium in which he introduced the conceptions of "time, space, place, and motion" he would need to develop his physics. These are common terms, but that was precisely the reason he needed to be careful: "The vulgar conceive [these] quantities under no other notions but from the relation they bear to sensible objects. And thence arise certain prejudices, for the removing of which, it will be convenient to distinguish them into absolute and relative, true

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[35] G.W.F. Hegel. *Introduction to The Philosophy of History*. 14.

[36] Louis Althusser, "From Capital to Marx's Philosophy," in *Reading Capital*. 39.

and apparent, mathematical and common."[37] The logical universe in which Newton's famous laws of motion reigned required these absolute terms to give his mathematical formulations access to the essence of Nature.

These terms formed the backdrop against which all physical activity takes place, the ultimate reference to which all the laws of nature refer, and the source of all essential features of objects. It is the inert stage on which things moved, in which the given subject of classical physics – the scientist – encounters independently existing objets of study. There was "absolute, true and mathematical time, [which] of itself, and from its own nature flows equably without regard to anything external"; "absolute space, [which] in its own nature, without regard to anything external, remains always similar and immovable"; and "absolute motion, [which] is the translation of a body from one absolute place into another."[38] These measurements were inaccessible to the *vulgus* but necessary for any "philosophical disquisitions." They were the essential kernels of classical knowledge, the registers in which the universe's true order was manifest. Time, space, and motion each appear in a relative form, easily measurable in reference to other objects. Newton's physics was concerned with their experimental extraction and theoretical abstraction:

> Times and spaces are, as it were, the places as well of themselves as of all other things. All things are placed in time as to order of succession and in space as to order of situation. It is from their essence or nature that they are places; and that the primary places of things should be moveable, is absurd. These are therefore the absolute places, and translations out of those places are the only absolute motions.
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> But because the parts of space cannot be seen or distinguished from one another by our sense, therefore in their stead we use

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[37] Isaac Newton. *Principia* (1687) in *On the Shoulders of Giants* ed. Stephen Hawking (Philadelphia: Running Press, 2002), 737.

[38] *Ibid.*, 738.

> sensible measures of them. For from the positions and distances of things from any body considered as immovable, we define bodies as transferred from some of those places into others. And so, instead of absolute places and motions, we use relative ones; and that without any inconvenience in common affairs; but in philosophical disquisitions, we ought to abstract from our senses, and consider things themselves, distinct from what are only sensible measure of them. For it may be that there is no body really at [absolute] rest, to which the places and motions of others may be referred.[39]

Newton posits these unique systems of reference as absolute and universal, despite the difficulty of apprehending them. To access these essential truths, and thus determine the ultimate laws of nature, it is necessary to carefully parse one's sense perceptions.

Newton's final line, which suggests that nothing might be truly at rest in absolute space, is significant. It underscores how these concepts of absolute space and time are embedded into Nature and might very well lie beyond all capacity for perception (since we sense qualities of things only in relation to each other). But solid physical knowledge must be determined in reference to these absolutes. Inertia is for Newton a feature of a massive body in absolute space. Forces induce changes to the body's absolute motion. Thus, Newton devises measurement schemes and correction equations to extract what he needs from what he has. This vexing empirical problem is identical to the one that faced the nineteenth-century ether detectives, who were occupied with the discovery of something just as elusive and essential. Indeed, one might read the ether of classical electromagnetism as being precisely the reference of absolute rest in true space that Newton sought.

These efforts – the homologous search for the ether and the extraction of absolute quantities – were neither easy nor optional. The empiricist problematic of classical physics required *both* to be found, despite the innate difficulties.

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[39] *Ibid.*, 739.

Without these essences, the entire edifice of physical theory would be unreasonable. Newton underscores the importance of the search for such essential knowledge in the final lines of his scholium, which suggest that this extraction is the objective of his nascent science: "How we are to collect the true motions from their causes, effects, and apparent differences and *vice versa*… shall be explained more at large in the following tract. For to this end it was that I composed it."[40]

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[40] *Ibid.*, 743.

THE OLYMPIA ACADEMY

> *We shall see that there are several kinds of hypotheses; that some are verifiable, and when once confirmed by experiment become truths of great fertility; that others may be useful to us in fixing our ideas; and finally, that others are hypotheses only in appearance, and reduce to definitions or to conventions in disguise. The latter are to be met with especially in mathematics and in the science to which it is applied. From them, indeed, the sciences derive their rigor; such conventions are the result of the unrestricted activity of the mind, which in this domain recognizes no obstacle. For here the mind may affirm because it lays down its own laws; but let us clearly understand that while these laws are imposed on our science, which otherwise could not exist, they are not imposed on Nature. Are they then arbitrary? No; for if they were, they would not be fertile. Experience leaves us our freedom of choice, but it guides us by helping us to discern the most convenient path to follow. Our laws are therefore like those of an absolute monarch, who is wise and consults his council of state.*[1]
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> *-Henri Poincaré, 1902*

In 1902, two years after graduating fourth in his class of five at the Zurich Polytechnic, Albert Einstein abandoned his search for a proper academic appointment. Thanks to the machinations of his schoolmate, Marcel Grossman, the patent office in the Swiss city of Bern offered Einstein the posi-

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[1] Henri Poincaré, *Science and Hypothesis*, (New York: Dover, 1952), xxii-xxiii.

tion of "Technical Expert Class 3 of the Federal Office for Intellectual Property with an annual salary of 3,500 francs."[2] Although his new position was of "the lowest rank" and said to be incredibly boring, Einstein was happy to have a steady source of income. After living with his parents in Milan and subsisting on the proceeds of his occasional private tutoring jobs, he was happy to be set up on his own. He spent six days a week at the office, reviewing the technical details of patent applications. Although he arrived at 8 am and spent eight hours sitting at his desk, he was able to slip in plenty of time for his own thinking. "I was able to do a full day's work in only two or three hours," he recalled later on. "The remaining part of the day, I would work on my own ideas."[3]

Although he was completely removed from the atmosphere of the academy, Einstein did not lack intellectual camaraderie. In the spring of 1902, Einstein placed an ad offering physics tutorials in a Bern newspaper. Maurice Solovine, a Romanian student at the University of Bern, saw the advertisement and called on Einstein. After two-and-a-half hours of conversation, the pair decided to begin meeting. During the third session, Einstein decided he had had enough of the arrangement. "You don't have to be tutored in physics," he told Solovine. "Just come see me when you want and I will be glad to talk with you."[4] They were soon joined by Conrad Habicht, who had studied mathematics at Einstein's alma mater. Mocking the self-important scholarly societies of their day, the trio called themselves the Olympia Academy and elected Einstein president.[5]

Despite the lighthearted nature of their Academy, it would end up being a revolutionary club, with far more in-

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[2] Walter Isaacson, *Einstein: His Life and Universe*, (New York: Simon and Schuster, 2007), 77.

[3] *Ibid.*, 78.

[4] *Ibid.*, 80.

[5] *Ibid.*, 80

fluence on the history of thought than most of the proper societies. In three short years, the radical ideas considered by the Olympia Academy would inspire Einstein to question the fundamental assumptions of classical physics in a flurry of intellectual activity. Together, the four short papers that comprise Einstein's 1905 *annus mirabilis* took on nearly every major physical problem of the nineteenth century and catapulted the humble president of the Olympia Academy from academic exile to international fame.

Over frugal dinners of sausage, Gruyère, fruit, and tea, the members of the Olympia Academy poured through philosophical texts, continuing to talk until morning. Sometimes, they would hike up a nearby mountain to watch the sun rise over the Swiss Alps. In addition to classics of literature, the Academy's reading list included David Hume's *A Treatise of human Nature,* Ernst Mach's *Analysis of Sensations* and *Mechanics and Its Development*, Baruch Spinoza's *Ethics*, and Henri Poincaré's *Science and Hypothesis.*[6] Hume's skepticism toward the possibility of *a priori* truth motivated Einstein to question the assertions of physical entities that eluded observation. Chief among these were the absolute space and time at the core of Newtonian mechanics. According to Hume, the mind is incapable of grasping an independently flowing time. Our only access to the idea of time comes through the succession of events: "As 'tis from the disposition of visible and tangible objects we receive the idea of space, so from the succession of ideas and impressions we form the idea of time, nor is it possible for time alone ever to make its appearance, or be taken notice of by the mind."[7] This identification of time with the observation of successive moments would be a powerful motivator or Einstein's soon-to-be invented special theory of

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[6] *Ibid.*, 81

[7] David Hume, *A Treatise on Human Nature*. (Oxford: Clarendon Press, 1896), 35.

relativity.

But Hume's empiricism was only one of several philosophies discussed by the Olympia Academy at their meetings in Bern. Two of the trio's favorite authors – Mach and Poincaré – wrote specifically about the physics of the day, criticizing a science that relied upon increasingly baroque, *ad hoc* solutions to stubborn problems but considered itself to be nearly complete. Reading these texts in the wake of Einstein's work on special relativity and quantum theory, they appear to be intensely suggestive of what was to emerge in the *annus mirabilis* papers. Indeed, analyzing the concerns that Mach and Poincaré raise in their lectures and essays provides us with a powerful tool with which we might more clearly understand the driving force behind Einstein's brilliant critiques.

Mach's primary philosophical concern was restricting the explanations of physical theories to observable phenomena.[8] Einstein attributed the care with which Mach approached physical problems to his "incorruptible skepticism and independence," which permitted him to critically examine the process of scientific thought.[9] Going beyond analysis of the specific assumptions undergirding physical theories, Mach concerned himself with dissecting the ways in which physical knowledge was produced. "It is the object of science," he wrote, "to replace, or *save*, experiences, by the reproduction and anticipation of facts in thought.... This economical office of science, which fills its whole life, is apparent at first glance; and with its full recognition all mysticism in science disappears."[10]

Working with this metaphor of science as an economical process, he denied the transparency of any aspect of the

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[8] Walter Isaacson, *Einstein,* 83 FN84

[9] *Ibid.,* 83. FN83

[10] Ernst Mach, *The Science of Mechanics*. Trans. Thomas J. McCormack. (Chicago: Open Court, 1902), 481.

production of scientific knowledge. Language, observation, even instruction deserve attention, since they each affect the ways in which scientists construct the objects of their investigations. For Mach, neither facts nor things are given to scientists in the world. Instead, there is a "reproduction of facts in thought," a process that he describes as abstraction. This is necessary because "no inalterable thing exists. The thing is an abstraction, the name a symbol, for a compound of elements from whose changes we abstract."[11] Previously, we discussed how Althusser identifies a theory of knowledge rooted in abstraction as empiricism, and one can apply this label to Mach with both historical and philosophical accuracy. But this abstraction is not the simplistic version Althusser rejects. Mach's philosophy recognizes the extent to which this abstraction process is contingent on choices, legacies, conveniences, and happenstance. In short, it depends on the action of men.

Despite Mach's emphasis on abstraction, he does suggest that there is an irreducible gap between the "things" on which scientists work and the real world in which they live. Mach maintains that it is an "absurdity" to think that one has "recourse to the conception of a thing-in-itself. Sensations are not signs of things, but, on the contrary, a thing is a thought-symbol for a compound sensation of relative fixedness. Properly speaking, the world is not composed of 'things' as its elements, but… what we call individual sensations."[12] The way Mach positions sensations here is key; he argues that one is restricted to starting with one's sensations and then building an object in thought, a "thing," from those raw materials. It is in this construction of a "thing" to be studied that Mach sees "science" happening. And it seems that Einstein took seriously this concern for the production, in thought, of the object on which a scientist goes to work. In an obituary pub-

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[11] Ernst Mach, *The Science of Mechanics,* 482.

[12] *Ibid.,* 483.

lished after his death in 1916, Einstein summed up Mach's philosophy: "Concepts have meaning only if we can point to the objects to which they refer and to the rules by which they are assigned to these objects."

Poincaré's *Science and Hypothesis* is also said to have been one of the Olympia Academy's favorites.[13] The book is filled with both heavily philosophical and rigorously scientific thought, a combination that was appropriate to the French polymath. This distinctive combination of abstract thought experiments and thoughtful criticisms of physics' unthought assumptions has strong echoes in Einstein's work. In his *Einstein's Clocks, Poincaré's Maps*, Peter Galison credits Poincaré's education at the Ecole Polytechnique for cultivating this flexible style of thinking. The Ecole, founded in 1794 to produce "a fraternity rigorously school in a mathematics-based engineering" that would manage the state and modernize its military, prized an "alliance of theory with practice." Poincaré, and his "contemporary Polytechnicians maintained a lifelong commitment to the link between abstract and concrete knowledge" that enabled them to serve as high-ranking ministers in government and international leaders in science.[14] For Galison, this "factory stamp" of the Polytechnique and his subsequent experience as the president of the *Bureau des Longitudes* were as important in forging the penetrating character of Poincaré's intellect as the work at the patent office was to Einstein's.

Poincaré is a critic of science, in the sense that he aims to understand capacities and determine limits of possibility. He begins *Science and Hypothesis* by describing a naïve impression of knowledge:

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[13] Walter Isaacson, *Einstein,* 125.

[14] Peter Galison, *Einstein's Clocks, Poincaré's Maps*. (New York: W.W. Norton, 2003), 49-53.

> To the superficial observer, scientific truth is unassailable, the logic of science is infallible; and if scientific men sometimes make mistakes, it is because they have not understood the rules of the game. Mathematical truths are derived from a few self-evident propositions, by a chain of flawless reasonings; they are imposed not only on us, but on Nature itself. By them the Creator is fettered, as it were, and His choice is limited to a relatively small number of solutions. A few experiments, therefore, will be sufficient to enable us to determine what choice He has made. From each experiment a number of consequences will follow by a series of mathematical deductions and in this way each of them will reveal to us a corner of the universe. This, to the minds of most people, and to students who are getting their first ideas of physics, is the origin of certainty in science.[15]

This view of scientific knowledge as revelation should be familiar from our discussion of classical physics. In its search for the laws of nature embedded in real things of the world, it is the essence of the empiricism Althusser decries. Rather than embracing a radical skepticism and issuing a "summary condemnation," Poincaré adopts a subtle analysis of the role of hypothesis in science, and finds that "not only is it necessary, but that in most cases it is legitimate." He distinguishes three types of hypotheses: some that are verifiable by experiment, some that aid in building a theory, and "others [that] are hypotheses only in appearance, and reduce to definitions or to conventions in disguise."[16] The book, which focuses on teasing out previously unrecognized hypotheses of the third type, clearly made an impression on the young Einstein. In 1905, he would display his keen understanding of each form of hypothesis on the way to formulating special relativity and his theory of light quanta.

Poincaré knew the importance of establishing conventions better than anyone else, conventions that were singularly relevant to the problems of Newtonian mechanics. As the president of the *Bureau des Longitudes*, he carried out an

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[15] Henri Poincaré, *Science and Hypothesis*, xxi

[16] *Ibid.*, xxii

imperial project to accurately map the world. As the name of his office suggests, this amounted to measuring longitude. Sailors, whose navigation demanded the greatest possible accuracy, have struggled to measure their east-west position for millennia. While sextants make latitude easy to measure by a single astronomical observation, the calculation of longitude requires the navigator to compare the state of the sky at his position to the simultaneous positions of the stars at a known location. Thus, accurate cartography ultimately reduced to a problem of time synchronization. Because it was nearly impossible to transport a mechanical clock to the far reaches of the empire and maintain strict synchronicity with a clock sitting in an observatory thousands of miles away, mapmaking's precision improved substantially with the invention of the telegraph, and later, the radio, which carried time signals from the Eiffel Tower to South America at the speed of light.[17] Poincaré led the effort to turn these new technologies into an effective and accurate clock synchronization system, with complex protocols for the transmission and calibration of the empire's far-flung observatory network. His problem was not to track Newton's "absolute, true, and mathematical time, [which] of itself, and from its own nature, flows equably without relation to anything external" but rather to ensure that clocks separated by vast distances always displayed the precise French time, which was defined by the master clock at the Paris Observatory.[18]

Consistent with his Polytechnique training, Poincaré brought this experience to bear in his criticisms of Newtonian mechanics. If he had a guiding ethos, it might have been that "some hypotheses are dangerous – first and foremost those which are tacit and unconscious. And since we make them

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[17] Peter Galison, *Einstein's Clocks, Poincaré's Maps,* 276.

[18] Isaac Newton, *Principia*, 738.

without knowing them, we cannot get rid of them."[19] The classically required absolute space and time were the two most frequent targets of his critiques, which exposed the conventionalism of these ideas. The problem was not the presence of the conventions themselves, since he viewed these as a necessary part of the construction of a scientist's object of study. He rejected the tacit assumption that these absolute entities were intrinsic to and required by Nature, not by man. He aimed to show how these conventions take the raw materials of measurable sensations in the world and produced, in thought, a coherent object of study.

He dismissed attempts to detect the ether and rejected the neutralizing theories of Fresnel, Lorentz, and others as *ad hoc* rationalizations for the inability of experiments to render its effects visible. ("An explanation was necessary, and was forthcoming; they always are; hypotheses are what we lack the least."[20]) Poincaré was able to do this with confidence, since he understood that the fundamental laws of mechanics rendered the ether necessary to support Maxwell's electromagnetic waves and serve as the reference for Newton's absolute motion: "The ether was invented to escape this breaking down of the laws of general mechanics…. If we did not wish to change the whole of the science of mechanics, we should have to introduce the ether, in order that the action which matter apparently undergoes should be counterbalanced by the re-action of matter on something."[21] For Poincaré, the ether had to exist to satisfy the Newtonian conventions that physicists mistook as real requirements imposed by Nature on mechanics. He did not find this logical necessity to be compelling evidence about the real world.

With respect to time, Poincaré argues that the implicit

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[19] Henri Poincaré, *Science and Hypothesis*, 151.

[20] *Ibid.,* 172.

[21] *Ibid.,* 170.

requirements of Newton's mechanics produced an even more confused theoretical situation, one in which artifacts of human psychology are mistakenly attributed to Nature itself. In his classic essay "The Measure of Time," he does not begin with the absolute time of Newtonian differential equations but rather with "the domain of consciousness, [in which] the notion of time is relatively clear."[22] Forgoing the notion of a universal time and starting from conscious experiences of succession and simultaneity, physics faces two substantial problems in the construction of a usable idea of time: "(1) Can we transform psychologic time, which is qualitative, into a quantitative time? (2) Can we reduce to one and the same measure facts which transpire in different worlds?"[23] Whereas Newtonianism takes absolute time as a given feature of the world that flows according to the natural laws physicists seek to reveal, Poincaré suggests that the scientist's first obligation is to construct time as a quantitative, coherent object before he can being to calculate anything.

It should not take the reader by surprise to learn that Poincaré does not consider the construction of an idea of time to be an easy, automatic, or transparent process. The key to the first problem is that "we have not a direct intuition of the equality of two intervals of time."[24] Any quantitative statement about time is necessarily the product of a measurement. In other words, time must be defined. For these measurements to serve as the basis for a rigorous scientific practice, the scientist must establish conventions by which they will be undertaken. Whatever the chosen standard of measurement, the strongest statement one can make about a given duration is that it has a certain magnitude relative to the convention-

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[22] Henri Poincaré, "The Measure of Time," in *The Foundations of Science*, trans. George Bruce Halsted. (New York: The Science Press, 1921), 223.

[23] *Ibid.*, 224.

