Introduction

Fifty years after the untimely death of Hans Reichenbach, the evolution of his views on space, time, and motion is receiving much due critical attention. While his mature views, expressed most famously in his book *Philosophy of Space and Time*, have long been commented upon, challenged, and amended by some of the most important figures in contemporary discussions of the philosophical foundations of physics, only in the last decade or so – a couple of generations removed from the heyday of logical empiricism – is the work of Reichenbach and contemporaries like Moritz Schlick and Rudolf Carnap being widely considered in terms of its value to the history of ideas.

This collection seeks to contribute to that growing conversation by bringing together English translations of nine essays from 1920–25, the period preceding *Philosophy of Space and Time*, that have not appeared in earlier collections of Reichenbach's writings. These articles range from technical discussions published in scientific journals, to overtly philosophical discussions and responses to philosophical opponents published in philosophical journals, to semipopular pieces designed to set out Reichenbach's interpretation of relativity theory in clear, explicit terms. It is hoped that by providing access to additional "data points," the discussion of the emergence of Reichenbach's later views may be advanced.

The first half of the 1920s was a period of crucial importance both to the burgeoning movement that would become analytic philosophy and to the philosophical development of Hans Reichenbach personally. This was the period that saw Schlick move to Vienna, the publication of Ludwig Wittgenstein's *Tractatus Logico-Philosophicus*, and Alfred Tarski's initial work on set theory. It was also the time in Reichenbach's life when he sought to put his name on the philosophical map. Leaving an engineering position in Berlin, he accepted his first academic post, *Privatdozent* at the Technische Hochschule in Stuttgart. As an assistant to the physicist Erich Regener, he undertook a diverse teaching load covering courses in modern physics, radio technique, and philosophy; his research largely focused upon developing a rigorous epistemic foundation for the theory of relativity – a project that he had started in Berlin after attending Einstein's lectures at the university there and that had led to the publication of his first book, *Theory of Relativity and A Priori Knowledge*, earlier in 1920.

This rigorous epistemic foundation would be laid out in terms of what Reichenbach called a "constructive axiomatization," appearing in full for the special theory of relativity in Reichenbach's 1924 publication *Axiomatization of the Theory of Relativity*. This axiomatization was set out with two equally ambitious goals in mind. First, it was to give a complete and unambiguous account of all of the empirical and definitional commitments of Einstein's theories. This would allow for an objective assessment of the strength of experimental evidence in favor of the theory, as well as a determination of exactly what portions of the theory remained empirically unconfirmed, and could be used to clarify and comment reasonably upon objections raised to the theory. This final concern was no small matter as Reichenbach notes that during this period, in discussions of the theory of relativity "dogmatic understanding is found next to clear insight."[1]

Armed with his analysis of relativity theory and his ability to translate complex technical notions into plain language, especially through the use of colorful analogies, Reichenbach set out to be Einstein's bulldog. Reichenbach would confront Einstein's critics on their own turf, whether in the scholarly arena or the popular press, whether the objection was based upon scientific, epistemological, logical, or intuitive grounds. He took it as his mission to defend and popularize the relativity theory, writing articles and responses in professional physics and philosophy journals, books for the general reader, and articles in popular science magazines, even giving a series of radio broadcasts.

Reichenbach saw the discussion of Einstein's work on relativity advancing on two distinct fronts. On one side were those commentators who took issue with the theory of relativity on physical or a priori grounds but who had little or no understanding of the details of the theory, and on the other side stood those opposed to Einstein despite being well schooled in physical theory. The first group contained its share of cranks. For example, in "Einstein's Theory of Motion" (Chapter 6 in this collection), Reichenbach recounts tales of such intellectual "off-key notes," including one opponent who wrote to the Swedish Academy demanding the Nobel Prize for uncovering "the 'miscalculation' in Einstein's theory." Reichenbach never held back on his sharp wit in dealing

1 Reichenbach 1920*a*, p. 2.

with such attacks, but far from engaging in mere ad hominem argument, he sought to clearly refute all objections.

But the group also contained a fair number of respected philosophers. Indeed, Reichenbach refers to this period as "a time of increasing philosophical unrefinement (including among the tenured philosophers)."[2] Criticism of relativity came from virtually all corners of the philosophical landscape, most notably from Neo-Kantians and Machian Positivists. A core group of Neo-Kantians, such as Ewald Sellien and Ilsa Schneider, realized the threat that relativity, with its lack of absolute time and its use of non-Euclidean geometry, posed to an orthodox understanding of the transcendental aesthetic and sought to provide a priori grounds for the theory's failure. To this audience, Reichenbach could point to his *Theory of Relativity and A Priori Knowledge*, in which he sought to salvage what he thought important in Kant and jettison that which he saw as problematic.

