Physics 115 **Fact Sheet** **Fall Term, 2005**

ASPECTS OF PHYSICS: RELATIVITY

INSTRUCTOR: Dr. David M. Cook, Department of Physics

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OFFICE HOURS: Most Sunday evenings, 7:00–9:00 PM; 1:30–3:00 PM M; 9:30–11:00 AM R; by appointment.

READING LIST:

1. *The Evolution of Physics*, A. Einstein and L. Infeld, which will provide necessary historical background and motivation for the development of relativity.
2. *Relativity:The Special and the General Theory*, A. Einstein, which will provide a detailed description of the essence of the special and general theories of relativity.
3. *Flatland/Sphereland*, E. A. Abbott and D. Burger, which, in a fairy-tale like presentation, will focus on ways in which one can learn about higher dimensions from observations made in lower dimensions.
4. *General Relativity from A to B*, R. Geroch, which will provide a detailed—and geometrically oriented—discussion of the general theory of relativity, including the curvature of space-time and black holes.

LIBRARY RESERVE: The following works have been placed on reserve at the library:

- [qQC6/T35] E. F. Taylor and J. A. Wheeler, *Spacetime Physics*
- [QC6/R388] R. Resnick, *Introduction to Special Relativity*
- [QC71/E515] A. Einstein, *Essays in Science*
- [QC16/E5F7] P. Frank, *Einstein: His Life and Times*
- [QC16/E5A3] A. Einstein, *Out of My Later Years*
- [QC6/.S6] E. E. Slosson, *Easy Lessons in Einstein*
- [QC16/E5I5] L. Infeld, *Albert Einstein: His Work and Its Influence on Our World*
- [QC16/E5C5] R. W. Clark, *Einstein: The Life and Times*
- [QC16/E5P26] A. Pais, *Subtle is the Lord*
- [QC6/R8] B. Russell, *The ABC of Relativity*
- [QC173.55/M66] D. Mook, *Inside Relativity*
- [QC6/G23] G. Gamow, *Mr. Tompkins in Wonderland*
- [QC125.2/C36] B. Casper, *Revolutions in Physics*
- [QC16/E5 P25] A. Pais, *Einstein Lived Here*
- QC16/E5B45] J. Bernstein, *Einstein*
- [Q175/K95] T. S. Kuhn, *The Structure of Scientific Revolutions*

While no specific assignments will be made in these materials, they may nonetheless be useful both as a supplement to the assigned readings and in connection with your preparation of the term paper to be written in the last four weeks of the term. You are urged to make a habit of browsing occasionally in this reserve shelf.

SCHEDULE: The schedule for this course is included later in this fact sheet.

READING ASSIGNMENTS: Most class periods will be devoted to discussion of assigned readings. Among other things, the accompanying schedule indicates the reading that should be completed *before* coming to each class.

THE LABORATORY SCIENCE REQUIREMENT: Please note that Physics 115 satisfies the B.A. and B.A./B.Mus. requirement for six units in a *non-laboratory* course in a natural science (Biology, Chemistry, Geology, Physics) but does *not* satisfy the B.A. or B.A./B.Mus. requirement for six units in a *laboratory* course in a natural science. Physics 115 satisfies the B.Mus. requirement for 'six units selected from departments and courses listed within the Division of Natural Sciences' (Biology, Chemistry, Geology, Mathematics, Physics).

NOTE SHEETS: Careful reading, of course, requires personal, aggressive, and thoughtful interaction with the text. Remaining alert both to the substance of the material and to the structure of its presentation, marking particularly significant passages directly in the text, and writing appropriate notes as your reading proceeds are essential components of careful reading. By the time you are finished with a particular reading assignment, your notes thereon should include

1. An identification of the main issue(s) addressed by the author;
2. An enumeration of the author's primary points, together with a (very brief) summary of the author's presentation or argument;
3. An enumeration of aspects you feel you don't yet fully understand; and
4. A summary of your personal reactions and thoughts as provoked by the reading.