[24] *Ibid.*

ally determined timekeeper. And even here, the physicist is not standing on solid ground, since the regularity of any motion – whether it is the period of a pendulum, the rotation of the Earth, or the decay of an atomic nucleus – is guaranteed only by a set of physical theories that take the passage of time as a metaphysical given and a mathematical variable. Poincaré goes to great lengths to prove to his readers that there is no way of escaping this logical loop, "that all these affirmations have by themselves no meaning. They can have one only as the outcome of a convention."[25] Galison argues that Poincaré developed this belief in the absolute necessity of convention during his time at the *Bureau des Longitudes*. There, the technical problem of long-distance timekeeping required a complex set of conventions in order to yield a global French time, accurately coordinated with the Paris Observatory's master clock.[26]

But even after settling on a convention by which the psychological notion of succession might be rendered a quantitative fact, Poincaré argues that one must figure out how to put "into the same frame so many worlds impenetrable to one another."[27] In the first instance, this is a problem of aligning the experiences of different consciousnesses, each perceiving an independent pattern of succession. But beyond since this problem might be surmounted with a suitable convention for measuring time, Poincaré's second problem becomes an issue of the temporal dimension of spatial separation. In his characteristically clearheaded way, Poincaré sums up the difficulties with a penetrating question: "Is not my present nearer my past of yesterday than the present of Sirius?"[28] To formulate a workable answer, one ties oneself up in a complex series of

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[25] *Ibid.,* 228.

[26] Peter Galison, *Einstein's Clocks, Poincaré's Maps*, 84-98.

[27] Henri Poincaré, "The Measure of Time," in *The Foundations of Science*, 228.

[28] *Ibid.,* 229.

questions about connecting cause and effect with determinate physical theories and defining succession and simultaneity. In thinking about a distant event, one has merely the sense impressions conveyed by a light or a sound, sense impressions that one inferentially connected as effects to a given cause. Even taking the velocity of transmission into account – as one does in astronomy or the sort of longitude measurements supervised by Poincaré – fails to eliminate the problem, since "such a velocity could not be measured without *measuring* a time."[29]

By design, Poincaré concludes without proposing a method by which one might escape this apparent tautology. Without a direct intuition of either simultaneity or the equality of two durations, there is no ground on which to think that time is absolute or given to scientists as a set of facts existing in the world. Therefore, science is restricted to constructing an idea of time by means of conventions and measurements. Fundamentally, time is not found. It is defined by a set of rules:

> These rules are not imposed upon us and we might amuse ourselves by inventing others; but they could not be cast aside without greatly complicating the enunciation of the laws of physics, mechanics, and astronomy. We therefore choose these rules, not because they are true, but because they are the most convenient, and we may recapitulate them as follows: "The simultaneity of two events, or the order of their succession, the equality of two durations, are to be so defined that the enunciation of the natural laws may be as simple as possible. In other words, all these rules, all these definitions are only the fruit of an unconscious opportunism.[30]

One is hard-pressed to read Einstein's 1905 paper on special relativity without perceiving echoes of Poincaré in a new mechanics that replaces Newton's absolutes with the conventions of possible measurement. Indeed, one can only

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[29] *Ibid.,* 234.

[30] *Ibid.*

imagine the fervor with which the members of the Olympia Academy must have debated these ideas on their midnight hikes in the Swiss Alps.

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For most Anglo-American philosophers, epistemology reduces to *the problem of knowledge*. Traditionally, philosophers answer this question with as simple a definition of knowledge as possible, a definition that presents itself in the form of a universally applicable test. Philosophers then deploy this definition to evaluate given statements or propositions, which are the currency of knowledge in analytic thought. In this conception, epistemology is "dominated by the 'problem' of the criteria by which a knowledge can be judged." The goal is to find a suitable "guarantee of its truth," which could be deployed as a bulwark against analytic philosophy's ultimate enemy: skepticism.[31] With the answer that knowledge is justified true belief, analytic philosophy considered the problem to be definitively solved. This account is contained in the following three necessary and jointly sufficient conditions:

> *A subject S knows that proposition P if and only if:*
> *i.* *P* is true.
> *ii.* *S* believes that *P* is true.
> *iii.* *S* is justified in believing that *P* is true.[32]

This account was satisfactory, at least insofar as one could give a compelling account of the "good reasons" undergirding justification. That they could trace a version of this theory back to Plato's *Theaetetus* provided analytic philoso-

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[31] Ben Brewster, "Glossary" in *Reading Capital,* 314.

[32] Richard Feldman, *Epistemology*, (Saddle River, NJ: Prentice Hall, 2003), 15.

phers with a great deal of encouragement.[33]

This was the comfortable state of affairs until 1963, when Edmund Gettier sowed the seeds of doubt with an essay, called "Is Justified True Belief Knowledge?" In this three-page paper, he posed a series of thought experiments in which a subject can be said to "know" a given proposition according to the justified true belief test reproduced above, even though philosophical intuition suggests otherwise. In these examples – known afterwards in the literature as Gettier cases and easily rehashed according to a well-established formula – subjects hold true, justified beliefs by mistake, thanks to propositions mischievously crafted with either disjunctive or transitive logic.[34] With their apparently secure discipline in shambles, analytic epistemologists set off in a race to craft a new answer to the problem of knowledge able to correctly handle the Gettier examples. They continue in pursuit of this goal today.

In *Reading Capital*, Althusser explicitly repudiates this problem of knowledge as the centerpiece of an "ideological philosophy." The terms *ideology* and *ideological* occupy important positions in Althusser's thought, but they are notoriously difficult to pin down in a single text, let along across his *oeuvre*. Some read this characteristic elusiveness as a useful way of building a series of philosophical structures without resorting to inflexible axiomatic logic. Others find it frustrating and accuse his ideas of lacking any serviceable meaning. Working at least provisionally with the former attitude, I take one of the tasks of this work to be situating the ideological, particularly in relation to its frequent counterpart, the scientific. Fortunately, Althusser provides an unusually lucid explanation of his absolute rejection of the problem of knowledge:

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[33] Sven Bernecker and Fred Dretske, "Introduction," in *Knowledge.* ed. Sven Bernecker and Fred Dretske (Oxford: Oxford UP, 2000). 3.

[34] Edmund L. Gettier "Is Justified True Belief Knowledge?" in *Knowledge.* ed. Sven Bernecker and Fred Dretske. (Oxford: Oxford UP, 2000), 13.

> In the theoretical mode of production of ideology (which is utterly different from the theoretical mode of production of science in this respect), the formation of a *problem* is merely the theoretical expression of the conditions which allow a *solution* already produced outside the process of knowledge because imposed by extra-theoretical instances and exigencies *to recognize itself* in an artificial problem manufactured to serve it both as a theoretical mirror and as a practical justification…. The whole history of Western philosophy is dominated not by the 'problem of knowledge,' but by the ideological *solution*, i.e., the solution imposed in advance by practical, religious, ethical, and political 'interests' foreign to the reality of knowledge, which this 'problem' had to receive.[35]

What, then, is the ideological solution for which the traditional problem of knowledge was posed? It is the sort of functional, logical test by which the truth of a proposition might be guaranteed. That the discipline lost this solution, which it believed it had held for millennia, in the space of three pages accounts for the trauma of the Gettier paper. And the extra-theoretical exigency that demanded such a sturdy guarantee of truth and began this "vicious circle"? It is precisely the fear motivating much of the analytic project: the perpetually looming skepticism that threatens to undermine belief in all of our truths, most importantly the Truth of God. One solves the traditional problem of knowledge by applying a test and getting a "yes" or "no" answer. So long as analytic epistemology categorizes propositions as either knowledge or not according to a logical test, there will be no place in its theoretical apparatus for ideology.

In the quote above, we see the strongest evidence yet of the Marxist logic intrinsic to Althusser's philosophy. Whether or not this philosophy is deployed in his familiar polemical style (the *raison d'être* of Althusser's epistemology was to prove that Marxism is a properly founded science, a debate from which this work abstains), he understands knowledge

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[35] Louis Althusser, "From *Capital* to Marx's Philosophy" in *Reading Capital*, 52-3.

to be something that is *produced*. In a structure homologous with the Marxist theory of commodity production, Althusser's epistemology sees the production process of knowledge as transforming a set of *raw materials* with a historically determinate *means of production*, according to an associated set of conditions. And just as Marxism replaces Adam Smith's universal and trans-historical classical liberalism with historical materialism, a theory (Althusser would say a science) of history, Althusser forges an epistemology in which time matters. Compared to the timelessness of ideological philosophy's problem of knowledge, this is a radical step.

But Althusser does not produce the necessary history of knowledge by merely collecting previously cataloged facts. This traditional approach, which Althusser traces to the ideology of the Enlightenment, treats knowledge as a pile of true propositions, consistent with the epistemic ideas of analytic philosophy. Such "idealist rationalism" is "the effect of the retrospective illusion of a given historical result which writes its history in the 'future anterior,' and which therefore thinks its origin as the anticipation of its end."[36] The first criterion of the justified true belief view given above (*P* is true) is applied in just this retrospective sense. Analytic epistemology usually defines the truth of a proposition by its correspondence to allegedly neutral facts about the world.[37] Insofar as these facts are those given by the reigning theory, what was in its time thought to be rigorous "knowledge" (e.g. the Universe is static) is later revealed to be untrue. The result – a Hegelian story in which Reason inevitably triumphs over ignorance – reassures holders of present day knowledge by depicting all strands of thought converging on the *telos* of contemporary science. The continuity of a narrative told in the future anterior all-but guarantees that current knowledge is funda-

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[36] *Ibid.*, 44

[37] Richard Feldman, *Epistemology*, 17-21.

mentally valid, even if current theories marginally improve in the future. Indeed, this aptly describes the self-consciousness of physicists at the turn of the twentieth century: Whatever refinements remained, they were sure their science properly grasped the Reason of the physical world.

This "teleology of reason" cannot suffice for Althusser's epistemology. Looking to his former student, Michel Foucault, for inspiration, Althusser argues for a different approach, one that questions the unities that smoothly develop along continuous histories:

> The real history of the development of knowledge appears to us today to be subject to laws quite different from this teleological hope for the religious triumph of reason. We are beginning to conceive this history as a history punctuated by radical discontinuities (e.g., when a new science detaches itself from the background of earlier ideological formations), profound reorganizations which… inaugurate with their rupture the reign of a new logic, which, far from being a mere development, the 'truth,' or 'inversion' of the old on, *literally takes its place*.[38]

Traditionally, "discontinuity was the stigma of temporal dislocation that it was the historian's task to remove from history."[39] Historians of continuity sutured these ruptures by transforming them into moments when causality, influence, and evolution help a subject to see what had previously eluded Reason. But Althusser values these revolutions in thought because in this relief they allow one to think a difference in which new objects, new problems, and new phenomena become visible. These eureka moments are the products of radical changes in the underlying epistemological structures, discontinuities that wreck the linearity of the usual history of ideas. In this mode, discontinuity "constitutes a deliberate operation on the part of the historian," a tool that brings funda-

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[38] Louis Althusser, "From Capital to Marx's Philosophy," in *Reading Capital*, 44.

[39] Michel Foucault, *The Archaeology of Knowledge,* trans. Rupert Swyer. (New York: Pantheon, 1972), 8.

mental changes into relief.[40]

Both Althusser and Foucault privilege moments of rupture – and articulate their discontinuous histories around these singularities – because "making historical analysis the discourse of the continuous and making human consciousness the original subject of all historical development and all action are the two sides of the same system of thought. In this system, time is conceived in terms of totalization and revolutions are never more than moments of consciousness."[41] This is the same empiricist error that takes discovery to be a heroic act, the unprecedented sighting of a really existing fact that the great man's predecessors overlooked. In the teleology of Reason intrinsic to continuous history, knowledge is reduced to a collection of facts, slowly accumulated over time and corresponding to the linear progress of human consciousness toward perfection. This is the attitude that reigns during a period Kuhn would call normal science. Like the traditional problem of knowledge, continuous history takes the form of a "guarantee that everything that has eluded [the subject] may be restored to him; the certainty that time will disperse nothing without restoring it in a reconstituted unity; the promise that one day the subject – in the form of historical consciousness – will once again be able to appropriate, to bring back under his sway, all those things that are kept at a distance by difference, and find in them what might be called his abode."[42] Indeed, continuity is a necessary condition of the traditional account of knowledge, since a transhistorical test of truth or knowledge only makes sense if nothing every really changes except the distance left between man and Truth.

Althusser advocates a telling of history that under-

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[40] *Ibid.,* 8.

[41] *Ibid.,* 12.

[42] Louis Althusser, "From Capital to Marx's Philosophy," in *Reading Capital*, 44.

stands knowledges on their own terms, rather than as incorrect but necessary steps on the way to today's truth. This means resisting any teleological view that "conceives the historical relation between a result and its conditions of existence as a relation of… expression."[43] Here, he continues to position himself against Hegel, who sees history as the dialectical movement towards self-conscious reason. Instead of this Idealist view, which sees the rational spirit embedded in every stage of a necessary historical development, Althusser argues that a given historical knowledges is connected by a relation production to a necessarily contingent theoretical conjuncture. To understand this relation requires that we "grasp the very special and paradoxical logic that leads to this *production*…. [We must] treat the ideology which constitutes the prehistory of a science… as a real history with its own laws and as the real prehistory whose real confrontation with other technical practices and other ideological or scientific acquisitions was capable, in a specific *theoretical conjuncture*, of producing the arrival of a science, not as its goal, but as its surprise."[44] As an example of a history that takes a discredited science at its word to understand the production of a science, he cites Foucault's *Madness and Civilization* and *Birth of the Clinic*.

Indeed, Foucault's *archaeology* seems to be the developed theory of history necessary for a fully coherent Althusserian epistemology. In *The Aracheology of Knowledge*, written after he completed the two studies Althusser cited, Foucault lays out a theory and methodology that he says he hopes will supplant the "ideological use of history, by which one tries to restore to man everything that has unceasingly eluded him."[45] Archaeology holds in abeyance the standard unities by which historians usually parse their documents: the

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[43] *Ibid.,* 45.

[44] *Ibid.*

[45] Michel Foucault, *The Archaeology of Knowledge.*, 14.

discipline, the book, the *oeuvre,* the tradition, the influence, the 'spirit.' Instead, it begins with "the project of a *pure description of discursive events*, [which serves] as the horizon for the search for the unities that form within it."[46] Whereas the history of thought seeks to reconstitute a system of thought, a process that requires assert the existence of an ideological "discursive totality," archaeology analyzes a discursive field by way of *statements,* "event[s] that neither the language (*langue*) nor the meaning can quite exhaust." The statement is a singular event, one that contains the specificity of its occurrence within it, not as an external context. It is permanently linked to the statements on all sides, both those that precede it and those that arise as its consequence.[47] By trading customary unities for the pure analysis of a discursive field, the archaeologist of knowledge can determine the unique existence of a statement.

Freed from the sutures that enforce linearity and coherence on history, "archaeology proceeds in the opposite direction: it seeks rather to untie all those knots that historians have patiently tied; it increases differences, blurs the lines of communication, and tries to make it more difficult to pass from one thing to another."[48] In the pure analysis of discourse, ruptures proliferate. For Althusser, some of these historical discontinuities take the form of *epistemological breaks*. In these moments, a science "detaches itself from [an ideology's] field in order to constitute itself as a science, but precisely this detachment, this 'break,' inaugurates a new form of historical existence."[49] With this transition, newborn sciences produce novel problems, which replace formerly intractable, or even invisible, conundrums. But to appreciate the full ex-

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[46] *Ibid.,* 27.

[47] *Ibid.,* 27-8.

[48] *Ibid.,* 170.

[49] Louis Althusser, "Marxism is not a Historicism," in *Reading Capital*, 133.

tent of the break, one must realize that the innovations are not just new questions getting at the same old things from another angle. Rather, these are new problems working on *new objects of knowledge.* The break is not the invention of a new hypothesis but "the radical foundation of a new space, a new *problematic* which allows the real *problem* to be posed."[50] It is in this sense that the break is truly epistemological and that it founds a new science. Recall that the problematic is "peculiar to a science." Thus it is "its absolute and definite condition of possibility, and hence the absolute determination of *the forms in which all problems must be posed*…in the science."[51] These epistemological ruptures are the radical discontinuities that articulate the history of thought proper to Althusser's philosophy.

But we should be careful. In general, Foucault's discontinuities are the dispersions intrinsic to the archaeological archive. Not every discontinuity is rupture sufficient to trigger an Althusserian epistemological break. This distinction extends to Kuhn's theory as well. Even though he chronicles several paradigm shifts in physics during the nineteenth century, I have argued that classical physics rested firmly on a Newtonian problematic. Just as not every archaeological discontinuity is an epistemological break, not every paradigm shift is profound enough to force a discipline onto a new problematic. We see this, for example, in the response to Michael Faraday's conceptual invention of the electromagnetic field. Although the concept was initially baffling, physicists were able to make sense of it once Maxwell published his 1861 paper, "On Physical Lines of Force." His force lines gave physicists a tool with which to handle this previously confounding entity. This was a paradigm shift in the study of electromag-

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[50] Louis Althusser, "From Capital to Marx's Philosophy," in *Reading Capital*, trans. Ben Brewster. (London: Verso, 1997), 53.

[51] *Ibid.* 25.

netism. But as we will see in the next chapter, the concept of the electric field did not initiate an epistemological break, since Maxwell was able to make sense of it on the classical paradigm with his dynamical theory of the field as stresses in the ether.

So, if a history of knowledges ought to take now-defunct systems of thought at their word in order to understand the logics underlying their facts, structuring their conclusions, and producing the surprise of an epistemological break, what is the proper object of such a study? For Foucault, the answer is the *archive*. For Althusser, the history of an ideology, a philosophy, or a science is not the analysis of a system of thought, as such, but the "histor[y] of *concepts organized into problematics*, whose synchronic combinations it is possible to reconstitute."[52] But as a science's problematic defines the forms in which questions can be posed, organizes the necessary structure of language, and determines the manner in which objects of knowledge are connected to real things, it is inaccessible to direct inquiry. To the minds of scientists in whom the philosopher remains asleep, unsolved problems present themselves as opportunities for research, interrogations of language lead rapidly to tautologies, and objects appear to be natural things in the world.

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The challenge in apprehending a problematic is finding a way in. This is particularly true in the case of an empiricist science such as Newtonian mechanics, since it takes itself to be directly studying real things in the world. If it takes its objects of knowledge to be already-existing things, there is no need to account for either their construction or the questions

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[52] Étienne Balibar, "The Elements of Structure and Their History," in *Reading Capital*, trans. Ben Brewster. (London: Verso, 1997), 251.

one poses about them. Insofar as the problematic defines the very reality on which a science works, it cannot be probed with experiments, since they are powered by questions posed on its terrain and presuppose the axioms responsible for its structure. Thanks to its deep epistemological status, the problematic resists direct exposure.

For a historian working in the future anterior, it might appear that an anomalous experimental result (e.g. the Michelson-Morley interferometer's failure to detect the ether wind) would be sufficiently jarring to force the discipline into a thoughtful (if implicit) evaluation of its problematic. This reading, however, is precisely the sort of ideological effect Althusser rejects. It takes the current ether-less physics as the *telos*, an inevitable expression of the Reason glimpsed decades earlier in Michelson's basement laboratory at the Case School of Applied Science. Instead, the archaeologist ought to treat this now-eclipsed physics according to the laws of its own discursive field.