Not all Neo-Kantians, of course, took such a dogmatic and flawed postion. Ernst Cassirer, in particular, is singled out by Reichenbach as having "awakened Neo-Kantianism from its 'dogmatic slumber', while its other adherents carefully tried to shield it from any disturbance by the theory of relativity."[3] Having attended Cassirer's lectures in 1913–14, and having been exposed to Kant earlier by Alois Riehl, Ernst von Aster, and Karl Stumpf, Reichenbach's work maintained a strong Kantian element throughout the entire span of his writings, but it is especially evident in this early period.

Beside the Neo-Kantian discussions, Machian positivists were also quite vocal on issues pertaining to the theory of relativity.

2 Reichenbach 1920*b*, p. 1.
3 Reichenbach 1921*a*, p. 25.

Ernst Mach himself simultaneously played the conflicting roles of forefather and opponent of the theory of relativity. Reichenbach's treatment of Mach's work is thereby both deferential and critical. We find repeated discussions of the insights that led Mach to overthrow the needlessly metaphysical foundation upon which Newton grounded his mechanics, but we also see repeated criticisms of Mach's attempt to respond to physical aspects of this question with a priori argumentation. The complete instantiation of a relativistic mechanics required not only the philosophical shift away from Newton provided by Mach, but also a physical alternative missing in his work. This, of course, Reichenbach finds in the work of Einstein.

Upon Mach's death, his successors divided along this fault line. Joseph Petzold seized on the "forefather of relativity" angle and sought to reconstruct the theory of relativity in purely phenomenal terms,[4] while Hugo Dingler aligned himself with Mach's opposition to Einstein. In his "Reply to H. Dingler's Critique of the Theory of Relativity" (Chapter 3 in this collection), Reichenbach systematically attacks Dingler's stance that seeks to undermine the observer dependence of distance and duration in the theory of relativity by trying to marry Mach's a priori relativistic understanding of translation to a Newtonian absolutist view of rotation.

Among the scientific objections raised to relativity theory, Reichenbach spends the most time considering suggested empirical mechanisms for the absolute determination of simultaneity for nonlocal events, such as the slow transport of clocks (see Chapter 7 in this collection). In other physical discussions he seeks to

4 For a full account of the Reichenbach/Petzold correspondence, see Hentschel 1991*b*.

clarify the impact on relativity theory of experiments designed to test the principle of the constancy of the speed of light using observations of the eclipses of the moons of Jupiter and empirical challenges to the results of the Michelson experiment (see Chapter 11 in this collection).

But not all commentators of the period were to be considered foes; there were friends involved in the discussion as well. Most notable among these is Moritz Schlick, a former student of Max Planck and the author of *Space and Time in Contemporary Physics*, a book that counted among its admirers Albert Einstein himself. Much has been made of Reichenbach's comments about Schlick's major work, *General Theory of Knowledge*, in Reichenbach's *Theory of Relativity and A Priori Knowledge* and the correspondence between Schlick and Reichenbach in 1920,[5] but less has been said about Reichenbach's published review of the work.[6] This review is included as Chapter 1 in this collection.

More complex is the case of Hermann Weyl, the accomplished mathematical physicist. Weyl not only understood the theory of relativity, but proposed an extension of it representing the first full attempt at a unified field theory. Reichenbach and Weyl discussed the foundations of relativity theory by correspondence, and Reichenbach refers deferentially to Weyl throughout his works, even mentioning Weyl's *Space, Time, Matter* as a preferred introduction to relativity for laymen. But the relationship took a turn for the worse when Weyl published a blisteringly negative review of Reichenbach's *Axiomatization of the Theory of Relativity*, calling the work "unsatisfactory" as a result of being "too cumbersome and overly obscure." Reichenbach responds in kind in "On the

5 See Friedman 1994 and 1999 and Coffa 1990.
6 The notable exception is Hentschel 1991*a*.

Physical Consequences of the Axiomatization of the Theory of Relativity" (Chapter 12 in this collection), offering what he terms a "strenuous defense" against Weyl's objections.[7]

In addition to attempting to clarify the muddled state of the discussion of relativity at that time, the second goal of Reichenbach's constructive axiomatization was to serve as a model for future philosophical research. Kant's doctrine of the synthetic a priori had been successful, Reichenbach contended, in demonstrating the role of constitutive elements in the groundwork of our knowledge. However, in light of the advances of mathematics at the end of the nineteenth century and of physics at the start of the twentieth, Kant's epistemology had displayed a fatal flaw. It was unable to free itself from the limitations of the Euclidean and Newtonian theories that it had been constructed to justify. Reichenbach sought to develop a "method of scientific analysis"[8] that contained the constitutive elements of Kant, but that replaced the apodictic nature of these concepts with a sophisticated sense of theory dependence. In this way, individual analyses would be theory-specific, but the epistemological basis of the method of the

7 For more on Reichenbach and Weyl, see Ryckman 1994 and 1996 and Rynasiewicz 2002 and 2005.

8 The term "*wissenschaftsanalytische Methode*" has been translated in this collection as the "method of scientific analysis" instead of using the phrase "method of logical analysis" employed by Maria Reichenbach in her translations. The reasons for this choice are twofold: first, it is closer to the literal translation of the term and, second, it distances the analytic process proposed in Reichenbach's version of Logical Empiricism from that of Rudolf Carnap's brand of Logical Positivsm, with which it is often wrongly conflated. Unlike Carnap's attempts to construct empirical claims using only logical and empirical terms, the observational atoms in Reichenbach's axiomatizations are still quite pregnant with theoretical terms, albeit terms of theories past. This difference renders the use of the adjective "scientific" instead of "logical" in this central phrase warranted in this context. For a discussion of the theory-laden aspects of observation sentences in Reichenbach's axiomatic method, see Gimbel 2004.

analyses would no longer be pregnant with the concepts of any particular theory.