The first three of these items have to do with understanding what the author is saying; the fourth item in part constitutes criticism of the author's ideas but more importantly makes explicit your intellectual growth as fostered by engagement with the author. While they will certainly not be limited to these four items, class meetings will start by considering them.

Each student is urged to prepare a note sheet containing the above four items prior to coming to each class. This note sheet need not be written in complete sentences, but entries should be arranged in groups by the categories identified above and (where appropriate) entries should be keyed to the text. I will not ask you to hand these sheets in but, together with the text itself (as marked during your reading), they will provide useful reference during class discussions.

WRITING EXERCISES: Each student will complete five writing exercises in this course. A short paper is due at 5:00 PM on Thursday, 1 October. Longer papers will be written on each of the first two books. In addition (because doing problems is part of learning physics), one problem set will be assigned. During the last four weeks of the term, each student will work on a term paper while readings and class discussions continue. Statements defining these exercises are included with this fact sheet.

EXAMINATIONS: Two closed-book examinations will be administered in this course. A mid-term will be given in class time on Friday, 28 October; the final examination is scheduled for 8:30 AM on Tuesday, 6 December. More information on each of these examinations will be provided in due time.

GRADING: Each student's grade in this course will be determined by the quality of the submitted written exercises and by the examinations. The various components will receive approximately the following weights:

First short paper	5%	Paper on Einstein	10%
Paper on Einstein/Infeld	10%	Term Paper	15%
Problem set	10%	Final examination	30%
Hour examination	20%		

Class participation will also be taken into account, possibly raising or lowering the grade determined by the above components by up to a full letter grade.

HONOR SYSTEM: Except where appropriate acknowledgments are given to the contributions of others, work submitted in response to assignments and examinations in this course is understood to originate with the student submitting the work, and the Lawrence Honor Code is to be reaffirmed on each submitted item. At the same time, students constitute a substantial intellectual resource for one another, and you are encouraged to talk about the material of the course with one another—over lunch or dinner, in small group conversations out of class, etc.—so as to tap into that resource. You should, however, be wary if you are *always* on the receiving end in these conversations. By the end of a group discussion on some topic of the course, you should be confident of your own personal understanding of the issues discussed.

SCHEDULE

We	21 Sep	Introduction
Fr	23 Sep	Einstein and Infeld: Introduction, Preface, Section I, pp. xi–35
Mo	26 Sep	Einstein and Infeld: Sections I, II, pp. 35–84
We	28 Sep	Einstein and Infeld: Section II, pp. 84–122
Fr	30 Sep	SHORT PAPER DUE Einstein and Infeld: Section III, pp. 125–153
Mo	3 Oct	Einstein and Infeld: Section III, pp. 153–199
We	5 Oct	Einstein and Infeld: Sections III, IV, pp. 199–245, 294-296
Fr	7 Oct	LECTURE PAPER ON EINSTEIN AND INFELD DUE
Mo	10 Oct	Einstein: Sections 1–10
We	12 Oct	LECTURE
Fr	14 Oct	Einstein: Sections 11–14 and Appendix 1
Mo	17 Oct	Einstein: Sections 15–17 and Appendix 2
We	19 Oct	LECTURE SHORT PROBLEM SET DUE
Fr	21 Oct	Einstein: Sections 18–24 and Appendix 3
Mo	24 Oct	Einstein: Sections 25–32 and Appendix 4
We	26 Oct	General Discussion/Review
Fr	28 Oct	IN-CLASS HOUR EXAMINATION
Mo	31 Oct	Abbott: Limitations and Part I , pp. vii–59
We	2 Nov	Abbott: part II, pp. 61–120 PAPER ON EINSTEIN DUE
Fr	4 Nov	NO CLASS – MID-TERM READING PERIOD
Mo	7 Nov	Burger: Einstein Happened, pp. vii–x; and Parts I and II, pp. 27–119
We	9 Nov	Burger: Parts III, IV pp. 120–205
Fr	11 Nov	Geroch: Introduction, Chapters 1, 2, pp. ix–36
Mo	14 Nov	Geroch: Chapters 3, 4, pp. 37–63
We	16 Nov	Geroch: Chapter 5, pp. 67–92
Fr	18 Nov	Geroch: Chapter 5, pp. 93–112
Mo	21 Nov	Geroch: Chapter 6, pp. 113–158
We	23 Nov	NO CLASS – THANKSGIVING VACATION
Fr	25 Nov	NO CLASS – THANKSGIVING VACATION
Mo	28 Nov	Geroch: Chapter 7, pp. 159–186
We	30 Nov	Geroch: Chapter 8, pp. 187–221
Fr	2 Dec	Catch-up/Review TERM PAPER DUE AT 5:00 PM
Tu	6 Dec	(8:30 AM) FINAL EXAMINATION