Even when an experiment yields an unexpected result, a mature and comprehensive problematic should have the flexibility to accommodate the surprise on its own terms. This is very similar to the way that Kuhn's paradigm responds to anomalies. Usually an adjustment in the reigning paradigm theory will be enough to handle anything strange that pops up. Normal science, the kind that progresses on the strength of an existing paradigm (and problematic), "does not aim at novelties of fact or theory, and when successful, finds none."[53] So long as a slight adjustment will suffice to deal with a stubborn result, there is no reason for a science to consider whether the problem is with their logic, as opposed to their hypotheses. Any science will exhibit a great deal of natural resistance to the former option, since it initiates a wrenching process that is, literally, unthinkable. At first glance, this might ap-

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[53] Thomas Kuhn, *The Structure of Scientific Revolutions*, 52.

pear to introduce too much flexibility into the paradigm for it to serve as the basis of a rigorous science. However, "by ensuring that the paradigm will not be too easily surrendered, resistance guarantees that scientists will not be lightly distracted and that the anomalies that lead to paradigm change will penetrate existing knowledge to the core."[54] In other words, the paradigm has so much built in elasticity that any stress powerful enough to rupture it will require that the science reform itself on a completely new foundation, that is, on the terrain of a new problematic.

Consider the situation facing turn-of-the-century physicists studying electromagnetic radiation. Maxwell's unification of light and electromagnetism was the pinnacle of the science and the theoretical culmination of Young's recognition that light is a wave. Physicists judged its validity to be like that of Newton's laws of mechanics: absolute. One of its major triumphs was the idea that the electromagnetic and luminiferous ethers were identical, an insight that reduced the number of universe-filling substances physicists required. Although Maxwell's canonical electromagnetic equations have no terms referencing properties of the ether, it was an essential piece of his overall theory, for it prevented him from relying on dubious actions at a distance.[55]

Although precision optical experiments had failed to detect the ether, this invisibility was satisfactorily explained at both first and second orders in v/c. In 1845, George Stokes had dispatched the first-order difficulty presented by astronomical measurements, which failed to detect the stellar aberration the ether wind was expected to cause. In response, he proposed that "the Earth and the planets carry a portion of the ether along with them so that the ether close to their surfaces is at rest relatively to their surfaces while its velocity

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[54] *Ibid.,* 65.

[55] Loyd Swenson, *The Ethereal Aether,* 27.

alters as we recede from the surface till, at no great distance, it is at rest in space."[56] Similarly, when Michelson and Morley's interferometer failed to detect the second order effects of the ether wind in 1887, there was a demand for an explanation, not a new physics.

This explanation was quick to follow. Its source, Hendrick Antoon Lorentz, had held an interest in the infamous 1887 experiment from its inception. Indeed, Michelson took on the project due to Lorentz's insistence that the former's earlier ether detection experiments had been inconclusive.[57] After another convincing null result, Lorentz tried "to remove the contradiction between Fresnel's [theory of the ether] and Michelson's result" by proposing that we "imagine that the motion of a solid body (such as a brass rod or the stone disc employed in the later experiments) through the resting ether exerts upon the dimensions of that body an influence which varies according to the orientation of the body with respect to the direction of motion."[58] If motion through the ether shortened rigid bodies by a proportion of 1 to – a theory that had been previously floated by both Fitzgerald and Voigt – the extra travel time it would take light to fight against the ether wind would be precisely cancelled by the savings from the decreased distance it would have to travel.[59]

In a retrospective history, it would be easy argue that because the "correct" equations describing length contraction due to motion were written down ten years before Einstein published the relativity principle, special relativity was really nothing new. But extracting these lines of math does not read the contraction theory according to its own laws. Indeed, one

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[56] George Stokes "On the Aberration of Light," *Phil. Mag.* 3d ser. 27:9-10 (July, 1845) qtd. in Loyd Swenson, *The Ethereal Aether,* 23-4.

[57] Loyd Swenson, *The Ethereal Aether,* 87-8.

[58] Hendrick Antoon Lorentz, "Michelson's Interference Experiment" (1895) in *The Principle of Relativity,* (London: Methuen & Co., 1923), 4-5.

[59] Philip Stehle, *Order, Chaos, Order.* (Oxford: Oxford UP, 1994), 156-161.

only needs to read Lorentz's next paragraph to understand the wholly dynamical nature of his theory:

> Surprising as this hypothesis may appear at first sight, yet we shall have to admit that it is by no means far-fetched, as soon as we assume that molecular forces are also transmitted through the ether, like the electric and magnetic forces of which we are able at the present time to make this assertion definitely. If they are so transmitted, the translation will very probably affect the action between two molecules or atoms in a manner resembling the attraction or repulsion between charged particles. Now, since the form and dimensions of a solid body are ultimately conditioned by the intensity of molecular actions, there cannot fail to be a change of dimensions as well.[60]

While the equations describing the apparent shortening might be the same as the transformations Einstein derived in his 1905 relativity paper, the two theories are not just different but, as we will see in the next chapter, mutually incoherent. For Lorentz, this shortening is a purely dynamic effect rooted in the absolute motion of a rigid body through the ether. Understanding Lorentz on his own terms, it is hard to conceive of him as a truly modern physicist, comfortable with the full implications of relativity theory. Rather than seeing Michelson and Morley's null result as fomenting a fundamental crisis for the science this archaeological reading shows how Lorentz's contraction hypothesis is just another solution *required* by the mechanical view to a problem posed by the necessity of the ether: "I believe every physicist feels inclined to the view that all the forces exerted by one particle on another, all molecular actions and gravity itself, are transmitted in some way by the ether…. We may, I think, even go so far as to say that, on the assumption [the ether is at rest], Michelson's experiment *proves* the changes of dimensions in question."[61] This is a theory grounded on the classical problematic.

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[60] Hendrick Antoon Lorentz, "Michelson's Interference Experiment" (1895) in *The Principle of Relativity,* 5-6.

[61] Hendrick Antoon Lorentz, *The Theory of Electrons*: (1906). 2nd Ed. (New York: G.E. Stechert, 1916), 45, 196. Emphasis his.

> *Only since Freud have be begun to suspect what listening and hence what speaking (and keeping silent), means; that this 'meaning' of speaking and listening reveals beneath the innocence of speech and hearing the culpable depth of a second, quite different discourse, the discourse of the unconscious. I dare maintain that only since Marx have we had to being to suspect what, in theory at least, reading and hence writing means.*[62]
>
> *-Louis Althusser, 1965*

So if a problematic is inaccessible to experimental verification, how might one comprehend its contours? For Althusser, the answer lies in reading. For an example of how to "construct the problematic, the unconsciousness of [a] text," he characteristically turns to Marx.[63] In *Capital*, Althusser argues, "Marx reads out loud to us" from the texts of classical political economy, and he does so on two registers. In the first reading, "Marx reads his predecessor's discourse (Smith's for instance) through his own discourse. The result of this reading through a grid, in which Smith's text is seen through Marx's, projected onto it as a measure of it, is merely a summary of concordances and discordances, the balance of what Smith discovered and what he missed, of his merits and failings, of his presences and absences." This mode of reading still cannot access the problematic, since it is terminally grounded in the visual metaphor of knowledge. It takes facts as givens and reduces the role of the thinker to that of the prospector. To learn more is to see more, and the reach of a knowledge is reducible to the prospector's visual acuity.[64] In this first mode,

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[62] Louis Althusser, "From Capital to Marx's Philosophy," in *Reading Capital*, 16.

[63] Ben Brewster, "Glossary" in *Reading Capital,* 317.

[64] Again, this describes the epistemology appropriate to the pre-Einsteinian scientific vision described in Richard Panek's *The Invisible Century*.

anything new Marx added to political economy was an omission, an oversight of Smith's; it "reduces Marx to Smith minus the myopia."[65]

It is in Marx's second mode of reading that Althusser locates *Capital's* real epistemological work. This time, Marx reads classical political economy against itself, no longer cataloging its sightings and oversights or comparing classical absences to Marxist presences. To stay with the visual metaphor, in this reading

> what classical political economy does not see, is not what it does not see, it is *what it sees;* it is not what it lacks, on the contrary, it is *what it does not lack;* it is not what it misses, on the contrary, it is *what it does not miss*. The oversight, then, is not to see what one sees, the oversight no longer concerns the object, but *the sight* itself. The oversight is an oversight that concerns *vision:* non-vision is therefore inside vision, it is a form of vision and hence has a necessary relationship with vision…. In this observation of non-vision, or of oversight, we are no longer dealing with a reading classical economics through the grid of Marxist theory, the latter providing the standard – for we never compare classical theory with anything *except itself*, its non-vision with its vision. We are therefore dealing with our problem in its pure state, defined in a single domain without any regression to infinity. To understand this necessary and paradoxical identity of non-vision and vision within vision itself is very exactly to pose our problem (the problem of the necessary connection which unites the visible and the invisible), and to pose it properly is to give ourselves a chance of solving it.[66]

The dynamics at play in this second reading should recall our discussion of the problematic in the last chapter, which is precisely the terrain on which objects and problems present themselves to a scientist. Theory is no longer the result of the visual powers of a transcendental subject confronting the world, since it is the field of the problematic "itself which *sees itself* in the objects or problems it defines – sighting being merely the

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[65] Louis Althusser, "From Capital to Marx's Philosophy," in *Reading Capital*, 18-9.

[66] *Ibid.,* 21.

necessary reflection of the field on its objects."[67] While the terrain of its problematic determines the absolute horizon within which knowledge is possible for a given science, it is not a terrain residing within a larger space. The crucial limits that the problematic places on knowledge are internal; the invisible resides *within* but is rendered invisible by the problematic's structural repression. By searching for the "non-vision within vision," this second mode of reading aims to make contact with those structures internal to the problematic and probe the limits of possibilities for knowledge production.

In calling this second mode a *symptomatic reading*, Althusser discloses his ambivalent relationship with psychoanalytic theory. Psychoanalysis occupies a liminal position in his theory: it is more than a metaphor – the concept of the symptom and the strategies employed in a symptomatic reading find their origins in therapeutic practice – but less than a foundation. Althusser was steeped in Freudian language and practice, both in his position at the *Ecole Normale Supérieure* and through a troubled personal history of analysis. Indeed, he describes the psychoanalytic motivations for his epistemology in a 1966 letter to his colleague, the analyst Jacques Lacan, which elucidates the relations between symptomatic reading and Lacan's ideas about the structure of the unconscious.[68] We might push this connection further by returning to Althusser's claim that "in every scientist, there sleeps a philosopher"[69] to argue that the problematic occupies the metaphorical position of the philosopher's unconscious. In symptomatic reading, then, we are analyzing his dreams to unpack the condensed epistemological and metaphysical commitments that make a smooth normal science possible.

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[67] *Ibid.,* 25.

[68] Louis Althusser, *Writings on Psychoanalysis: Freud and Lacan*. Trans. Jeffrey Mehlman. (New York: Columbia UP, 1996), 170-2

[69] Louis Althusser, *Philosophy and the Spontaneous Philosophy of the Scientists* p. 111.

This letter, taken together with the sections of *Reading Capital* that it references, suggests that Althusser's symptomatic reading is at least modeled after the practice of analysis. In both cases, the strategy is to locate a *symptom*, an anomalous presence or absence that betrays the underlying logical structure responsible for determining the possibilities for thought. Symptomatic reading, then, is the process by which these textual seams are identified and subsequently ripped open to produce a supplementary text, articulated in the lapses and phantoms of the first. It is by reading the written text's conscious ideas against its unvoiced logic that the reader is able to chart the problematic's terrain. Symptoms are the residues of the necessary collisions between the problematic's logic and its internal limits, which constrain the range of questions that might be asked at the same time that they make the production of knowledge possible at all.

Returning to Poincaré armed with this Althusserian concept, we witness a masterful reading of Newtonian physics' problematic.[70] In searching for definitions and conventions masquerading as hypotheses, those dangerous ones that "are tacit and unconscious," he is seeking the unacknowledged

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[70] A crucial point: no matter how penetrating, a given reading cannot be simply considered to be or not to be a symptomatic one. Althusser insists that he does not simply find a symptomatic reading in Marx, but produces one through *his own* symptomatic reading. The title of *Reading Capital*, which was born from a seminar on *Capital* held at the *École Normale Supérieure* in 1965, is intended to underscore the primary importance – and intrinsic complexity – of reading in Althusser's philosophy. There "is no such thing as an innocent reading," he stresses, and this is a self-described philosophical one. His aim is to understand the object of *Capital* and make manifest the philosophy that exists in practical state in this text.* Similarly, I aim to undertake in this work a symptomatic reading of an archive of physics literature. I do not mean to claim that Poincaré was *doing* a symptomatic reading, merely that we can *read* one in his essays.

*Louis Althusser, "From *Capital* to Marx's Philosophy," in *Reading Capital*, 13-15.

logical foundations of the contemporary physics.[71] Although he aims to make these assumptions explicit and reduce their number as much as possible, he recognizes their necessity if the structure of physics is to remain intact. None of these fundamental laws is independent; as an ensemble in the edifice of Newtonianism, they are load bearing. None is unambiguously higher than another: They flow into each other like the water in Escher's gravity-defying aquaduct. As structural elements of the discipline's underlying problematic, they hold or fail together: "If we construct a theory based upon multiple hypotheses, and if experiment condemns it, which of these premises must be changed? It is impossible to tell. Conversely, if the experiment succeeds, must we suppose that it has verified all these hypotheses at once? Can several unknowns be determined from a single equation?"[72]

Poincaré's symptomatic reading reaches its zenith in "The Classical Mechanics." He begins with a complaint: Physicists rarely "distinguish between what is experiment, what is mathematical reasoning, what is convention, and what is hypothesis."[73] He then goes on to criticize four elements of Newtonian reason, which classical mechanics takes as fundamental laws of Nature:

> 1. There is no *absolute space*, and we only conceive of relative motion; and yet in most cases mechanical facts are enunciated as if there is an absolute space to which they can be referred.
>
> 2. There is no *absolute time*. When we say that two periods are equal, the statement has no meaning, and can only acquire a meaning by a convention.
>
> 3. Not only have we no direct intuition of the equality of two periods, but we have not even direct intuition of the *simultaneity* of two events occurring in two different places....

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[71] Henri Poincaré, *Science and Hypothesis*, 151.

[72] *Ibid.* 151-2.

[73] *Ibid.* 89.

> 4. Finally, is not our *Euclidean geometry* in itself only a kind of convention of language? Mechanical facts might be enunciated with reference to a non-Euclidean space which would be less convenient but quite as legitimate as our ordinary space; the enunciation would become more complicated, but it still would be possible.
>
> Thus, absolute space, absolute time, and even geometry are not conditions that are imposed on mechanics. All these things no more existed before mechanics than the French language can be logically said to have existed before the truths that are expressed in French.[74]

To call these criticisms prescient is to lapse into the retrospection of ideological history. Instead, it is proper to consider this a list of four symptoms of the Newtonian problematic. Here, Poincaré might be said to have spelled out four laws of Nature, but laws of a different sort than his contemporaries might expect: These are laws imposed *on Nature*, the object on which physics works, *by mechanics*, as a necessary condition of intelligibility. They are conventions that allowed classical physicists to parse, measure, and predict. Reduction requires decomposition, and these absolutes are required for second order differential equations, which comprise the mathematics of Newtonian mechanics, to make any sense.[75] Only the absence of an international summit separates the prescriptive nature of these conventions from those established at the May 1875 Convention of the Meter, a crowning achievement of French scientific precision and rationality.[76]

Despite the fact that no coherent classical physicist could dispute these premises, Poincaré does not just assert their absolute necessity to Newtonian mechanics. He shows us this interdependence by trying to envision ways to test the fundamental principle on which all mechanics relies: the principle of inertia. Imagining astronomers living in a solar sys-

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[74] *Ibid.* 90. My emphasis.

[75] *Ibid.*, 154.

[76] Peter Galison, *Einstein's Clocks, Poincaré's Maps*, 84-98.

tem similar to our own, he describes possible alternatives to the principle of inertia that they might devise. If the planets had perfectly circular orbits and masses small enough to make the perturbative effects of mutual gravitation irrelevant, they could lay down the law that the motion of a body is entirely dependent on its position. It would take the cataclysmic intervention of a foreign star to disrupt the orbits and overturn this now-erroneous physical law.[77] But what then, he asks, is the status of the classical principle of inertia, which anticipates straight-line motion from every unaccelerated object?

> Has the generalized law of inertia been verified by experiment, and can it be so verified? When Newton wrote the *Principia*, he certainly regarded this truth as experimentally acquired and demonstrated…. It was so proved by the laws of Kepler. According to those laws, in fact, the path of a planet is entirely determined by its initial position and initial velocity; this, indeed, is what our generalized law of inertia requires…. But astronomy is not the whole of physics. May we not fear that some day a new experiment will falsify the law in some domain of physics? An experimental law is always subject to revision; we may always expect to see it replaced by some other and more exact law. But no one seriously thinks that the law of which we speak will ever be abandoned or amended. Why? Precisely because it will never be submitted to a decisive test.[78]

And why will mechanics never test the principle of inertia? Because all the explanations possibly produced by classical mechanics are required to obey Newton's laws of motion.

Trying to guarantee its validity by probing non-inertial motion is just as insurmountable. Newton's second law, which states that a force accelerates a mass according to the proportionality $\mathbf{F}=m\mathbf{a}$, is equally unverifiable. Measuring acceleration "directly" requires basic assumptions about absolute space and time. No matter how one approaches the problem of mass, one is never able to reach it any more directly than ratios of forces and accelerations, gravitational fields and

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[77] Henri Poincaré, *Science and Hypothesis*, 93-4.

[78] *Ibid.,* 95-6.

orbital radii, or volumes and densities, and each of these terms rests on its own irreducible combinations of Newtonian assumptions. Poincaré's conclusion: "There is no escape from the following definition, which is only a confession of failure: *masses are coefficients which it is found convenient to introduce into calculations*."[79] Any rigorous concept of force is equally conventional and circular. The only way out is an anthropomorphic statement that "force is the cause of motion… and this definition, if we had to be content with it, would be absolutely fruitless, would lead to absolutely nothing… [for] a definition must have mathematical rigor [and] this rigor does not exist."[80]

Poincaré's essays are full of such symptomatic readings, and everywhere he pushes far enough to encounter the classical problematic, he experiences the frustration of the absolute limits presented by its internal structure. The very laws that make physical knowledge possible are beyond the probative domain of any classical physicist's experiment. These symptoms, logical creases that provide Poincaré a line of flight into the structure of the classical problematic, divulge unconscious relations that tie the knowledge of classical physics to its proper objects. As an empiricist science, Newtonian mechanics takes itself to be dis-covering the laws of nature as revealed in the essences of real things in the world. With his symptomatic reading, Poincaré shows that it is men who are the true lawmakers.

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[79] *Ibid.,* 103.

[80] *Ibid.,* 98-9.

THE BREAK – EINSTEIN'S *ANNUS MIRABILIS*

It is known that Maxwell's electrodynamics – as usually understood at the present time – when applied to moving bodies, leads to asymmetries which do not appear to be inherent in the phenomena. Take, for example, the reciprocal electrodynamic action of a magnet and a conductor. The observable phenomenon here depends only on the relative motion of the conductor and the magnet, whereas the customary view draws a sharp distinction between the two cases in which either the one or the other of these bodies is in motion. For if the magnet is in motion and the conductor at rest, there arises in the neighbourhood of the magnet an electric field with a certain definite energy, producing a current at the places where parts of the conductor are situated. But if the magnet is stationary and the conductor in motion, no electric field arises in the neighbourhood of the magnet. In the conductor, however, we find an electromotive force, to which in itself there is no corresponding energy, but which gives rise – assuming equality of relative motion in the two cases discussed – to electric currents of the same path and intensity as those produced by the electric forces in the former case.