In Michael Friedman's terminology, Reichenbach tried to move epistemology from the synthetic a priori to the "relativized *a priori*."[9] But like Kant and Hume before him, whose attempts to radically revise philosophical discourse fell stillborn from the presses, Reichenbach's axiomatization received less attention and acclaim than he had hoped it would, being too technical for philosophical audiences and too philosophical for scientific readers. This work, however, along with the aid of Einstein and Max Planck, was sufficient to land Reichenbach a teaching position in natural philosophy at the University of Berlin in 1926. Returning to Berlin, Reichenbach would go on to publish his best-known work, *Philosophy of Space and Time*, organize the Gesellschaft für Empirische Philosophie, and begin and edit the journal *Erkenntnis* in conjunction with Rudolf Carnap in Vienna and later in Prague.

It has been noted by several significant commentators[10] that Reichenbach's views on space, time, and motion underwent a significant alteration in the years between *Theory of Relativity and A Priori Knowledge* and *Philosophy of Space and Time*. He began the decade eschewing Poincaré's conventionalist doctrine and ended it as a self-proclaimed adherent. Different accounts are offered to explain this shift. With respect to this discussion, three foci of Reichenbach's discussions in the following essays should be introduced: the undermining of Newton's doctrine of absolute time, the constructability of a light geometry, and the emergence of Reichenbach's empiricist version of geometric conventionalism.

9 See Friedman 1994 and 1999.
10 For example, see Friedman 1994 and 1999, Coffa 1990, and Ryckman 1994, 1996, and 2003.

While Reichenbach's views on the epistemology of geometry have far and away garnered the most critical attention from scholars, it is not the topic that dominates Reichenbach's own works. While geometric concerns are certainly discussed in the works of this period, much more attention is paid by Reichenbach during this period to issues of time. Indeed, significant discussions of absolute and relativistic time may be found in the majority of the articles in this collection, and time is the sole matter of attention in several of them.

This should not be unexpected. In section II of *Theory of Relativity and A Priori Knowledge*, Reichenbach argues that the main philosophical upshot of Einstein's special theory of relativity is a correction to the classical notion of time. We find this position maintained throughout the articles in this collection, which are largely devoted to mining Reichenbach's axiomatization of the special theory for its philosophical ramifications. Reichenbach argues that among the most significant results of this axiomatic project are (1) the positing of a distinction between the epistemological and physical senses of absolute time, and (2) the explicit determination of what empirical evidence supports Einstein's arguments for the dissolution of absolute time in the physical sense.[11]

But significant attention is also paid to geometrical concerns. Of the initial results of the constructive axiomatization, Reichenbach repeatedly cites the possibility of the construction of a light geometry in Minkowski space-time as one of the most important. Reichenbach argues in his "Report on an Axiomatization of

[11] For a discussion of the introduction of Reichenbach's famous ε-formulation of Einstein's definition of simultaneity and the role it plays in his view of time in the special theory of relativity, see Rynasiewicz 2002.

Einstein's Theory of Space-Time" (Chapter 4 in this collection) that it is possible to determine a space-time geometry univocally without the use of material rods or clocks. The combination of empirical axioms governing the behavior of light and needed coordinative definitions are by themselves sufficient to completely describe the geometric structure of Minkowski space-time. Matter axioms need only specify that material bodies conform to the geometry specified by light signals.

This emphasis on the constructability of a light geometry suited Reichenbach's aims in a couple of ways. For his professional audience, the ability to derive the space-time metric from purely optical phenomena placed the foundation of Einstein's theory on almost entirely firm ground. With only a couple of small exceptions, the experimental evidence for each of the light axioms used to create the light geometry was widely accepted within the scientific community. One could ground the theory's validity upon innocuous results from optics without reference to the more contentious descriptions of the behavior of matter. This was also useful for his discussions geared toward the popular audience, where Reichenbach could now set out the counterintuitive results of the theory as flowing from an almost fully supported and completely independent evidentiary basis.

Unfortunately, Reichenbach's claims of the complete and unique constructability of the light geometry failed. Weyl pointed out to Reichenbach that the geometry of relativistic space-time was, in fact, underdetermined by the purely optical means Reichenbach employed. If one makes certain topological assumptions and restricts consideration to spaces free of singularities, then the light geometry is constructable in the way that Reichenbach requires. But this assumption requires an axiom, an empirical foundation. One can easily solve this problem through the