STATEMENT ON SHORT PAPER: (due Friday, 30 September)

Limiting yourself to a page and a half of double-spaced, typed text, write a brief, well-organized discussion of *one* of the following topics. Your final product is to be handed in at the start of class on Friday, 30 September. (All page references are to Einstein and Infeld.)

1. Explain what Einstein and Infeld mean by the following statement: "Human thought creates an ever changing picture of the universe." (p. 9)
2. Explain the difference between gravitational and inertial mass. (pp. 31–35)
3. Explain what is meant by the mechanical view of the universe. (pp. 51–55)

STATEMENT ON PAPER ON EINSTEIN AND INFELD: (due Friday 7 October)

Write a well organized, three to five page paper on one of the following two topics. Your completed paper is to be turned in at the start of class on Friday, 7 October. (All page references are to Einstein and Infeld.)

1. "We have seen that this law of inertia cannot be derived directly from experiment, but only by speculative thinking consistent with observation. The idealized experiment can never be actually performed, although it leads to a profound understanding of real experiments." (p. 8)

   "The ideal conductor or insulator is a fiction which can never be realized." (p. 72)

   "The concept of a plane wave, like many other physical concepts, is no more than a fiction which can be realized with only a certain degree of accuracy." (p. 105)

   "Unfortunately, we cannot place ourselves between the sun and the earth to prove the exact law of inertia and to get a view of the rotating earth. This can be done only in imagination." (p. 155)

   Discuss in general terms and illustrate by suitable examples the role of idealization and abstraction in the development of successful theoretical approaches to understanding physical phenomena.

2. ". . . the meaning of experiments does not become apparent until theory makes it so." (p. 69)

   "It is hardly possible to imagine such experiments performed as accidental play, without the pre-existence of more or less definite ideas about their meaning." (p. 71)

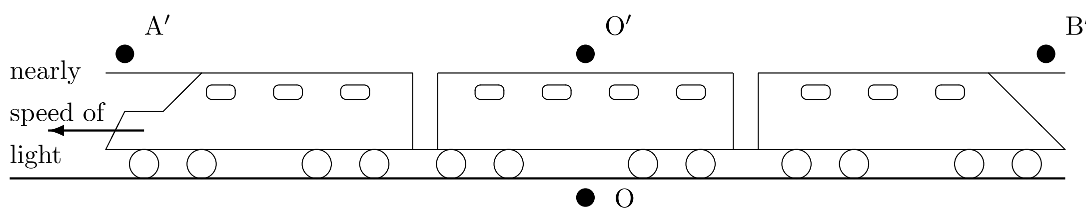
   "With the help of physical theories, we try . . . to order and understand the world of our sense impressions." (p. 296)

   These quotations from Einstein and Infeld hint at the author's conviction that the prevailing theoretical framework influences the kinds of experiments regarded to be worthwhile and hence influences the directions in which science advances from its current state. Discuss this point, both in general terms and by means of specific examples.