Examples of this sort, together with the unsuccessful attempts to discover any motion of the Earth relatively to the "light medium," suggest that the phenomena of electrodynamics as well as of mechanics possess no properties corresponding to the idea of absolute rest. They suggest rather that, as has already been shown to the first order of small quantities, the same laws of electrodynamics and optics will be valid for all frames of reference for which the equations

> *of mechanics hold good. We will raise this conjecture (the purport of which will hereafter be called the "Principle of Relativity") to the status of a postulate, and also introduce another postulate, which is only apparently irreconcilable with the former, namely, that light is always propagated in empty space with a definite velocity c which is independent of the state of motion of the emitting body. These two postulates suffice for the attainment of a simple and consistent theory of the electrodynamics of moving bodies based on Maxwell's theory for stationary bodies. The introduction of a "luminiferous ether" will prove to be superfluous inasmuch as the view here to be developed will not require an "absolutely stationary space" provided with special properties, nor assign a velocity-vector to a point of the empty space in which electromagnetic processes take place.*[1]
>
> *-Albert Einstein, "On the Electrodynamics of Moving Bodies," 1905*

In 1905, when Einstein published four papers that would shake physics to its logical core, none of classical physics' theories was held in higher esteem than Maxwell's electrodynamics. By Einstein's time, the theory had united the electromagnetic forces with the wave theory of light, thereby proving that the two sets of phenomena were transmitted by one and the same universe-pervading ether. Maxwell's mathematical formulation of the relations between electricity and magnetism survive today, nearly unchanged. In four partial differential equations, he was able to rigorously connect the presence and motion of charged particles (current and charge distribution) to magnetic () and electric () fields:[2]

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[1] Albert Einstein, "The Electrodynamics of Moving Bodies," (1905) in *On the Shoulders of Giants*. Ed. Stephen Hawking. (New York: Running Press, 2002), 1167-8.

[2] Edward M. Purcell, *Electricity and Magnetism*. (Boston: McGraw Hill, 1985). 330

$$\nabla \times \vec{E} = -\frac{1}{c}\frac{\partial \vec{B}}{\partial t} \qquad \nabla \cdot \vec{E} = 4\pi\rho$$

$$\nabla \times \vec{B} = \frac{1}{c}\frac{\partial \vec{E}}{\partial t} + \frac{4\pi}{c}\vec{J} \qquad \nabla \cdot \vec{B} = 0$$

Although these equations include no terms representing motion in the ether, it was an essential feature of Maxwell's total theoretical apparatus. He called his theory of the electromagnetic field "a *dynamical theory*, because it assumes that in that space [in the neighborhood of the electric or magnetic bodies] there is matter in motion, by which the observed electromagnetic phenomena are produced."[3]

Although Maxwell's energy-bearing field equations seem prescient to modern eyes, this is but another error of retrospective history. In his landmark 1864 address to the Royal Society in London, there was no hint of such ideas. He imagined "an ethereal medium pervading all bodies, and modified only in degree by their presence; that the parts of this medium are capable of being set in motion by electric currents and magnets; that this motion is communicated from one part of the medium to another…; and that energy in two different forms may exist in the medium, the one form being the actual energy of motion of its parts, and the other being the potential energy stored up in…elasticity." Despite the apparent complexity of this ether, he was sure that "such a mechanism must be subject to the general laws of Dynamics."[4] His reluctance to include any action-at-a-distance in his theory of electromagnetism – consistent with the reigning mechanical view – demanded that his fields were mathematical representations of physical states of the ether.

In Einstein's reading, the key feature of this elastic

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[3] James Clerk Maxwell, *A Dynamical Theory of the Electromagnetic Field* (1864), 34

[4] *Ibid.,* 39.

medium was that it was an absolute frame of reference for electromagnetism. If Maxwell's electromagnetic waves were travelling through this medium, then motion relative to the medium would be just as important as motion of objects relative to each other. Of course, physicists could only measure the latter. This discrepancy between the observable features of electromagnetic interaction and its classical description in theory reaches its climax with induction, a phenomenon in which electricity and magnetism gracefully intertwine. The most interesting case involves a loop of wire and a magnet: moving these two relative to each other induces a current to flow around the wire loop. For a hypothetical experimenter, it doesn't matter which object he fixes to his lab bench and which he moves. As long as the objects' relative motion is identical, the induced current will be as well.

But this is not the case if one were to explain the phenomenon using Maxwell's electrodynamics in 1905. Assuming that the Earth carried with it an ethersphere – as the failure of countless ether detection experiments suggested – then one of these objects, fixed firmly to the bench, is at rest relative to the ether. This situation required two explanations. If the loop were fixed, then the motion of the magnet would create an electric field, which would contain the energy sufficient to cause a current to flow in the wire. On the other hand, if the magnet were fixed, there would be no electric field. Instead, there would be an electromotive force (with no associated energy) on the charged particles in the wire, arising from motion through the magnetic field.

Einstein begins his June 1905 paper, "On the Dynamics of Moving Bodies," with a symptomatic reading of this Maxwellian induction asymmetry. This symptom, two incongruous explanations for one apparent phenomenon, "together with the unsuccessful attempts to discover any motion of the Earth relatively to the 'light medium,' suggest[s] that the phenomena of electrodynamics as well as of mechanics possess no properties corresponding to the idea of absolute rest."[5] With this reading, Einstein accomplished in three paragraphs what a century of precision experiments failed to do: He banished the ether.

Whereas every null result of an ether detection experiment merely provided the opportunity for a new hypothesis of precise cancellation, Einstein was able to read both the induction asymmetry and the ether as symptoms of a more fundamental problem with classical logic. As we have seen, the belief in absolute space and the idea of absolute rest relative to it is not a confusion built up over time by misguided physicists. Instead, the existence of absolute rest is a principle that lies in classical physics' Newtonian bedrock, on top of which the rest of the theoretical edifice had been built. In producing this symptomatic reading and unearthing this logically required incoherence, Einstein was able to perceive the problematic of classical physics.

As with the diagnosis of a disease or the analysis of a patient, the symptom is neither the problem nor its simply understandable result. It would be an empiricist error to assume that identifying an asymmetry in Maxwell's dynamical explanation of induction reveals the problems with Newtonian logic. Einstein was able to understand the problematic only because he treated the asymmetry and the ether as *symptoms*, overdetermined products of the underlying logical structure. In order to banish the ether, he had to remove its *raison d'être:* absolute rest. He had to understand that the ether was a symptom of the manner in which classical physics posed its questions, the result of the problematic's intersecting, internal limits.

Here, we see the true power of a symptomatic reading. Borrowing again from psychoanalysis, Althusser describes the

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[5] Albert Einstein, "On the Electrodynamics of Moving Bodies," in *On the Shoulders of Giants,* 1167

symptom as the product of *overdetermination*, or "the effectivity of a structure on its elements."[6] This complex structure (the problematic) is reflected in the symptom (the contradiction between the single phenomenon and the dual explanations). To read symptomatically means to trace this "presence of the structure in its effects." It is penetrating precisely because it views the problematic, the structure undergirding the thought of a given science, not as "an essence outside the [physical] phenomena which comes and alters their aspect, forms, and relations and which is effective on them as an absent cause, absent because it is outside them. The absence of the cause in the structure's 'metonymic causality' on its effects is not the fault of the exteriority of the structure with respect to the [physical] phenomena; on the contrary, it is the very form of the interiority of the structure, as a structure, in its effects."[7] A symptomatic reading is one that does not shrink from this tangled web of (il)logic, merely treating the symptom and pushing no further. Rather, it engages with the apparent contradiction in order to produce an understanding of a latent structure, the problematic on which this knowledge is grounded.

After his reading of the induction asymmetry, it would have been impossible for Einstein to merely abandon the ether. This would have amounted to no more than exorcising the symptom and leaving behind incoherence. For his reading to make sense, Einstein had to construct a new problematic on which physical knowledge might be refounded. This production of a new epistemological structure distinguishes a symptomatic reading from a *break*. In Althusser's epistemology, there is no such thing as a knowledge without a problematic; without an underlying structure language would have no

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[6] Louis Althusser, "From *Capital* to Marx's Philosophy," in *Reading Capital*, 29.

[7] Louis Althusser, "Marx's Immense Theoretical Revolution," in *Reading Capital*, trans. Ben Brewster. (London: Verso, 1997), 188.

bite and logic no form. This explains why an epistemological break must be powered by a symptomatic reading, since a scientific problematic must arise directly from the ashes of the ideological problematic of its pre-history. It also makes clear why a symptomatic reading alone is insufficient to effect a break: without a new problematic on which to stand, the knowledge has nowhere to go. We might say that this is why, despite his brilliant symptomatic reading, Poincaré's work was not a break. Without forging a new problematic – that is, a new physics – Poincaré's criticism could not set off such a tectonic shift.

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Einstein's new problematic rests on two postulates. The first is an extension of an idea originating with Galileo, who argued that someone trapped in the windowless cabin of a ship would not be able to determine the vessel's velocity by any mechanical means, provided that it were sailing at a constant speed and in a straight line. Rigorously formulated, this Galilean invariance holds that the laws of mechanics are the same in any inertial frame. It is a fundamental tenet of Newtonian mechanics. Einstein extended this thinking with his Principle of Relativity: "The same laws of electrodynamics and optics will be valid for all frames of reference for which the equations of mechanics hold good."[8] This postulate obviously abandons any need for Newton's absolute rest, but its full implications only become apparent when combined with "another postulate, which is only apparently irreconcilable with the former, namely, that light is always propagated in empty space with a definite velocity *c*, which is independent of

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[8] Albert Einstein, "On the Electrodynamics of Moving Bodies," in *On the Shoulders of Giants*, 1167-8.

the state of motion of the emitting body."[9] Einstein declares that *c's* status as a "universal constant" is "in agreement with experience."[10] But this is not a paper responding to experimental data or describing some elusive physical phenomenon. From these two postulates and an analysis of the relationships between rigid bodies, Einstein not only works out the special theory of relativity, which revolutionizes the physical concepts of space and time but also begins the construction of a new, scientific problematic for modern physics.

Recall how, in *The Measure of Time*, Poincaré argues that we have intuition neither for duration of time nor the simultaneity of distant events. The only raw materials on which to build physical knowledge are sense impressions. Rather than "flow[ing] equably without regard to anything external," Poincaré holds that a unified notion of time must be produced in thought according to pre-established conventions.[11] In his June 1905 paper, Einstein moves right from dismissing the reality of the luminiferous ether to building a new problematic with a kinematical analysis of these same criticisms. Insofar as Poincaré read the symptoms in classical physics' notion of absolute time, Einstein's paper can be said to define a new idea of time that avoids these same errors.

Working with rigid bodies, Einstein encounters a demand for "time" to describe the motion of a particle in a Euclidean space. Before defining a velocity, however, he cautions that "a mathematical description of this [motion] has no physical meaning unless we are quite clear as to what we understand by 'time.' We have to take into account that all our judgments in which time plays a part are always judgments of *simultaneous events.*" While simultaneity may appear to be a physical given ("If for instance, I say, 'That train arrives here

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[9] *Ibid.,* 1167-8.

[10] *Ibid.,* 1170.

[11] Isaac Newton, *Principia* in *On The Shoulders of Giants*, 738.

at 7 o'clock," I mean something like this: "The pointing of the small hand of my watch to 7 and the arrival of the train are simultaneous."), this is only true if the event is happening in the same location as the watch.[12]

Determining the simultaneity of distant events turns out to be a trickier problem, but one that lies at the foundation of the relativistic notion of time. Following Einstein's thought experiment, let us suppose that there exist two stationary[13] clocks, situated at distant points *A* and *B*. An observer at *A* would then be able to measure the time value of events in the neighborhood of *A* by noting the position of clock A simultaneous with the event. The situation would be identical for the observer at *B*. While each observer is capable of comparing and ordering events in the vicinity of his own location, "it is not possible, without further assumption to compare, in respect of time, an event at *A* with an event at *B*. We have so far defined only an '*A* time' and a '*B* time.' *We have not defined a common 'time' for A and B,* for the latter cannot be defined at all unless we establish *by definition* that the 'time' required by light to travel from *A* to *B* equals the 'time' it requires to travel from *B* to *A*."[14] With this definition, it is possible to synchronize the two spatially separated clocks.

Immediately, we find an irreducible difference between this approach and the Newtonian one. In the Scholium with which he opens his *Principia*, Newton acknowledges the difficulty of measuring absolute time and space. Nevertheless,

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[12] Albert Einstein, "On the Electrodynamics of Moving Bodies," in *On the Shoulders of Giants*, 1168

[13] One might ask: How can Einstein use the word "stationary" only a few paragraphs after he banished the Newtonian concept of absolute rest? The answer is that these clocks may still be considered "stationary" as long as they are said to be stationary relative to some other object. In this case, the clocks must be stationary relative to each other. We will soon see the full complexity that emerges from this apparently simple idea.

[14] Albert Einstein, "On the Electrodynamics of Moving Bodies," in *On the Shoulders of Giants*, 1169.

making *accurate* measurements of these absolutes is the stated goal of his science. In a Newtonian regime, correct clocks would be those that ticked along at the same rate as the flow absolute time. In contrast, there is no place in Einstein's definition of synchronism for accuracy. All that exists is *precision*, that is, whether the two clock correspond with each other. Without an absolute time to use as a reference, Einstein must assert definitions and conventions, which are thus inseparable from the quantities themselves. If there is no absolute time for his clocks to track, no standard with which to verify their accuracy, there can be no rigorous concepts of "time," "simultaneous," or "synchronous" apart from convention. Thus, the special theory of relativity dispenses with the idea that there is a physically meaningful "time" contained in the world, waiting to be found. Instead, "time," as an object of physical knowledge, must be produced, in thought, according to a recognized convention. Far from being a given thing in the world, in relativity theory, time is a problem solvable only with a known synchronization scheme.

> *I have tried to show that the raw material which the mode of production of knowledge works on… had to take very different forms according to the degree of development of knowledge in its history; for example, that there is a great difference between the raw material on which Aristotle worked and the raw material on which Galileo, Newton or Einstein worked – but that formally this raw material is a part of the conditions of production of all knowledge. I also tried to show that even though it is clear to everyone that the greater the progress of a branch of knowledge, the more elaborate becomes the raw material, though the raw material of a developed science obviously has nothing in common with 'pure' sensuous intuition or mere 'representation,' nevertheless, however far back we ascend into the past of a branch of knowledge, we are never dealing with a 'pure' sensuous intuition or representation, but with an ev-*

> *er-already complex raw material, a structure of 'intuition' or 'representation' which combines together in a peculiar 'combination' sensuous, technical and ideological elements; that therefore knowledge never, as empiricism desperately demands it should, confronts a pure object which is then identical to the real object of which knowledge aimed to produce precisely… the knowledge. Knowledge working on its 'object,' then, does not work on the real object but on the peculiar raw material, which constitutes, in the strict sense of the term, its 'object' (of knowledge), and which, even in the most rudimentary forms of knowledge, is distinct from the real object.*[15]
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> *-Louis Althusser, 1965*

Althusser sets up a contrast between ideological empiricism and the scientific. The epistemological break marks the transition from one mode of production of knowledge to another, from one problematic to another, from the pre-history of a science to its proper existence. This thesis argues that Einstein's 1905 *annus mirabilis* should be read as just such a moment of transition: Einstein did not add more knowledge on top of an already existing collection of facts. His 1905 papers were the first blows, the primary break, that initiated a radically shift from the empiricist problematic of classical physics to the scientific problematic of modern relativity and quantum physics.

Of course, neither theory emerged as an Athena, born fully formed from the head of a god. Einstein worked in a definite theoretical conjuncture, steeped as he was in Poincaré's brilliant symptomatic readings of Newtonian logic, Lorentz's theory of length contractions and "local time," Maxwell's successful electrodynamics, and Planck's successful but *ad hoc*

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[15] Louis Althusser, "From Capital to Marx's Philosophy," in *Reading Capital*, 42-3.

solution to the blackbody problem. Moreover, Einstein's papers did not contain fully articulated theories, ready to replace a classical problematic so successful that physics was widely considered to be a complete science. Nor did they contain the germs that would necessarily develop into the complex, modern theories of general relativity and quantum mechanics. These theories required decades of elaboration before they would achieve the coherence and acceptance of the science they would replace. And Einstein played vastly different roles. The former was born in Einstein's Zurich notebooks, after his schoolmate Marcel Grossman taught him Riemann's non-Euclidean geometry. The latter suggested that on a fundamental level, the universe operates according to chance; this was a conclusion against which Einstein labored until the end of his life. Holding out hope that a unified field theory would one day supplant a probabilisitic quantum mechanics, he never really abandoned the tentativeness of his 1905 "light quanta" paper, "On a Heuristic Point of View About the Creation and Conversion of Light."

How then, with so many apparent caveats as to its definitiveness, can this thesis hold that Einstein's *annus mirabilis* is a genuine epistemological break? To make this argument, we must seize Althusser's clue, which guided our analysis of the classical problematic: to read the structure of a science's problematic we should examine the manner in which it understands its *object of knowledge*, since "the conception of knowledge underlying the object of knowledge… makes [the] knowledge what it is."[16] Following this reading strategy, we will understand Einstein's papers as initiating an epistemological break by forging a radical new conception of physics' proper object of knowledge.

Recall the empiricist conception of knowledge that

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[16] Louis Althusser, "From Capital to Marx's Philosophy," in *Reading Capital*, 34.

undergirds classical physics. Classical mechanics' incredible success in the nineteenth century – particularly Maxwell's electrodynamics and the kinetic theory of gases – suggested "that the mechanical view can be consistently applied to all branches of physics, that all phenomena can be explained by the action of forces representing either attraction or repulsion, depending only upon distance and acting between unchanged particles."[17] The objects on which this science worked were taken to be the real things, already existing in the world, that is, fundamental particles moving around. Classical physics' power was its ability to parse the world with differential equations, which extracted the particles' essential properties. By relating their masses (quantity of undifferentiated matter, pure substance) and their coordinates in the passive container of Newtonian absolute space and absolute time, mechanics could extract the deterministic Laws of Nature. According to Althusser, an empiricist problematic treats knowledge as something to be extracted from real things in the world. Empiricist science, then, aims to dis-cover the essential kernel at the heart of every thing.

With our symptomatic reading of Einstein's papers, we can understand the new conception of knowledge that emerges with special relativity and quantum theory. And again, we look to the object of knowledge, as a clue to this *scientific* problematic's internal structure. What distinguishes a scientific problematic from an empiricist one is that the former recognizes a strong distinction between the *real object* – the thing, which exists out in the world, independently of one's thoughts about it – and the *object of knowledge* – the object on which a science does its labor. Whereas empiricism conflates these two, believing that discovery is an unveiling of the essence within the *real object* itself, a truly scientific problematic acknowledges the production, in thought, of the *object of*

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[17] Albert Einstein and Leopold Infeld, *The Evolution of Physics*, 65.

knowledge from a set of relevant *raw materials*.

One can only appreciate the truly Marxist nature of Althusser's epistemology in his narrative of how a scientific problematic produces theoretical knowledge. A science's particular theoretical practice begins with the production process of the object of knowledge. This "takes place entirely in knowledge and is carried out according to [its own] order, in which the thought categories, which 'reproduce' the real categories do not occupy the same place as they do in the order of [the real], but quite different places assigned them by their function in the production process of the object of knowledge."[18] Careful to avoid charges of idealism of consciousness, Althusser stresses that this production is the work of neither "a 'pure' transcendental subject [n]or 'absolute consciousness.'" Rather, he describes the "thought" in which the object of knowledge is produced as "a peculiar real system, established on and articulated to the real world of a given historical society, which maintains determinate relations with nature, a *specific* system, defined by the conditions of its existence and practice, i.e., by a *peculiar structure*, a determinate type of 'combination' between its peculiar raw material (the object of *theoretical practice*), its peculiar means of production, and its relations with the other structures of society."[19] To be considered scientific, a given system of thought must take its theoretical practice to be a truly creative force. While an empiricist knowledge would consider its excavation and appropriation of a real thing to be a transparent process that merely allows the subject to know the thing's true essence, a properly founded science imagines its "theoretical practice, i.e. thought's labor on its raw material, as the 'labor of trans-

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[18] Louis Althusser, "From Capital to Marx's Philosophy," in *Reading Capital*, 41.

[19] *Ibid.,* 42.

formation' of intuition and representation into concepts."[20]

In Einstein's kinematical construction of "time" by way of a clock synchronization convention, we see exactly the sort of awareness of the production, in thought, of an object of knowledge that Althusser would call "scientific." Einstein was familiar with Kant's argument that time is the form of inner intuition, since his *Critique of Pure Reason* was on the Olympia Academy's reading list, but his special relativity paper explicitly rejects the notion that a rigorous physics could be based on *a priori* intuition alone.[21] Following Poincaré, Einstein built a scientifically usable concept of time from definitions and conventions. His "common time" requires measurement and long-distance coordination. On the terrain of relativity's problematic, an event's "time" is not a particle's essential datum, a coordinate in Newton's passive container of absolutes. "Time" itself becomes an object of study in Einstein's relativity paper, and its complex must be produced in thought like any other. In this production process, science is restricted to a definite set of raw materials, the sense impressions of light signals. One might object to this claim by arguing that there can be nothing real in a thought experiment like Einstein's. However, this misses the key point: on Einstein's new problematic, knowledge is absolutely limited to what can be measured. Unlike classical physicists, who first assume that there is an absolute, independently flowing time and then try to accurately track it, Einstein's only assumption is the ability to measure local simultaneity. From this modest basis, he produces a "common time," which has radically different properties than Newton's absolute time.

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[20] *Ibid.*

[21] Walter Isaacson, *Einstein*, 82-3.

> *There exists an essential formal difference between the theoretical pictures physicists have drawn of gases and other ponderable bodies and Maxwell's theory of electromagnetic processes in so-called empty space. Whereas we assume the state of a body to be completely determined by the positions and velocities of an, albeit very large, still finite number of atoms and electrons, we use for the determination of the electromagnetic state in space continuous spatial functions, so that a finite number of variables cannot be considered to be sufficient to fix completely the electromagnetic state in space. According to Maxwell's theory, the energy must be considered to be a continuous function in space for all purely electromagnetic phenomena, thus also for light, while according to the present-day ideas of physicists, the energy of a ponderable body can be written as a sum over the atoms and electrons. The energy of a ponderable body cannot be split into arbitrarily many, arbitrarily small parts, while the energy of a light ray, emitted by a point source of light is according to Maxwell's theory (or in general according to any wave theory) of light distributed continuously over an ever increasing volume….*
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> *It seems to me that the observations on "blackbody radiation," photoluminescence, the production of cathode rays by ultraviolet light, and other phenomena involving the emission or conversion of light can be better understood on the assumption that the energy of light is distributed discontinuously in space. According to the assumption considered here, when a light ray starting from a point is propagated, the energy is not continuously distributed over an every increasing volume, but it consists of a finite number of energy quanta, localized in space, which move without being divided and which can be absorbed or emitted only as a whole.*[22]
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> *-Albert Einstein, "On a Heuristic Point of View About the Generation and Conversion of Light," 1905*

Einstein published "On a Heuristic Point of View About the Generation and Conversion of Light" in March

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[22] Albert Einstein, "On a Heuristic Point of View About the Generation and Conversion of Light," in *The Old Quantum Theory.* ed. D. Terr Haar. (London: Pergamon, 1967), 91-2.

1905. In a letter sent in May to Conrad Habicht, his Olympia Academy comrade, he discusses the four papers that would undermine the reigning view of physical reality. Of the four, he described only the March paper, which proposed that electromagnetic radiation exhibited properties consistent with a corpuscular theory, as "very revolutionary."[23] If its reception by the day's leading physicists is any measure, this description was well warranted: "The physics community at large received [Einstein's] light-quantum hypothesis with disbelief and with skepticism bordering on derision.... From 1905 to 1923, he was a man apart in being the only one, or almost the only one, to take the light-quantum seriously."[24] Although heretical, Einstein's suggestion that light be treated as if it were composed of a "finite number of energy quanta" would profoundly alter the way physicists conceived of nature and of their science.

Just as in his special relativity paper, which would come out a few months later, Einstein began his light quanta paper with a symptomatic reading of Maxwell's electrodynamics. Rather than reporting on new experimental evidence, his paper addressed "an essential formal difference" between Maxwell's theory of electromagnetism and the dominant mechanical view. On the one hand, classical mechanics works by assuming that ponderable bodies are composed of discrete particles, and that all physical phenomena can be described by differential equations tracking their motions. Each particle was said to have a finite energy, which inhered within it. Together, these energies determined the time evolution of any system. On the other hand, Maxwell's electrodynamics consists of fields and waves, physical entities that filled all space. The theory describes the energies associated with these elec-

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[23] Quoted in Walter Isaacson, *Einstein*, 93.

[24] Abraham Pais, *Subtle Is The Lord: The Science and the Life of Albert Einstein*, (Oxford: Oxford UP, 1982), 357.

tromagnetic phenomena with continuous spatial functions. Because Maxwell's equations represent fields in space as continuous functions, calculus' concept of the limit reaches its full potential in classical electromagnetism, moving smoothly from the arbitrarily small infinitesimal to the infinite reach of the integral. This limiting procedure, parsing the world in infinitely small bits and building to a continuous whole, simply doesn't work with mechanic's discrete particles, since the reality of atoms and electrons imbues the physical world with an absolute granularity.

This mathematical difference between the continuous and the discrete is the formal basis for the classical distinction between waves and particles. Physicists might build statistical models of continuous phenomena by starting with discrete elements, but for all properly classical descriptions of a wave, these imaginary divisions were expected to disappear as their number was pushed to the infinite limit. Planck was following this standard "binning" procedure when he discovered the quantum of action, *h*, in his formula for the energy distribution (*U*) of blackbody radiation as a function of frequency (ν) and temperature (*T*):[25]

$$U = \frac{8\pi h\nu^3}{c^2}\frac{1}{e^{\frac{h\nu}{kT}} - 1}$$

The usual procedure when concocting such a statistical law is to push to the limit where the bin size (*h*, in this case) approaches zero. Planck's problem, was that *h* appears twice as a proportionality constant and doesn't cancel out. He could not remove it with a limit. Since it was inconceivable that such quantization could apply to the radiation waves filling the blackbody chamber, Planck ascribed this granularity

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[25] Max Planck, *The Theory of Heat Radiation*. Trans. Morton Masius. (Philadelphia: P. Blackiston's Son & Co., 1914), 168.

to the material oscillators with which he had modeled the cavity's walls. In Abraham Pais' reading, Planck "hid" the quantum of action in the poorly understood interaction between matter and radiation.[26]

This should not be taken to mean that in his initial explanation Planck was trying to defend Maxwell's electrodynamics through deception. Rather, his conclusion – that quantization was an effect of the thermal equilibrium maintained between the electromagnetic radiation and the "resonators" embedded in the cavity's wall, not a feature of the waves themselves – was the only logical option. Epistemologically, we can take this as an effect of the classical problematic, which had no place to quanta in the radiation field. Even Einstein's light quanta paper acknowledges that the wave theory and its continuous spatial functions have "been excellently justified for the representation of purely optical phenomena and [are] unlikely ever to be replaced by another theory."[27] The idea of discrete energy quanta is incoherent with this view.

But we can push further, and recognize the necessity of maintaining the rigid distinction between continuous waves and discrete particles as a characteristically empiricist urge. Recall that an empiricist problematic conflates the *real object* and the *object of knowledge*, producing the illusion that its science is working directly on things in the world. In this mode of inquiry, knowledge always already exists, but is merely concealed in the essential kernel, overlaid with the inessential dross. The empiricist scientist, then, is in the business of discovering that kernel, releasing the truth about the world inside. In concert with the associated epistemology, which takes knowledge to be justified true belief, truth is an issue of correspondence between the *'logical' order*, "which governs the cat-

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[26] Abraham Pais, *Subtle Is The Lord*, 383-4.

[27] Albert Einstein, "On a Heuristic Point of View About the Generation and Conversion of Light," in *The Old Quantum Theory*, 91.

egories of *thought* in the process of knowledge," and the '*real' order*, "which governs the *real* categories" existing the world.[28] This should not be a surprising conclusion, since the material that comprises the logical order (in empiricist thought) is taken to be the knowledge extracted from the real things themselves. If this is the case, then there should be a rigorous identity between the logical and the real orders.

Indeed, the correspondence theory of truth amounts to determining whether this identity exists. When the question of a theory's truth is posed "in the field of an empiricist problematic…, [the interpreter is] seeking to prove, in the first case, that the 'logical' order, being identical in essence with the real order and existing *in* the reality of the real order as its essence itself, can only follow the real order; in the second case that the real order being identical in essence with the 'logical' order, the real order, which is then merely the existence of the logical order, must follow the logical order."[29] Because this correspondence is a necessary condition of any empiricist truth, Planck, as a purely classical physicist, was obliged to let the logical distinction between continuous and discrete mathematics reign. There was simply no place in the logical order of classical physics for quantized field equations; thus, there was no place in the real order for radiation quanta to exist.

Perhaps inspired by Kant's critical supposition that "objects must conform to our cognition,"[30] Einstein did not assume that the distinction in classical logic between the continuous and the discrete obligated that electromagnetic radiation refrain from behaving as if it were corpuscular. The paper's title, "On a *Heuristic* Point of View About the Generation and Conversion of Light," gestures toward the conventional-

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[28] Louis Althusser, "From Capital to Marx's Philosophy," in *Reading Capital* p. 46.

[29] *Ibid.* 46-7.

[30] Immanuel Kant, *The Critique of Pure Reason*, trans. Paul Guyer and Allen W. Wood. (Cambridge: Cambridge UP, 1998), 110.

ism intrinsic to any scientific object of knowledge. At the end of its introduction, Einstein explains his goal for the paper: "In the following, I shall communicate the train of thought and the facts which led me to this conclusion, in the hope that the point of view to be given may turn out to be useful for some research workers in their investigations."[31] This could have come straight from Poincaré, who argued forcefully that conventions are chosen for their convenience, rather than their necessity. With objects of knowledge constructed in ways that yield tractable problems, there is no reason to assume that rigorous identities between the real and logical orders should exist. At most, one might expect analogies or isomorphisms between relations among objects of knowledge and relations among things.

In his light quanta paper, Einstein neither argues that physics should abandon Maxwell's electrodynamics nor expresses doubt that diffraction is the result of interfering light waves. He contends that adopting his heuristic principle – that quantization is a feature of the radiation field rather than a mere artifact introduced by the cavity's walls – provides reasonable explanations for formerly intractable problems. But in order to make this highly controversial argument, he would have to accomplish two theoretical feats: conclusively demonstrate that quantization is a feature of the radiation field itself (as opposed to some feature of the poorly understood light-matter interaction) and explain some other as-yet baffling phenomenon with his light quanta.

Before advancing his own theory of blackbody radiation, Einstein works through the previously dominant explanations, highlighting their problems. (Since Gustav Kirchhoff had coined the term "blackbody radiation" in 1862, wave after wave of physicists had tried to model its distinctive spec-

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[31] Albert Einstein, "On a Heuristic Point of View About the Generation and Conversion of Light," in *The Old Quantum Theory,* 92.

trum, which depends only on temperature and is independent of the material emitting it. Its stubborn history is reflected in Einstein's 1913 quip: "It would be edifying if we could weigh the brain substance which has been sacrificed by the physicists on the altar of the [Kirchhoff function]; and the end of these cruel sacrifices is not yet in sight!"[32]) First, he discusses the solution that follows from Rayleigh's work, which described the radiation spectrum in the cavity as a collection of standing electromagnetic waves. But using the equipartition principle to specify the associated energies leads to the so-called ultraviolet catastrophe: The model's unlimited high-frequency vibration modes suggest that the spectrum should have infinite energy. This is obviously wrong. He also discusses Wien's law, which had previously been shown to hold only at large frequencies and low temperatures.[33]

When Einstein introduces Planck's distribution function as the solution to the frustrating blackbody problem, he does so with an important caveat: the "determination of elementary quanta given by Mr. Planck is, to a certain extent, independent of the theory of blackbody radiation constructed by him." This is an important argument, for it allows Einstein to show that in the high frequency limit of ultraviolet light, Planck's and Wien's equations are equivalent. Working in this limit and employing some crafty mathematical manipulations, Einstein shows that a formula for the entropy of the blackbody radiation (based on Wien's solution) varies with volume in a familiar manner. This, in turn, justifies treating the radiation with Boltzmann's statistical methods, which describe the

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[32] Albert Einstein, quoted in Abraham Pais, *Subtle is the Lord*, 372.

[33] Einstein: "From the observations made so far on "blackbody radiation," it is clear that the law $\rho = \alpha\nu^3 e^{-\beta\nu/T}$ put forward originally for "blackbody radiation by Mr. W. Wien is not exactly valid. However, for large values of ν/T, it is in complete agreement with experiment."

-Albert Einstein, "On a Heuristic Point of View About the Generation and Conversion of Light," in *The Old Quantum Theory,* 98.

entropy of a system as a function of its instantaneous state. In his own derivation, Planck reluctantly leaned on Boltzmann's statistics, but it was merely an intermediate step. Einstein, in contrast, argues in his light quanta paper for "the consistent application of Boltzmann's principle." On the strength of his statistical analysis, Einstein derives an equation for the instantaneous state (*W*) of the blackbody radiation field as a function of the volume of the cavity (V):

$$W_{Radiation} = \left(\frac{V}{V_0}\right)^{n \cdot \frac{\varepsilon}{h\nu}}$$

This equation has the same form as the one that describes the instantaneous state of an ideal gas, composed of *n* freely moving particles, as a function of volume:

$$W_{Gas} = \left(\frac{V}{V_0}\right)^{n}$$

Since Planck's distribution function is independent of his underlying theory of blackbody radiation, Einstein is free to derive from it a specific description of the radiation's behavior.[34] His statistical analysis shows that the blackbody radiation behaves like an ideal gas within certain limits of validity. His conclusion: "Monochromatic radiation of low density behaves – as long as Wien's radiation formula is valid – in a ther-

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[34] These equations describe the probability difference were a radiation field or an ideal gas to occupy a certain volume, V, compared to a reference volume, V_0. Einstein is arguing here that since these two equations have the same form, they should be taken to describe analogous physical situations. In the gas equation, n designates the number of gas molecules in the system of interest. By analogy, Einstein is arguing that the radiation field can be thought of as a collection of n light quanta, each with a characteristic energy, $\varepsilon = h\nu$, proportional to the frequency of the light (ν) and the quantum (h), Planck's new constant of nature.

modynamic sense as if it consisted of mutually independent energy quanta of magnitude .” Since he derived this result without reference to the interaction of the blackbody radiation with the matter in the cavity's walls, Einstein shows here that the energy quantization that pops out of Planck's theory is a feature of the electromagnetic field itself.[35]

The rest of Einstein's light quanta paper applies this “heuristic principle” to other phenomena. The most important application of the light quanta is the photoelectric effect, a poorly understood phenomenon first noticed by Hertz while studying the electromagnetic wave nature of light. Hertz noticed that the behavior of an arc of electricity across a spark gap depends on whether it is exposed to light or placed in the dark. Subsequent experiments showed that the observed spark was composed of electrons streaming from the metal, and that the electrons' energy depends directly on frequency of the incident light. (Experiments are usually done with high-frequency ultraviolet light.) Counterintuitively, the intensity of the incident light was shown to have no effect on the electrons' energy. In 1905, nothing more was known, and physics had no reasonable explanation for how light might be able to produce sparks.[36]

Armed with his concept of light quanta, Einstein was the first to give a compelling physical account of the photoelectric effect:

> According to the idea that the incident light consists of energy quanta with an energy h , one can picture the production of [sparks] by light as follows. Energy quanta penetrate into a surface layer of the body, and their energy is at least partly trans-

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[35] Albert Einstein, “On a Heuristic Point of View About the Generation and Conversion of Light,” in *The Old Quantum Theory,* 95-102. In quoting from Einstein's paper, I have modified the equations to bring them more into line with contemporary notation and to emphasize the aspects of their form that are relevant to his – and my – argument. Hopefully, these changes will aid the mathematically disinclined reader follow the current line of reasoning.

[36] Abraham Pais, *Subtle is the Lord*, 379-80.

> formed into electron kinetic energy. The simplest picture is that a light quantum transfers all of its energy to a single electron…. An electron obtaining kinetic energy inside the body will have lost part of its kinetic energy when it has reached the surface. Moreover, we must assume that each electron on leaving the body must produce work *P*, which is characteristic for the body. Electrons that are excited at the surface and at right angles to it will leave the body with the greatest normal velocity. The kinetic energy of such electrons is[37]

$$KE_{e^-} = h\nu - P$$

With this paragraph, Einstein explained a phenomenon that had resisted coherent theorizing for four decades. His simple equation matched all of the known features of the photoelectric effect: there is a direct relationship between the energy of the ejected electrons and the frequency of incident light; the electrons' energy is independent of the intensity of the incident light; and the effect does not depend on type of material used. Moreover, he predicted that "the number of electrons leaving the body should be proportional to the intensity of the incident light," a relation unknown to physicists of the day (and later verified).[38]

In Einstein's transformation of Planck's nearly imaginary quantum of action into the light quanta, we can read a strong epistemological shift. Whereas Planck had quickly relegated the quantum to, at most, a strange feature of the baffling matter-light interaction, Einstein was willing to dismiss rigid constraints of the mechanical view and follow the thread of quantization into the radiation field. It is not that he failed to understand how his heuristic was inconsistent with the classical distinction between waves and particles, but that violating this principle of order had powerful implications. Producing a new object of knowledge, a semi-corpuscular ra-

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[37] Albert Einstein, "On a Heuristic Point of View About the Generation and Conversion of Light," in *The Old Quantum Theory,* 104-5.

[38] *Ibid.,* 105-6.

diation field, made the formerly unyielding photoelectric effect not just tractable but quite straightforward. Although Einstein's quantum theory of the photoelectric effect was soon confirmed by experiment and widely adopted, the concept of the light quantum got almost no traction in the wider physics community. It just didn't make any sense.

> *It is the field of the problematic that defines and structures the invisible as the defined excluded, excluded from the field of visibility and defined as excluded by the existence and peculiar structure of the field of the problematic; as what forbids and represses the reflection of the field on its object, i.e., the necessary and immanent inter- relationship of the problematic and one of its objects. This is the case with oxygen in the phlogistic theory of chemistry, or with surplus value and the definition of the 'value of labour' in classical economics. These new objects and problems are necessarily invisible in the field of the existing theory, because they are not objects of this theory because they are forbidden by it – they are objects and problems necessarily without any necessary relations with the field of the visible as defined by this problematic. They are invisible because they are rejected in principle, repressed from the field of the visible: and that is why their fleeting presence in the field when it does occur (in very peculiar and symptomatic circumstances) goes unperceived, and becomes literally an undivulgeable absence – since the whole function of the field is not to see them, to forbid any sighting of them. Here again, the invisible is no more a function of a subject's sighting than is the visible: the invisible is the theoretical problematic's non-vision of its non-objects, the invisible is the darkness, the blinded eye of the theoretical problematic's self-reflection when it scans its non- objects, its non-problems without seeing them, in order not to look at them.*[39]
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> *-Louis Althusser, 1965*

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[39] Louis Althusser, "From Capital to Marx's Philosophy," in *Reading Capital*, 25-6.