PROBLEM SET: (due Wednesday, 19 October)

Solutions to or discussions of the following three problems are to be written out (typing is not necessary) carefully but briefly and handed in at the start of class on Wednesday, 19 October. A paragraph on each problem will be sufficient. In this assignment, I am most interested in your understanding of the physics, but I shall still expect a clear and logically structured exposition of your solution.

1. As shown in the figure below, three observers (A′, O′, and B′) are riding on a train that is moving *to the left* at nearly the speed of light relative to O, who is standing on the ground beside the rails. A′ is in front, O′ is *exactly* at the middle, and B′ is at the rear. At the very instant that O′ passes O, it happens that two flash signals reach O and O′ simultaneously, one from A′ and the other from B′. Was the signal from A′ emitted before, simultaneously with, or after the signal from B′? Present the answer given by O and the answer given by O′, with a careful defense of each.



2. A worried student writes, "Relativity must be wrong. Consider a 20 meter pole carried so fast in the direction of its length that it appears to be only 10 meters long in the barn's frame of reference. At some instant, the pole can be entirely enclosed in a barn 10 meters long. Looked at from the runners frame of reference, however, the barn appears to be contracted to half its length. How can a 20 meter pole fit into a 5 meter barn? Does not this unbelievable conclusion prove that relativity contains somewhere a logical inconsistency?" Write a brief reply to the worried student explaining how, from the perspective of the special theory of relativity, the pole and barn can be treated from each frame of reference without contradiction. *Hint*: Look closely at the events that play a role in determining whether the pole is in the barn or not.

3. Starting with the Lorentz transformation for intervals,

$$\Delta x' = \frac{\Delta x - v\,\Delta t}{\sqrt{1 - v^2/c^2}} \qquad ; \qquad \Delta t' = \frac{\Delta t - v\,\Delta x/c^2}{\sqrt{1 - v^2/c^2}}$$

(a) find an expression for the spatial separation relative to O′ of two events that are simultaneous ($\Delta t = 0$) relative to O but—again relative to O—are separated spatially by Δx, (b) find an expression for the velocity $V' = \Delta x'/\Delta t'$ of an object relative to O′ in terms of the velocity $V = \Delta x/\Delta t$ of that same object relative to O, and (c) show that $(\Delta x)^2 - c^2(\Delta t)^2$ is invariant to the Lorentz transformation, i.e., show that $(\Delta x)^2 - c^2(\Delta t)^2 = (\Delta x')^2 - c^2(\Delta t')^2$.

STATEMENT ON PAPER ON EINSTEIN: (due Wednesday 2 November)

Write a well organized, three to five page paper on one of the following topics. Your completed paper is due at the beginning of class on Wednesday, 2 November.

1. The special theory of relativity leads to a number of predictions that seem to violate ordinary common sense. Discuss at least three such predictions in some detail.
2. In Einstein and Infeld, the authors refer to the equality of gravitational and inertial mass as "the neglected clue" (pg. 32). Lay out the essential conceptual ideas underlying the *general* theory of relativity and, in particular, explain carefully the conceptual distinction between gravitational mass and inertial mass and explain why the equality of these two masses is crucial for the general theory of relativity. (I realize that a component of this topic duplicates one of the topics on the first short writing assignment, but the context of that component is different here and must be laid out as part of your paper this time.)

STATEMENT ON TERM PAPER: (due 5:00 PM, Friday 2 December)

Your final paper in this course is due at 5:00 PM on Friday, 2 December. In contrast to the previous papers (which have focused on single works that we have all read), your final paper is to summarize the results of a (small) research effort on your part. Several topics are suggested below. (I am willing to listen to proposals for alternative topics.) The readings we have examined in class provide a starting point—but *only* a starting point—for each of these topics. Your task for this assignment is to seek additional information from as many sources as you can locate—look first at the books on reserve in the library—and then to write a carefully constructed five to eight page paper summarizing what you have learned about your topic. Careful documentation is required, not only through consecutively numbered footnotes or endnotes identifying the source of each quotation or major idea not your own but also through the inclusion of a bibliography of the works consulted.[1]

The following topics are suggested as possibilities for your final term paper. Topic 1 is already quite narrowly defined. The remaining topics, however, are less specific and offer more room for adjustment or refinement in response to your initial reading in the appropriate general areas.