Einstein's *annus mirabilis* is the fulcrum around which this work pivots. In the first instance, this thesis argues that Einstein's 1905 papers inventing special relativity and quantum theory should be read as an Althusserian break, in which a new scientific problematic burst forth from a symptomatic reading of its pre-history, the ideological problematic of Newtonian mechanics. This approach is mutually beneficial. On the one hand, Althusser's epistemology of physics is the perfect tool with which to do a philosophical close reading of Einstein's *annus mirabilis* papers, since it permits us to grasp not only how they changed the direction of physics inquiry but also how they initiated a break to a new problematic. In this reading, we can probe the logical structures that undergird both classical and modern physical knowledge to gauge the papers' profundity. On the other hand, because Einstein's *annus mirabilis* is the quintessential scientific revolution, it serves as a template around which we can develop Althusser's epistemology as a coherent philosophy of science, generalized from his intra-party Marxist polemics. By producing the *annus mirabilis* as a theoretical problem, we get to work on the terrain of the Althusserian problematic, the logical structure supporting this thesis' philosophical inquiry, and develop an understanding of its contours, its internal limits, and its possibilities for knowledge production.

This leads to the thesis' second level of analysis: In drawing out an Althusserian epistemology of science (as opposed to an epistemology justifying the existence of Marxism *as a* science), I aim to place it in the context of a broader philosophy of science. While I hope Althusser's theory of the problematic, symptomatic reading, and the epistemological break is coherent on its own terms, alone it is not sufficient for understanding how scientific logics and scientists work. To accomplish this goal – the production of a coherent philosophy of science, of which Althusserian epistemology is but a part – requires placing it in concert with other philosophical positions that have similar theoretical orientations. I believe we have found these intellectual companions in Foucault's archaeology and Kuhn's theory of scientific revolution as paradigm change. Rather than forcing the issue by relying on the philosophical suggestiveness of common analogies, I hope this thesis works these separate theories together with a philosophical rigor that acknowledges both their concordances and incompatibilities.

Before we jump too far ahead and permit aspirations to replace arguments, let us return to Einstein's 1905 papers and determine if they did in fact initiate an epistemological break. For the most reliable test of whether the papers produced a new problematic for modern theoretical physics, we will return to the visual metaphor of knowledge and ask if certain objects, previously excluded from the domain of classical knowledge, became visible in Einstein's thought. Of course, this is not a question of whether or not Einstein had the intellectual acuity to see what Lorentz, Planck, and Poincaré missed. In Althusser's epistemology, the sighting of something new "is not longer the act of an individual subject, endowed with the faculty of 'vision,' which he exercises either attentively or distractedly; the sighting is the act of its structural conditions, it is the relation of immanent reflection between the field of the problematic and its objects and its problems…. It is this field itself which sees itself in the objects or problems it defines – sighting being merely the necessary reflection of the field on its objects."[40] An object remains invisible because it is defined as such, its possible recognition repressed by the problematic's internal structure. While a symptomatic reading might register a necessary absence in a carefully teased-out logical hiccup, the invisible object will only escape "the [original problematic's] inner darkness of exclusion" if the knowledge is refounded on the terrain of a new problematic.

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[40] *Ibid.,* 25.

So, we can determine if Einstein's *annus mirabilis* was a epistemological break by looking for the transformation of non-objects – defined as invisible by classical physics' problematic – into legitimate objects of knowledge – produced according to the logic of the problematic of modern physics. Fortunately, Einstein's papers contain two perfect transformations on which to perform this analysis: the production of relativistic time from Lorentz's local time and the birth of the light quanta from Planck's quantum of action. In both of these cases, Einstein took an existing theory – Lorentz's transformation equations and Planck's blackbody function – and restated it on new foundations. To some, this might appear to be a mere reinterpretation and charge that Einstein adds nothing fundamentally new. But this attitude is mired in an empiricism that takes knowledge to be the extracted essence of things. We have already seen how Althusser rejects this revelation-based epistemology for one that recognizes the production in thought of objects of knowledge, which are absolutely distinct from the real objects themselves. Reading our two transformations through this grid, we will see how Einstein takes non-objects, explicitly understood to be no more than mathematical artifacts necessary for fitting a functional curve to some observed data, and transforms them into important objects of knowledge with really existing implications for the physical world.

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Let us begin with the set of transformation equations that Lorentz invokes "in order to explain the absence of any effect of the earth's translation" in the Michelson-Morley experiment. These equations transform the "real" coordinates of absolute space and time (x, y, z, t), in which the ether is at rest, to the "effective" coordinates (x', y', z', t') corresponding to the electromagnetic properties of an object moving at a velocity (v) on the order of the speed of light (c) in the positive x direction:[41]

$$x' = k\,(x - vt)$$

$$y' = y$$

$$z' = z \qquad \text{where} \qquad k = \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}}$$

$$t' = k\left(t - \frac{v}{c^2}x\right)$$

In chapter two, we discussed Lorentz's dynamical justification for the length contraction of fast-moving objects (that is, the transformation of x into x'). This set of transformations is a natural extension of that reasoning. In the classical view, they are required in order to have a set of coherent differential equations for the electrodynamics of a moving body of the same form as the differential equations for stationary electrodynamics.

Although the identical equations reappear in Einstein's 1905 special relativity, Lorentz's "effective coordinates" (x', y', z', t') most definitely do *not* have the same meaning as Einstein's relativistic coordinates (x', y', z', t'). The absolute difference between the two theories is manifest in t', which Lorentz terms "local time" as opposed to the "true time," t. The names say it all: for Lorentz the stationary frame of the ether is the only true reality. He regards t' as a mathematical contrivance, which is necessary so that Maxwell's differential equations have the same form for moving and stationary processes. It has no physical meaning. t corresponds to the Newton's "absolute, true, and mathematical time, [which] of itself, and from its own nature flows equably without regard

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[41] Hendrick Antoon Lorentz, *The Theory of Electrons*, 195-7. I have slightly alerted the equations to aid the reader.

to anything external."[42]

Theoretically, the only similarity between Einstein's special relativity paper and Lorentz's *Theory of Electrons* is the form of the transformation equations. These transformations share neither the same justifications nor the same physical meaning. Whereas Lorentz invents his transformation equations to account for Michelson and Morley's null result, Einstein deduces them from a kinematical analysis of rigid bodies in motion. Because he deduces them from his two postulates without relying in any way on a theory of electromagnetism, the transformations occupy a far more fundamental position in Einstein's relativistic physics than they do in even the most baroque classical formulations. His deduction involves a series of subtle thought experiments, in which observers moving relative to each other make measurements by means of coordinated light signals.[43] In these thought experiments, we see the beauty with which the two postulates of special relativity – first, that the laws of physics are identical for all observers moving at constant velocities relative to each other, and second, that the light propagates at a constant speed *c,* whether emitted by a stationary or a moving body – form a logically coherent and complete basis for modern physics and the beauty with which light stitches together our perceptions of space and time.

From these thought experiments, Einstein rederives the Lorentz transformations. Far from being an absolute and passive container for events, relativistic time depends on the relative motion of different observers. Because space and time cannot be disentangled and distant events only become register with the arrival of a light signal, Einstein concludes "we

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[42] Isaac Newton, *Principia* in *On The Shoulders of Giants*, 738.

[43] For the sake of brevity, I will omit a detailed description of these thought experiments. For a better explanation than I could ever muster, please see either Einstein's 1905 special relativity paper or his *Relativity: The Special and the General Theory* (New York: Three Rivers Press, 1961).

cannot attach any *absolute* significance to the concept of simultaneity, but that two events which, viewed from a system of coordinates are simultaneous, can no longer be looked upon as simultaneous events when envisaged from a system which is in motion relatively to that system."[44] This is a result that follows readily from the time transformation equation. But in world that has no ether, that is no frame corresponding to absolute rest, all times have the same status; there is no "true time," only "local times." Einstein can make this radical claim only because he has effected a break into a new problematic, which recognizes that its objects of knowledge are produced and distinct from the real objects. Fundamentally, Einstein argues in his relativity paper that any scientifically useful "time" is only that, an object of knowledge produced according to a given set of conventions.

This break was confirmed three years later by a young physicist named Hermann Minkowski, who developed the now-familiar concept of four-dimensional spacetime, which emerged as the proper object of relativistic physics. In the introduction to his now-famous lecture, he made a startling claim that is the first logical extension of Einstein's break: "Henceforth space by itself and time by itself are doomed to fade away into mere shadows, and only a kind of union of the two will preserve an independent reality."[45]

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In his light quanta paper, Einstein introduces Planck's distribution function as the empirical solution to the vexing problem of blackbody radiation. But calculating the energy

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[44] Albert Einstein, "The Electrodynamics of Moving Bodies," in *On the Shoulders of Giants*. 1171.

[45] Hermann Minkowski, "Space and Time," in *The Principle of Relativity,* (London: Methuen & Co., 1923), 75.

distribution of this "normal spectrum" is not among Einstein's goals; his paper is a true text of theoretical physics in that he allows the mathematical and theoretical arguments to lead him to posit a new, meaningful feature of reality. This is the only way that he could divorce *h* from the light-matter interaction and make a strong claim about the fundamental logic of physics: waves and particles are not exclusive categories actually existing in the real order of things, but are rather the solutions to theoretical problems, posed in thought. In classical thought, the empiricist problematic demanded a one-to-one correspondence between the logical order (equations) and the real order (things). Because light had been "proven" beyond a reasonable doubt to be composed of waves, which could only be represented in mathematics by continuous spatial functions, there was nothing in the real world for *h* to correspond to.

In his thoroughly classical *Theory of Heat Radiation*, Planck assigns *h* a non-causal role in the emission of energy from the "resonators" in the cavity wall. It appears to him that a resonator can only emit energy "when its energy of vibration, *U*, is an integral multiple *n* of the quantum of energy, . Whether it then really emits or whether its energy of vibration increases further by absorption will be regarded as a matter of chance." This strange emission behavior is indeed the granular outlier in Planck's theory; he demonstrates to his satisfaction that the resonators' absorption is still a continuous function. Indeed, Planck argues that his hypothesis of quanta should "not be regarded as implying that there is no causality for emission [of energy]; but that the processes which cause the emission will be assumed to be of such a concealed nature that for the present their laws cannot be obtained by any but statistical methods." Ultimately, Planck is forced to acknowledge that *h* is a new fundamental constant of nature, inextricably connected to *k*, which plays an important role in Boltzmann's statistical mechanics. Yet Planck never assigns the constant, which now bears his name, any determinate physical meaning. It remains a mathematical parameter necessary to fit his theoretical line to some experimental data.[46]

Einstein pulls his semi-corpuscular theory right from Planck's blackbody function, by pushing it to the ultraviolet limit. A more modern argument might rewrite the function in the following way:[47]

$$U = \left(\frac{8\pi\nu^3}{c^2}\right)\left(h\nu \cdot \frac{1}{e^{\frac{h\nu}{kT}} - 1}\right)$$

In this formulation, the "wave-like" and "particle-like" natures of the radiation field are separated. At the low frequencies of infrared light, the first term dominates. It is what a purely classical analysis of waves would yield. Indeed, a formula of this type (second order in ν, no *h*) appears in Einstein's paper as a failed theory of the blackbody. The second term dominates the function in the ultraviolet limit of high frequency. This is where the fundamental quantization of *h* is significant; it is the region Einstein probes in his 1905 paper.

Only on the terrain of a scientific problematic, one that recognizes that it constructs its objects of knowledge (rather than extracting them ready-made from nature) could this flexible, semi-corpuscular theory be at all comprehensible. Making any coherent physical meaning from this intrinsic duality requires suspending the empiricist question of whether there is an identity between given logical and real orders.

For Althusser, this problem is "an *imaginary* one." On

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[46] Max Planck, *The Theory of Heat Radiation*, 153-72.

[47] There is a strong technical justification for this way of writing Planck's distribution law. The first term is a "wave-like" term that comes from an argument about phase space. The second, "particle-like" term includes all the factors of *h*, as well as the formula for counting indistinguishable bosons (e.g. photons), later called "Bose-Einstein statistics."

the terrain of a scientific problematic, which takes its object of knowledge to be produced, in thought, from some raw materials, there is a firm distinction between the object of knowledge and the real object in the world. Thus, the scientific "distinction of objects implies a radical distinction between the order in which 'categories' appear in knowledge, on the one hand, and in… reality on the other…. We can admit no *one-to-one correspondence* between the different moments of these two distinct orders."[48] We have already seen how the production of an object of knowledge necessarily involves conventions and definitions, required not by nature but rather by the exigencies of formal tractability. This process yields an object on which the scientific mind might work. Thus, the relationship of the logical and real orders can never exceed *analogy*, a relation that lacks the theoretical rigor necessary for a one-to-one correspondence. Because the construction is always directed by the aim of producing feasible problems for research, the logical order cannot be taken to be a rigid constraint on reality.

Einstein provisionally adopts his heuristic principle of energy quanta because it makes blackbody radiation and the photoelectric effect tractable problems. But quanta do not help with everything; Einstein acknowledges that optical interference only makes sense if light is treated as a wave. For the first time in this debate, which stretches back to the seventeenth-century dispute between Newton and Huygens, there is a possibility of compromise: light is both *like a wave* and *like a particle*. But this statement of dual analogies is literally meaningless in the logical world of the classically dominant mechanical view. In order for Einstein to make this move, he had to give it up and refound science on a new ground, a new problematic.

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[48] Louis Althusser, "From *Capital* to Marx's Philosophy," in *Reading Capital*, 47.

> *Science is not just a collection of laws, a catalogue of unrelated facts. It is a creation of the human mind, with its freely invented ideas and concepts. Physical theories try to form a picture of reality and to establish its connection with the wide world of sense impressions. Thus, the only justification for our mental structures is whether, and in what way, our theories form such a link.*
>
> *We have seen new realities created by the advance of physics. But this chain of creation can be traced back far beyond the starting point of physics. One of the most primitive concepts is that of an object. The concepts of a tree, a horse, any material body, are creations gained on the basis of experience, though the impressions from which they arise are primitive in comparison with the world of physical phenomena….*
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> *The psychological subjective feeling of time enables us to order our impressions, to state that one event precedes another. But to connect every instant of time with a number, by the use of a clock, to regard time as a one-dimensional continuum, is already an invention. So also are the concepts of Euclidean and non-Euclidean geometry, and our space understood as a three-dimensional continuum.*[49]
>
> *-Albert Einstein, 1938*

So, what can we make of these theories, which in one sense survived the *annus mirabilis* and in some other very important senses perished? How do we read Planck or Lorentz's classical treatises today, when they were written in a scientific language we no longer truly speak? Clearly, their epistemological value exceeds their mathematical output, the blackbody function's line or the Lorentz transformations' conversion factors. Insofar as they have any physical meaning, these equations exist in discursive environments that are more than external contexts. How might we understand the difference between the Lorentz's *t'* and Einstein's?

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[49] Albert Einstein and Leopold Infeld, *The Evolution of Physics*, 294-5.

I propose we return to Foucault's archeology and adopt its concept of "the statement" *(l'énoncé)* as a way to distinguish between the multiple instantiations of these equations on different problematics. In *The Archaeology of Knowledge,* Foucault displays a characteristic reluctance to provide a straightforward definition of "the statement," even though it is the basic unit of the pure analysis of a discursive field. Instead, he argues by circumscription, a mode that Michel Serres has appropriately described as using "the language of geometry."[50] On a practical level, this geometric method amounts to defining a concept by telling us what it is *not*, drawing lines or distinctions that rigorously determine its position within his system of thought. This is how we come to understand the statement: It is not a proposition, not a sentence, not a speech act. Yet it does say something, it does have a logical structure, and it is enunciated at a certain time and place.

Foucault's most important distinction, for our purposes, is between the statement and the proposition:

> I do not think that the necessary and sufficient condition of a statement is the presence of a defined propositional structure, or that one can speak of a statement only when there is a proposition. In fact, one can have two perfectly distinct statements, referring to quite different discursive groupings, where one finds only one proposition, possessing only one value, obeying only one group of laws for its construction, and involving the same possibilities of use.

In this distinction, we see a familiar contrast. On the one hand, we have analytic epistemology, which takes the logical proposition as its timeless currency of truth. On the other, we have the epistemology developed here, in which a statement's meaning overflows the banks of its isolated logical content to include its position within a given discursive field. Thus, the same proposition – e.g. Planck's law or the Lorentz

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[50] Michel Serres, "The Geometry of the Incommunicable: Madness," Trans. Felicia McCarren. in *Foucault and his Interlocutors*. Ed. Arnold I. Davidson. (Chicago: U. Chicago P, 1997), 39.

transformations – can constitute radically different statements, depending on their enunciations. We have seen the irreducible difference in meaning between the equations representing Lorentz's dynamical contractions and those Einstein derives from the kinematics of rigid bodies. That analytic epistemology, produced as the ideological answer to the empiricist problem of knowledge, would treat this twice-enunciated proposition with a single logical test should be taken as further evidence that it is not up to the challenge posed by Einstein's *annus mirabilis*.

Our Althusserian epistemology is perfectly suited to evaluate statements, rather than propositions. In the case of the dual Lorentz transformations, we have one proposition enunciated twice, once on either side of an epistemological break. Because these two enunciations situate the proposition on separate problematics, they convey different meanings and operate with different logics, even while maintaining the same mathematical formulation. There are two reasons why the selfsame proposition acquires distinct meanings in this situation. The first is an issue of language. Insofar as the problematic determines the possibilities for knowledge in a given science with an internal logical structure, it defines the possible meanings that language can convey. In physics, this is manifest in the changing meanings of mathematical formulae vis-à-vis Nature.

The second, and more potent, reason that the a proposition alters its meaning from one problematic to the next is an issue of objects: they change. We have already seen how problematics produce their own objects of knowledge, so it should make sense that even preserved equations have new targets. The Lorentz transformations, for example, might convert t to t' both before and after Einstein, but the objects these variables represent are different. For Lorentz, the equations converted absolute, "true time" to the effective, "local time" experienced by a moving body. For Einstein, t and t' are ontologically on par, merely labels for distinct inertial reference frames.

In trying to make sense of scientific knowledge, Poincaré notes the historical persistence of certain relations – mathematically represented by differential equations – even after their underlying theories have been discredited. How, he asks, are Fresnel's equations purporting to describe the ether still useful even if one abandons faith in such a substance? He concludes that despite the naïve belief that in science we are learning about things, our knowledge is limited to describing relations. "If the equations remain true," he writes,

> it is because the relations preserve their reality. They teach us now, as they did then, that there is such and such a relation between this thing and that; only, the something which we then called *motion*, we now call *electric current*. But these are merely names of the images we substituted for the real objects, which Nature will hide forever from our eyes. The true relations between these real objects are the only reality we can attain, and the sole condition is that the same relations shall exist between these objects as between the images we are forced to put in their places…. That a given periodic phenomenon (an electric oscillation, for instance) is really due to the vibration of a given atom, which behaving like a pendulum, is really displaced in this manner or that, *all this is neither certain nor essential.* But that there is between the electric oscillation, the movement of the pendulum, and all periodic phenomena an intimate relationship which corresponds to a profound reality; that this relationship, this similarity, or rather this parallelism, is continued in the details; that it is a consequence of more general principles…, this we may affirm; this is the truth which will ever remain the same in whatever garb we may see fit to clothe it…. *Hypotheses of this kind have therefore only a metaphorical sense. The scientists should no more banish them than a poet banishes metaphor; but he ought to know what they are worth.*[51]

If scientific revolutions teach us anything, it should be that science is an endeavor of human creativity and convention. Objects come and go as the theoretical strength of their problematic waxes and wanes. Changing grounds will

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[51] Henri Poincaré, *Science and Hypothesis*, 161-5. Emphasis added

transform old relations into new knowledges. Einstein's *annus mirabilis* surely did not deliver physics from this continual upheaval. Insofar as modern physics' problematic recognizes that it produces its own world of objects, that its problems are of its own making, and that its mathematical relations are not the essence of natural law but analogies; in short, that it strives to know what its knowledge is worth, it rests on secure terrain.