Each topic is accompanied by a number of suggested references. Those supplied with a library call number (in square brackets) are owned by the Lawrence library and are either on reserve or available for borrowing. Those with the call designation '[DMC]' can be borrowed from Mr. Cook. All journal articles can be found in bound volumes in the stacks in the library. While pieces of some articles are too advanced—and, here and there, far too advanced—for this course, all of many and most of the rest of the articles should be of value as you write on the topic.

1. Twin (or Clock) Paradox

   At birth, one of two twins is placed in a rocketship and sent on a long journey at speeds close to the speed of light. Ultimately, the traveller returns to the birthplace. Special relativity predicts that the traveller will be younger than the stay-at-home twin. But how does one decide *which* twin made the journey? A paper on this topic would lay out and comment on this famous paradox.

   Beginning sources:

   - J. Bronowski, "The Clock Paradox", *Scientific American*, February, 1963, pp. 134 ff.
   - Mendel Sachs, "Space, Time, and Elementary Interactions in Relativity", *Physics Today*, February, 1969, pp 51–60.

[1] I will not insist on any particular style, but whatever style you adopt must be consistently used throughout your paper. You might find it worthwhile to review the section titled "Documentation", "Library Research", "Footnoting", or some other equivalent title in your favorite style manual or handbook, e.g., Section 33 in the *Harbrace College Handbook*, Eighth Edition (Harcourt, Brace, Jovanovich, New York, 1977) or pages 86–157 in *A Pocket Style Manual*, Second Edition (Bedford Books, Boston, 1997) by Diana Hacker.

- [QC6/R388] R. Resnick, *Introduction to Special Relativity* (Wiley, New York, 1968) Supplementary Topic B.
- [q.QC23.F47] Richard Feynman *et al.*, *The Feynman Lectures on Physics, Volume I* (Addison-Wesley, Reading, MA, 1963). You will find Section 16–2 particularly useful, though—ignoring the detailed mathematics, you may find parts of Chapters 15 and 16 useful as well.
- [DMC] E. F. Taylor and J. A. Wheeler, *Spacetime Physics, Second Edition*, Chapter 4 (Freeman, New York, 1992) ISBN 0-7167-2327-1.
- [q.QC6/T35] E. F. Taylor and J. A. Wheeler, *Spacetime Physics, First Edition* (Freeman, San Francisco, 1966) ISBN 0-7167-0336-X. Look particularly at problem 49 (pg. 94).
- J. C. Hafele and Richard E. Keating, "Around the World Atomic Clock: Predicted Relativistic Time Gains", *Science* **177**, 166–167 (14 July 1972).
- J. C. Hafele and Richard E. Keating, "Around the World Atomic Clock: Observed Relativistic Time Gains", *Science* **177**, 168–170 (14 July 1972).
- Chalmers W. Sherwin, "Some Recent Experimental Tests of the 'Clock Paradox' ", *Physical Review* **120**, 17–21 (1960).

2. Experimental Tests of Special Relativity

The predictions of the special theory of relativity are often at odds with the corresponding classical predictions. Numerous experimental results, however, support special relativity. A paper on this topic might focus *extensively* on a single test (e.g., the Michelson - Morley experiment: Identify the experiment, discuss what motivated its performance, explore the role it actually played in Einstein's development of special relativity, compare the original perception of the experiment when it was performed with its perception from the perspective of special relativity, etc.). Alternatively, it might survey each of several separate tests less fully. In either case, your paper should begin with a brief description of the essence of the theory of special relativity.