APPENDIX A: THE DEVELOPMENT OF RELATIVITY

The mechanical view of the physical universe reached its height during the nineteenth century. Since Newton wrote down his famous laws of motion, which united the celestial and terrestrial realms with a single set of natural laws, physicists had worked to understand all matter in terms of the motions of fundamental particles existing in an inert, absolute space and measured in reference to a time that "flows equably without relation to anything external."[1] By the end of the century, there were obviously still unanswered questions and unaccounted-for deviations from theoretical predictions, but physicists largely viewed their science as nearing completion. The vast majority of their collective attention was directed at refinement of experiments and more exact calculations of nature's fundamental constants.

Physicists saw the success of James Clerk Maxwell's theoretical formulation of electricity and magnetism, published in 1873, as their science's crowning achievement. This mathematical unification of electric and magnetic phenomena followed from a series of experiments and preliminary theories that conclusively linked these two apparently distinct characteristics of matter. In 1819, Hans Christian Oersted stumbled upon this connection in a lecture demonstration when he placed a magnet parallel to a current-carrying wire and observed a force that tended to rotate the magnet until it rested at a right angle to the wire. Though André-Marie Ampère

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[1] Philip Stehle, *Order, Chaos, Order*, 7.

was able to quickly formulate a mathematical description of this force – thereby laying the foundation of electrodynamics – there was no clear understanding of the underlying physics.[2] In 1831, Michael Faraday discovered that if he aligned a magnet along the axis of a loop of wire, he could induce a current to flow by moving the magnetic toward or away from it. Together, these experiments conclusively demonstrated that electric and magnetic phenomena should not be treated separately, but rather were two aspects of a single characteristic of matter.

His work on inductance led Faraday to attempt to describe the way in which these electromagnetic forces were transmitted from one object to another. Previous physicists had argued that the forces electric charges exerted on each other were instances of action-at-a-distance in the same way that Newton's gravitational force bound faraway celestial bodies into orbits without any comprehensible mechanical cause. But the prevailing mechanical view resisted this interpretation. In its place, Faraday theorized the existence of the *ether*, a medium that filled all space and transmitted the disturbances that caused electromagnetic phenomena. He conceived of these disturbances as stresses in the ether analogous to the mechanical stresses transmitted through solid matter.[3] From here, Faraday was able to introduce the radical idea of the *field*, which he represented as curved lines of force that traced paths from positive to negative electric charges.

Initially, Faraday's concept of force lines gained little traction, even though the concept of light-carrying luminiferous ether had been around for centuries. However, in 1856, Maxwell published a paper on electromagnetic fields that argued successfully for an interpretation of Faraday's ethereal, electromagnetic force lines as indications of fluid flow. All of

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[2] *Ibid*, 18.

[3] *Ibid.*

space, Maxwell argued, could be theoretically filled with electromagnetic force lines indicating the state of the field at every point. Analysis of this "geometric" model could also yield information about the local intensity of the field: "If we consider these curves not to be mere lines, but as fine tubes of variable section carrying an incompressible fluid, then, since the velocity of the fluid [varies] inversely as the section of the tube… we might represent the intensity of the force as well as its direction by the motion of the fluid in these tubes."[4] This analogy to fluid flow had a couple of advantages that galvanized scientific opinion in its favor. First, it was a familiar concept that not only provided an easily accessible visual rendering of these hard-to-grasp fields but also had been leaned on before to explain complex physical phenomena, most notably the recently abandoned caloric theory of heat. More importantly, this model provided a material basis for electromagnetic forces that avoided any necessity to rely on instantaneous action at a distance as an explanation and was thus consistent with the mechanical view.

Maxwell's set of four equations[5] describing electromagnetism, published in 1873, was the zenith of classical physics' explanatory power. These equations tied together charges and fields and electricity and magnetism into a coherent set of natural laws: Electric charges give rise to electric fields in the ether; if these charges are in motion (i.e. there is an electric current), they will produce a magnetic field; as electric or magnetic fields oscillate in time, they give rise to each other. According to Maxwell's theory, these fields travel

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[4] James Clerk Maxwell, quoted in Philip Stehle, *Order, Chaos, Order*. p. 20

[5] The importance of these equations demands their inclusion in modern vector notation. 1. Gauss' law: $\nabla \cdot \vec{E} = 4\pi\rho$ 2. Gauss' law for magnetism: $\nabla \cdot \vec{B} = 0$ 3. Faraday's law of induction: $\nabla \times \vec{E} = -\frac{1}{c}\frac{\partial \vec{B}}{\partial t}$ 4. Ampère's circuital law: $\nabla \times \vec{B} = \frac{4\pi}{c}\vec{J} + \frac{1}{c}\frac{\partial \vec{E}}{\partial t}$. From *Order, Chaos, Order*. p. 25.

as waves through the ether, which both transmits the necessary stresses and provides a privileged rest frame in which all of the universe's electromagnetic phenomena can be easily calculated. The presence of c in the equations indicates how Maxwell's theory restricted the transmission of these waves to the speed of light, formally eliminating any troublesome instantaneous action at a distance.

Maxwell's laws received substantial experimental support after Heinrich Hertz observed many of the predicted features of electromagnetic waves in his laboratory. He produced electromagnetic, transverse, standing waves, measured their finite speed, and induced a current flow in a faraway circuit. But more importantly, he demonstrated that electromagnetic waves not only had the same speed as light waves but also shared the same polarization properties, allowing the identification of light as a form of electromagnetic disturbance and suggesting that Faraday's stress-supporting medium was the same as optics' luminiferous ether. Hertz, however, did not occupy himself with studying the ether, since he took Maxwell's laws to consist of only his four equations, and none includes any reference to the ether.

Armed with a functioning wave theory of electromagnetism, late nineteenth century physicists occupied much of their time chasing after the ether. Some tried to figure out what properties the ether must have in order to be consistent with existing and successful physical theories. This was a considerable challenge. Celestial mechanics suggested that the ether must be almost weightless and have zero friction both because the potentially retarding effects of a universe-filling substance had never been detected and in order to account for light's ability to travel long distances across space. Wave mechanics, however, required that this incompressible medium should have a nearly infinite rigidity in order to be capable of transmitting transverse waves with the extremely high frequencies of the electromagnetic spectrum. These characteristics are apparently irreconcilable.

Measurements of the apparent positions of stars suggested that the Earth should be moving through the ether without disturbing it. This implied that there should be something akin to an *ether wind* on the planet's surface. Since all light waves were thought to travel by vibrations in the ether, this medium represents an absolute rest frame in which Maxwell's equations should hold. Thus, physicists concluded the ether wind should effect the transmission of light on Earth and be somehow detectable with their optical instruments. However, all attempts to experimentally detect the ether's presence failed. To explain these failures, Augustin-Jean Fresnel, a French physicist, suggested that the Earth might drag along a portion of the ether with it, cancelling out terrestrial effects to the detectable, first-order limit. However, in 1887, Albert Michelson and Edward Morley conducted the most famous and sophisticated of these many ether-detection attempts at what is now Case Western Reserve University in Ohio. Their interferometer was large enough to be theoretically capable of detecting second order effects of the ether wind, which were calculated to be on the order of one part in 10^8, or about one wavelength of visible light over a path of fifty meters. A half-silvered mirror split the device's beam of light into two paths at a right angle. By mounting the interferometer on a rotating base, Michelson and Morley hoped to align one beam with the ether wind and the other orthogonal to it and measure the difference in travel time.

The interferometer's failure to detect an ether wind came as a rude shock. That no amount of insulation or refinement could fix this problem was even worse. Physicists, however, did not take this to be an indication of the failure of the ether concept. To explain the null result, the Dutch physicist Hendrick Antoon Lorentz suggested that the dimension in the direction of any object's motion through the ether was contracted by a factor of , shortening the path that light would have to traverse just enough to make up for the retarding effects of the ether wind. For Lorentz, this effect was firmly rooted in the prevailing theory of the ether. However, his prediction of high-speed length contraction would outlast the theory of the ether and gain central importance in Einstein's theory of special relativity.

As evidence for the ether's existence continued to evade experimenters, physicists continued to seek coherent explanations for all of these null results. Some looked back to Galileo for support. Before Galileo, physicists considered easy-to-measure velocity to be the quantity of interest in a mechanical system. Galileo, however, showed that the velocity and the position of an object depend on the reference frame in which the measurement occurs. For example, if a ball is dropped inside the cabin of a ship moving in a straight line at a constant speed, both the path and the instantaneous velocity depend on whether they are measured by an observer standing in the cabin or another watching from the shore; only the ball's acceleration is the same to both observers. Galilean invariance, as this is called, also holds that the kinematical equations for this motion can be transformed with a set of simple equations to describe the experiment from any non-accelerating reference frame.[6] Of course, these transformations operated only on the three spatial coordinates and left the time coordinate unchanged.

There were several attempts to apply the Galilean invariance transformations to the dynamics of electromagnetism. In 1887, Woldemar Voigt wrote a set of equations that transformed the electromagnetic wave equation from the rest frame of the ether to another moving at a constant velocity

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[6] Suppose there are two *spatial* coordinate systems, with the primed coordinates (x',y',z') moving to the right at speed v relative to the unprimed coordinates (x,y,z), then the transformations of Galilean Invariance will be as follows: $x'=x+vt$; $y'=y$; and $z'=z$.

relative to it. But in order for the wave equation to maintain its proper form in the moving frame, Voigt was forced to introduce a transformation relation for the time variable. That Maxwell's equations did not survive these transformations intact was not a problem for Voigt, since they were only supposed to hold in the reference frame in which the ether was at rest.

Around the turn of the century, Lorentz developed a similar theory, which not only transformed the spatial coordinates but also introduced a dilated "local time" coordinate. This theory included several other features of what would eventually become Einsteinian relativity, including length contraction, rest mass transformation, and electromagnetic field transformations. Indeed, Lorentz's transformations, written with modern notation, look remarkably similar to the equations Einstein would eventually adopt.

Thus, it might be tempting to argue that Einstein did not really change much either in his 1905 relativity paper, "On The Electrodynamics of Moving Bodies," or in his subsequent work elaborating special relativity and his decade-long effort to generalize it to explain gravitation. This would be a mistake. While Lorentz's method calculated a slower "local time" in a moving reference frame, he viewed this as a mathematical contrivance. Lorentz's theory was oriented toward explaining why the ether had not been detected – he even derived equations for Fresnel's ether drag – and the only physically real quantities were the ones measured in the ether's rest frame. He had no physical interpretation of his "local time," since it existed only to balance Maxwell's equations for a moving frame; Newton's "universal time" was still the only one that really mattered in Lorentz's world.

In that 1905 paper laying out the foundations of special relativity, Einstein was not working to explain any experimental data, unlike most physics papers of his day. Instead, he relied on two postulates, analysis of apparent contradictions in the existing theory of electrodynamics, and a number of subtle thought experiments about time synchronization. His first postulate, called the relativity principle, asserted the complete equivalence of all "systems of coordinates in uniform translatory motion," while the second claimed that light appears to move at the same speed, *c*, regardless of the motion of either the observer or the source.[7] These principles allowed him to finally banish the Newtonian ether as a privileged, absolute rest frame for the universe. The idea of an absolute, distinct, and regularly flowing time dropped away, along with this inert spatial backdrop. In its place, Einstein proposed a geometric interpretation of a four-dimensional spacetime. In September of that same year, Einstein published a brief note in *Annalen der Physik* based on his recent work. The article posits that an object's inertia depends on its energy content: $E=mc^2$. (There will be much more about these papers in the chapter on Einstein's *annus mirabilis*).

Though Einstein's invention of special relativity had broken sharply with the existing Newtonian physics and described the existence unified spacetime in which the speed of light was the ultimate upper limit of information transmission in the universe, he was frustrated by its limitations. In particular, special relativity only holds for uniform, constant velocity inertial reference frames and does not say anything about Newtonian gravity. In 1907, he began the decade-long process of generalizing his theory with his invention of the "equivalence principle." Starting from the equality of *inertial* mass (an object's tendency to resist acceleration) and *gravitational* mass (the mass that figures into Newton's gravitational force equation[8]), Einstein proceeded by thought experiment to argue that gravitation and acceleration are physically indis-

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[7] Albert Einstein, quoted in Philip Stehle, *Order, Chaos, Order*, 169.

[8] $F_g = \frac{Gm_1m_2}{r^2}$

tinguishable. Indeed, if one were standing on the ground of a windowless chamber, there is no experiment that could determine whether that chamber was experiencing an upward acceleration or if it existed in a gravitational field.[9]

This article, published in the *Yearbook of Radioactivity and Electronics*, also made a number of predictions that would later provide the first – and decisive – experimental validation of Einstein's relativity theory. First, he predicted that clocks in an accelerated environment (or equivalently, under the influence of a strong gravitational field) should run more slowly. Similarly, the spectrum of visible light emitted from a source of large mass, (a star, for example) should be shifted toward the long-wavelength, lower energy, red end of the spectrum as it loses energy climbing up gravitational field. Finally, he predicted that massive objects should bend passing light in an effect called "gravitational lensing." While this substantial conceptual advance would guide his subsequent efforts, it would take Einstein until 1915 to completely formulate this general theory, and key measurements of these effects wouldn't be completed until four years after that.

For the whole first decade of the twentieth century, Einstein felt the same way about mathematics that he had as a student: he hated it. But he was no fonder of experimentation (while he never failed mathematics, Einstein did receive the lowest possible grade in the course "Physics Experiments for Beginners" at the Zurich Polytechnic Institute).[10] Thus, his initial papers were more conceptual, with their carefully designed thought experiments, than formal. This would, however, have to change for him to continue making progress. In 1908, Hermann Minkowski, Einstein's former math teacher at the Zurich Polytechnic, formalized the insights of

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[9] This holds for a homogenous, static gravitational field and a uniform, rectilinear acceleration.

[10] Walter Isaacson, *Einstein,* 34.

Einstein's special relativity paper by mathematically combining space and time into an undifferentiated, four-dimensional coordinate system. While relative motion contracts spatial dimensions and dilates time, the four-dimensional spacetime interval between events remains invariant.

As relativity matured, Einstein searched for mathematics not merely capable of formalizing his physical intuitions but rather equipped to be an engine of discovery in its own right. In 1911, Einstein published an initial prediction of the angle by which a ray of light would bend as it passed near the sun. Though this first estimate of 0.83 seconds of arc would be revised several times before Sir Arthur Eddington measured it on a daring expedition during the solar eclipse of 1919.[11] But the counterintuitive idea that gravity was capable of bending light suggested to Einstein that there must be some new kind of geometry at play.

In 1912, he appealed to his former classmate and close friend Marcel Grossmann for help in finding a method to deal with the non-Euclidean geometry of curved surfaces. Grossmann, who routinely outperformed Einstein in their Polytechnic mathematics classes, suggested that Einstein read the work of Bernhard Riemann, whose work on tensor algebra was permitting geometers to probe radical new curved spaces. Einstein suspected that in the case of gravitational lensing, light rays were following geodesics, which are the paths of shortest possible distance on a surface. In Euclidean geometry, that is flat space, geodesics are straight lines, but on the surface of a curved manifold, such as four-dimensional spacetime, the geodesic is curved. The northern great circle route flown by transatlantic airliners is the most familiar application of the concept of a geodesic. Indeed, many familiar rules of Euclidean geometry, such as the constant sum of the angles in a triangle (180°), change when calculated on the surface of

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[11] *Ibid,* 191.

a curved manifold. To calculate the geodesic of a given manifold, in fact to do any math on a manifold, the concept of the tensor is essential. A tensor is like a generalized, many-dimensional vector that has quantitative meaning only when it is applied to a manifold but is generally covariant, meaning it can be transformed by rotations and translations in space without losing the essential relationships encoded in its elements. With Grossmann's assistance, Einstein adopted a great deal of tensor algebra, not only from Riemann but also from the Italians Gregorio Ricci-Curbastro and Tullio Levi-Civita. Their work on non-Euclidean geometry would be the key Einstein needed to fully formulate general relativity.

Armed with this new geometry, Einstein set to work generalizing relativity from two angles. This effort is preserved in his 1912 Zurich Notebooks, which show him both trying to deduce appropriate equations from the formal requirements of geometry and working from his physical intuition to find sensible equations that could be made generally covariant. Indeed, ensuring this covariance quickly emerged as the principle challenge to his developing theory. Though he was able to figure out some equations that he would return to years later, Einstein was met with intense frustration. In the years following the 1913 publishing of his *Entwurf* theory, Einstein would come to realize a number of substantial problems with his equations, including a lack of covariance. To add to this sense of urgency, David Hilbert, a German mathematician with whom Einstein had spent a great deal of time explaining his theory and its problems, was racing to figure out the correct field equations.

In October 1915, Einstein finally abandoned his *Entwurf* theory, which had too many problems and few remaining virtues. When he returned to the mathematical strategy he had employed in his 1912 Zurich Notebooks, he began focusing as closely as possible on Riemann's tensor algebra. After a month and a half of feverish, illness-inducing, solitary work, he presented a series of Thursday lectures to the Prussian Academy, a regular gathering of scientific luminaries at the Prussian State Library, with his promising results.[12] On November 25, 1915, Einstein presented his final lecture, "The Field Equations of Gravitation," to the academy. In it, he presented a set of covariant field equations that explain the fundamentally geometric nature of gravity:[13]

The first, known as Einstein's equation, relates the curvature of spacetime to the presence of matter and energy and describes the motion of objects in a gravitational field. The second, the geodesic equation, calculates the geodesic of a given manifold. In general relativity, objects tend to follow geodesic motion; the geodesic equation defines this path.

These equations allowed Einstein to make several measurable predictions that would soon be able to give his theory the support of empirical validation. First, he calculated the precession of Mercury's perihelion, a slight deviation from the orbit predicted by Newtonain mechanics that had been irking astronomers since the 1840s. That Einstein's general relativity was able to predict the correct value of 43 arcseconds per century was an immediate confirmation of his success. In addition, he predicted that starlight passing by the sun should experience a gravitational deflection of 1.75 arcseconds. But since this prediction could only be tested during a total solar eclipse, the only time starlight would be visible right next to the sun, he had to wait until Sir. Arthur Eddington's May 1919 expedition to the island of Principé, near Africa, for complete vindication.

Initially, there was concern that the differential equa-

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[12] *Ibid.,* 214-5.

[13] Sean M. Carroll, *Spacetime and Geometry*. (San Francisco: Addison Wesley, 2004), 2.

tions in the equations of general relativity were too complicated for anyone to find a physically meaningful solution. However, in January 1916, an astronomer named Karl Schwartzschild mailed Einstein a solution for the spacetime manifold surrounding a spherical star. His solution predicted the existence of black holes decades before any empirical evidence supported their reality. As physicists started to grapple with the implications of general relativity, cosmology emerged as the most crucial arena. Einstein worked on theories about the shape, history, and boundaries of the universe. When Einstein realized that his field theories seemed to suggest that the universe was necessarily expanding or contracting, he added a new term, called the cosmological constant, to the left side of Einstein's equation in order to bring it into agreement with the conventional physical wisdom. After Edwin Hubble later convinced Einstein with his astronomical data that the universe is actually expanding, Einstein called the cosmological constant his "biggest blunder."[14]

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[14] Walter Isaacson, *Einstein,* 255.

APPENDIX B: THE DEVELOPMENT OF QUANTUM THEORY

While the inventions of both quantum mechanics and general relativity required radical changes in physicists' conception of nature, their patterns of historical development were quite different. Key elements of each theory were born of thought experiments in Einstein's brain, but his attitudes towards his creations were nearly opposite. From 1905 to the 1920s, Einstein worked passionately to generalize his special theory of relativity and develop a fully geometric model of the universe. He did not have the same infatuation with light quanta. Indeed, when others' work showed that fundamental randomness was a necessary consequence of the universe's small-scale discontinuity, Einstein worked with an intense – and ultimately futile – zeal to reintroduce the lost determinism of Newton's mechanics.

The nature of light has vexed physicists and philosophers for millennia. From Aristotle and Descartes' arguments for various wave-like theories of light to Newton's corpuscular hypothesis, light's vexing character eluded complete explanation. Though Christian Huygens had proposed a wave theory of light before Newton wrote his *Opticks*, the venerable British physicist dismissed the idea of light as a wave. Newton did, however, retain Huygen's theory of the luminiferous ether, which was thought to be a universal substance that transmitted the disturbances of light waves and had been a feature of optical theories at least since Descartes' *plenum*. The wave theory of light provided a number of compelling explanations for optical phenomena including its medium-dependent speed, refraction, and reflection.

In 1803, the wave theory of light, known as the Huygens-Fresnel principle, received substantial experimental support when Thomas Young published a description of his famous double-slit experiment. As Young illuminated a pair of narrow, closely spaced slits with a thin beam of light, he observed a distinctive pattern of light and dark fringes. If light were composed of particles, one would expect a diffraction grating (the modern analog of Young's double slit) to produce a smooth superposition of the individual slits' hill-shaped bright spots. But the diffraction effects Young observed could only be produced by the interference of waves, which he took to include both longitudinal and transverse components. Recreating the setup in a shallow ripple tank clearly illustrated not only how plane waves produce diffraction effects, but also how a wave theory accounts for reflection and refraction. In 1821, Fresnel calculated that light must be entirely composed of longitudinal waves, providing a sturdy explanation for its bi-directional polarization.

The most conclusive support for the wave theory of light came in the form of Maxwell's electromagnetic equations. Once Hertz showed that electromagnetic waves had the same propagation speed and polarization properties as visible light, it became clear that light was a form of electromagnetic radiation. These were among the properties predicted by Maxwell's theory that Hertz was able to detect in his lab. As is the custom in physics, this unification was taken to mean that researchers were on the right track. Maxwell's wave theory of light was the pinnacle of classical physics; its success decisively banished any remaining corpuscular theories of light.

It was during Hertz's experiments to detect electromagnetic waves that he stumbled upon the photoelectric effect. His apparatus had a resonant loop of wire with a gap across which a spark would jump when an incident wave induced a current flow. When he moved the gap into a dark container in order to see the faint spark more clearly, he noticed that it became shorter. Further tests revealed that the lengthening of the spark depended on the wavelength of the light illuminating the gap in the wire; ultraviolet light had the largest effect while red light had almost none. It seemed that the light was freeing negative ions at the end of the metal wire. Surprisingly, the intensity of the light had no effect on the energy of the ions. This was extremely confusing, since any mechanical interpretation would predict that a more intense electromagnetic field should increase the ionization energy. While several eminent physicists tried to explain the photoelectric effect on the basis of the classical theory of electromagnetism, it wasn't until Einstein's 1905 introduction of light quanta that it was fully understood.

Although atomic spectroscopy had begun in 1814 with Joseph Fraunhofer's observation of the bright yellow spectral lines of a flame, which he labeled "D-lines," there was no compelling interpretation until 1859. In that year, Gustav Kirchhoff and Robert Bunsen established that each element produced a distinctive pattern of spectral lines and associated Fraunhofer's D-lines with sodium. They also noticed that a gas could absorb light with the precise wavelengths of its constituent elements' spectral lines, enabling the first spectroscopic analysis of sun's atmosphere. In 1885, Johann Jakob Balmer fitted the first formula to the spectral lines of hydrogen gas. His refined formula, achieved with the aid of several physicists including Johannes R. Rydberg, accurately described the spectra not only for hydrogen, but also for lithium, sodium, potassium, and other alkalis.[1] Despite their accuracy and the correct underlying assumption that some sort of resonant effect was involved, without knowledge of the electron

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[1] Philip Stehle, *Order, Chaos, Order,* 63-4.

there would be no physical interpretation of these formulae for a couple of decades.

Toward the end of the nineteenth century, rapid advances in technology allowed physicists to probe more deeply into the structure of matter than ever before. At the same time, a debate was raging among physicists over the emerging atomic theory of matter. By 1895, the idea that matter is composed of molecules and atoms, understood as the smallest form of matter retaining a substance's particular chemical properties, was gaining traction. While the developing science of thermodynamics did not require a belief in the reality of atoms, the kinetic theory of gasses did. However, many of the kinetic theory's most important elements, including Maxwell's velocity distribution for gas molecules, the equipartition of energy theorem, the Dulong-Petit theory of heat capacity, and the concrete measurements of atomic weights were either incomplete or had significant inconsistencies with materials' observed behaviors. And while Robert Mayer and Rudolf Clausius had discredited caloric theory by showing heat to be a form of energy, its connection to particulate motion remained unclear.[2] Fluids were still at the explanatory root of radiation, electricity, and magnetism.

One such important, but seemingly mundane, technological advance was a marked improvement in the power of vacuum pumps. While physicists had been observing the sparks across gasses at low pressure since the 1700s, by the 1870s it was possible to evacuate glass tubes to pressures much less that one millimeter of mercury and see new effects. When William Crookes brought the pressure in a glass tube below 0.077 mm Hg, he was able to produce a new type of ray that emerged from the cathode and caused the glass on the far side of the tube to phosphoresce. By studying the effects of magnetic and electric fields on these cathode rays, it was possible

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[2] *Ibid.*, 57.

to describe the rays as a stream of extremely light, negatively charged particles emanating in straight lines from the cathode. In 1897, J.J. Thomson, working at Cambridge University, measured the ratio of these particles' charge, *e,* to their mass, *m*. Because this ratio did not depend on the material used as a cathode, Thomson was able to claim that he had discovered a new fundamental type of matter, "the substance from which all the chemical elements are built up."[3]

Experimental support for this new form of matter coalesced in the last decade of the nineteenth century. In 1896, the year before Thomson's measurement of the *e/m* ratio, Pieter Zeeman had observed that sodium D-lines seemed to split when the light source was exposed to a magnetic field. Lorentz, working with Zeeman in Leiden, developed an elaborate theory of oscillating charged particles in the sodium atoms that were affected by the external magnetic field. Though more precise measurement of the Zeeman effect would later invalidate Lorentz's theory, the *e/m* ratio of these oscillating particles matched Thomson's measurement. The ratio also fit the particles jumping across Hertz's spark gap. Together, this evidence permitted Thomson to jettison the troublesome theory of electricity that modeled it as a fluid flowing through wires. Instead, he suggested that atoms were composed of stationary positive charged particles and the freely moving negatively charged electrons. Looking backward after the invention of quantum mechanics, the graininess Thomson ascribed to electricity gains theoretical weight beyond the discovery of a new fundamental particle. From this perspective, Thomson quantized electricity.

From this same retrospective position, the most important phenomenon that occupied the attention of turn-of-the-century physicists is blackbody radiation. As defined by Gustav Kirchhoff in 1860, a blackbody is an ideal object

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[3] J.J. Thomson quoted in Philip Stehle, *Order, Chaos, Order*, 81.

that absorbs all incident electromagnetic radiation. When a blackbody is heated, it emits a distinctive radiation spectrum with peak intensity at a temperature-dependent wavelength. Together, these properties permit a blackbody to settle into a thermal equilibrium with its surroundings. The classic set-up for studying blackbody radiation is a thermally isolated, closed cavity with inside walls that act as a perfect blackbody. According to Maxwell's electrodynamics, the isotropic radiation in the cavity will produce a radiation pressure. In 1884, Ludwig Boltzmann theorized that the total energy density of this thermal radiation is proportional to the absolute temperature of the cavity raised to the fourth power, a relationship now called the Stefan-Boltzmann law.[4]

In 1893, Wilhelm Wein showed that the wavelength at which a hot blackbody's spectrum reaches its maximum is inversely proportional to its absolute temperature. Combining this result with thermodynamic logic, Wein wrote a formula for the blackbody spectrum as a function of temperature and wavelength.[5] However, Lord Rayleigh criticized Wein's distribution function because it predicted that the spectrum's maximum energy would flat line with increasing temperature, a prediction he did not find compelling.[6] Rayleigh followed with his own theoretical formulation that relied on tracking the resonant frequencies of electromagnetic waves in the cavity. But since Rayleigh did not limit the number of high frequency resonant modes, he produced a function that diverged quickly at low wavelengths, failing to yield a maximum.[7] This problem, later dubbed the "ultraviolet catastrophe" by Paul Ehrenfest for its problems at high frequencies, implied that

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[4] $U(T) = \sigma_B \cdot T^4$ from Philip Stehle, *Order, Chaos, Order.* p. 49

[5] $u(\nu,T) = \alpha \cdot \nu^3 \cdot e^{-\beta\nu/T}$, where α and β are adjustable constants. *Ibid.,* 106.

[6] *Ibid.*, 106.

[7] The Rayleigh-Jeans law, as it is known, stated that $u(\nu,T) \propto \lambda^{-4}$

the total energy of blackbody spectrum should be infinite.[8] This was clearly wrong.

When Wein formulated his distribution function, his function closely matched the existing data, and the function was considered by some to be a universal law of nature.[9] By the summer of 1900, however, technical advances in the equipment used to test blackbody theories had advanced substantially. As experimenters began gathering new data at high wavelengths and high temperatures, Wein's law ran into trouble. The energy plateau that his theory required at high temperature failed to materialize and its prediction for high wavelength behavior did not match experimental data. While Wein's distribution function produced a spectrum with a maximum energy density at a determinate wavelength (thus avoiding an ultraviolet catastrophe), the Rayleigh-Jeans law had a better description of the spectrum's temperature dependence and high wavelength behavior. Individually, however, neither description was correct.

Max Planck, however, began working on blackbody radiation before Wein's distribution was discredited by the new data. Wein's original derivation of his famous spectrum was based on the statistical methods Boltzmann had invented to connect the kinetic theory of gasses with the rapidly developing thermodynamic theory of entropy. Planck had great faith in the results of thermodynamics, but in the 1890s, he refused to believe that the second law of thermodynamics, which states that the entropy of an isolated system tends to increase, should be interpreted statistically. Thus, he embarked on an effort to re-derive Wein's law on purely thermodynamic terms.

After he had presented his new derivation in 1899, Planck was shocked to learn that new experimental results had

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[8] *Ibid.,* 49

[9] *Ibid.,* 111.

invalidated Wein's function. During the fall of 1900, Planck worked to identify the flaws in his own derivation of the Wein spectrum. His approach relied on a model that had the walls of the blackbody cavity composed of many oscillating charged particles that could absorb the ambient electromagnetic radiation on the way to thermal equilibrium. Initially, Planck had treated the entire system of many oscillators merely as a large multiple of a single one, assuming that they would all react identically to the radiation. But when he mathematically decoupled these oscillators, he opened up a new set of possible solutions. He selected the solution with the form that best fit the available data; his choice had no underlying physical motivation.

In order to justify this choice, Planck applied thermodynamic analysis to a single one of his hypothesized oscillators. Forced to explain how a set of identical oscillators in the same environment could exist in different states, he decided to adopt Boltzmann's statistical methods, his original intention notwithstanding. In deriving his statistical mechanics, Boltzmann had to divide up the continuous spectrum of possible molecular motions into a set of discrete velocities so that he could use the tools of probability theory. At the end of his analysis, he took a limit and returned to a continuum of energies. Planck followed this procedure, quantizing the possible states of his oscillator. As he manipulated his function of a single oscillator's energy back into the form required by the entire blackbody spectrum[10], he was forced to introduce a new constant, *h*, which specified the size of his energy quantum. This led him to the final, and correct, formula for the spectrum of a hot blackbody:[11]

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[10] In particular, the argument of the denominator's exponential had to be a function of ν/T in order to be consistent with Wein's still-intact displacement law.

[11] Philip Stehle, *Order, Chaos, Order,* 123.

$$U = \frac{8\pi h\nu^3}{c^2}\frac{1}{e^{\frac{h\nu}{kT}} - 1}$$

But since Planck's constant appears as a proportionality constant, its value must be fixed. This prohibited him from using Boltzmann's limit trick to return his theory to a continuum. The quantization had to stay.

Without a coherent physical model to back up his formula, Planck was unable to fashion a clear interpretation of his new constant. *h* connected frequency energy in an unprecedented way. Initially, Planck held it to be an artifact of his statistical approach. If it had any physical meaning at all, he ascribed it to the oscillators, not to the electromagnetic radiation. Nevertheless, Planck's law fit the existing blackbody data to within the limits of experimental precision, encouraging quick and broad acceptance of his theory. His radical new assumption and his introduction of a new constant were widely ignored. When any attention was directed their way, *h* was perceived to be a necessary formality without any profound physical significance.[12]

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[12] *Ibid.*, 132.

BIBLIOGRAPHY

Althusser, Louis. “From Capital to Marx’s Philosophy” in Reading Capital. Translated by Ben Brewster. London: Verso, 1997.

———. “The Object of Capital” in Reading Capital. Translated by Ben Brewster. London: Verso, 1997.

———. “Marx’s Immense Theoretical Revolution,” in Reading Capital. Translated by Ben Brewster. London: Verso, 1997.

———. “From Capital to Marx’s Philosophy,” in Reading Capital. Translated by Ben Brewster. London: Verso, 1997.

———. Philosophy and the Spontaneous Philosophy of the Scientists. Translated by Gregory Elliott. London: Verso, 1990.

———. Writings on Psychoanalysis: Freud and Lacan. Translated by Jeffrey Mehlman. (New York: Columbia UP, 1996)

Balibar, Étienne. “The Elements of Structure and Their History,” in Reading Capital. Translated by Ben Brewster. London: Verso, 1997.

Bernecker, Sven and Fred Dretske, “Introduction,” in Knowledge. ed. Sven Bernecker and Fred Dretske Oxford: Oxford UP, 2000.

Brewster, Ben. “Glossary” in Reading Capital. London: Verso, 1997.

Carroll, Sean M. Spacetime and Geometry. San Francisco: Addison Wesley, 2004.

Einstein, Albert. “The Electrodynamics of Moving Bodies,” (1905) in On the Shoulders of Giants. Ed. Stephen Hawking. New York: Running Press, 2002.

———. “On a Heuristic Point of View About the Generation and Conversion of Light,” in The Old Quantum Theory. ed. D. Terr Haar. London: Pergamon, 1967.

———. "The Problem of Space, the Ether, and the Field in Physics" (1934) in Beyond Geometry. ed. Peter Pesic Mineola, NY: Dover, 2007.

———. Relativity: The Special and the General Theory. New York: Three Rivers Press, 1961.

Einstein, Albert and Leopold Infeld. The Evolution of Physics. Austin: Touchstone, 1967.

French, A.P. Special Relativity. Boca Raton, FL: CRC Press, 1968.

Feldman, Richard. Epistemology, Saddle River, NJ: Prentice Hall, 2003.

Foucault, Michel. The Archaeology of Knowledge Translated by Rupert Swyer. New York: Pantheon, 1972.

Galison, Peter. Einstein's Clocks, Poincaré's Maps. New York: W.W. Norton, 2003.

Gettier, Edmund L. "Is Justified True Belief Knowledge?" in Knowledge. ed. Sven Bernecker and Fred Dretske. Oxford: Oxford UP, 2000.

Bottomore, Tom. A Dictionary of Marxist Thought. Oxford: Blackwell, 1983.

Hegel, G.W.F. Introduction to The Philosophy of History. Translated by Leo Rauch. Indianapolis: Hackett, 1988.

Heisenberg, Werner. "The Copenhagen Interpretation of Quantum Theory" in The World Treasury of Physics, Astronomy, and Mathematics, ed. Timothy Ferris. Boston: Little, Brown, and Co., 1991.

Helmholtz, Hermann von. "On the Conservation of Force," in Scientific Memoirs, ed. John Tyndall and William Francis. London: Taylor and Francis, 1853.

Hume, David. A Treatise on Human Nature. Oxford: Clarendon Press, 1896.

Huygens, Christiaan. Treatise on Light. Translated by Silvanus P. Thompson. Chicago: Chicago UP, 1912. Accessed from Project Gutenberg e-Book, http://www.gutenberg.org.

Isaacson, Walter. Einstein: His Life and Universe, New York: Simon and Schuster, 2007.

Kant, Immanuel. The Critique of Pure Reason. Translated by Paul Guyer and Allen W. Wood. Cambridge: Cambridge UP, 1998.

Kuhn, Thomas. The Structure of Scientific Revolutions. Chicago: Chicago UP, 1970.

Laplace, Pierre-Simon. A Philosophical Essay on Probabilities. (1820) reprinted, New York: Dover, 1951.

Lorentz, Hendrick Antoon. "Michelson's Interference Experiment" (1895) in The Principle of Relativity, London: Methuen & Co., 1923.

———. The Theory of Electrons: (1906). 2nd Ed. New York: G.E. Stechert, 1916.

Minkowski, Hermann. "Space and Time," in The Principle of Relativity, London: Methuen & Co., 1923.

Newton, Isaac. Principia (1687) in On the Shoulders of Giants ed. Stephen Hawking Philadelphia: Running Press, 2002.

Pais, Abraham. Subtle Is The Lord: The Science and the Life of Albert Einstein. Oxford: Oxford UP, 1982.

Planck, Max. The Theory of Heat Radiation. Translated by Morton Masius. Philadelphia: P. Blackiston's Son & Co., 1914.

———. A Survey of Physics. Translated by R. Jones and D.H. Williams. London: Methuen & Co., 1925.

Poincaré, Henri. "The Measure of Time," in The Foundations of Science. Translated by George Bruce Halsted. New York: The Science Press, 1921.

Purcell, Edward M. Electricity and Magnetism. Boston: McGraw Hill, 1985.

Serres, Michel. "The Geometry of the Incommunicable: Madness," Translated by Felicia McCarren. in Foucault and his Interlocutors. Ed. Arnold I. Davidson. Chicago: U. Chicago P, 1997.

Stehle, Philip. Order, Chaos, Order. Oxford: Oxford UP, 1994.

Stokes, George. "On the Aberration of Light," Phil. Mag. 3d ser. 27:9-10 (July, 1845)

Swenson, Lyod. The Etherial Aether: A History of the Michaelson-Morley-Miller Aether-Drift Experiments, 1880-1930. Austin: Texas UP.

Young, Thomas. "The Bakerian Lecture: On the Theory of Light and Colours," Phil. Trans. R.S. 92: 14, 16, 18, 21 (1802).