Beginning sources:

- Mendel Sachs, "Space, Time, and Elementary Interactions in Relativity", *Physics Today*, February, 1969, pp 51–60.
- Robert S. Shankland, "Michelson and His Interferometer", *Physics Today*, April, 1974, pp. 37–43.
- J. C. Hafele and Richard E. Keating, "Around the World Atomic Clock: Predicted Relativistic Time Gains", *Science* **177**, 166–167 (14 July 1972).
- J. C. Hafele and Richard E. Keating, "Around the World Atomic Clock: Observed Relativistic Time Gains", *Science* **177**, 168–170 (14 July 1972).
- Nalina Easwar and Douglas A. MacIntire, "Study of the effect of relativistic time dilation on cosmic ray muon flux—An undergraduate modern physics experiment", *American Journal of Physics* **59**, 589–592 (1991).
- H. J. Hay, J. P. Schiffer, T. E. Cranshaw, and P. A. Egelstaff, "Measurement of the Red Shift in an Accelerated System Using the Mössbauer Effect in Fe^{57}", *Physical Review Letters* **4**, 165 (1960).
- Chalmers W. Sherwin, "Some Recent Experimental Tests of the 'Clock Paradox' ", *Physical Review* **120**, 17–21 (1960).
- [QC173.55/M66] Delo E. Mook and Thomas Vargesh, *Inside Relativity* (Princeton University Press, Princeton, NJ, 1987), Chapters 3 and 4, ISBN 0-691-08472-6.

3. The Theory of General Relativity

General relativity came into being as physicists tried to remove all reference to any specially singled-out coordinate systems from the laws of physics. Write about the general theory of relativity. Your paper should give attention to (1) the starting point for the development of the theory, (2) the major predictions of the theory, and (3) the experimental evidence that supports it. Do not ignore any one of these three components altogether, but you are free to choose your own relative emphases. In dealing with predictions and experimental support, do not limit yourself to the three classical tests (extra precession of the orbit of Mercury; the bending of light by strong gravitational fields; the gravitational redshift) but find out about some of the more recent cosmological issues (white holes, black holes, wormholes, expansion of the universe, ...) that, in the last three or four decades, have resulted in a blossoming of interest in general relativity.

Beginning sources:

- Mendel Sachs, "Space, Time, and Elementary Interactions in Relativity", *Physics Today*, February, 1969, pp 51–60.
- [QB981.K3] William J. Kaufmann, III, *Relativity and Cosmology, Second Edition* (Harper Row, New York, 1977) ISBN 0-06-043572-0.
- [QB331.N37] Jayant V. Narlikar, *The Lighter Side of Gravity* (W. H. Freeman, San Francisco, 1982) ISBN 0-7167-1344-6.
- [QC6/T526] Kip S. Thorne, *Black Holes and Time Warps: Einstein's Outrageous Legacy* (W. W. Norton, New York, 1994) ISBN 0-393-03505-0.
- Philip C. Peters, "Black Holes: New Horizons in Gravitational Theory", *American Scientist* **62**, 575-583 (1974).
- [QB981.W48] Steven Weinberg, *The First Three Minutes: A Modern View of the Origin of the Universe* (Basic Books, 1977).
- Robert Wald, "Particle Creation near Black Holes", *American Scientist* **65**, 585–590 (1977).
- [QB981.S554] Joseph Silk, *A Short History of the Universe* (Freeman, New York, 1994) ISBN 0-7167-5048-1.
- Joseph Silk, *The Big Bang* (Revised and Updated Edition) (Freeman, New York, 1989) ISBN 0-7167-1997-5. A copy of the original edition (1980; ISBN 0-7167-1085-4) is in the library ([QB981.S55]).
- R. V. Pound and G. A. Rebka, Jr., "Variation with Temperature of the Energy of Recoil-Free Gamma Rays from Solids", *Physical Review Letters* **4**, 274–275 (1960).
- R. V. Pound and G. A. Rebka, Jr., "Apparent Weight of Photons", *Physical Review Letters* **4**, 337–341 (1960).
- [QC173.55/M66] Delo E. Mook and Thomas Vargesh, *Inside Relativity* (Princeton University Press, Princeton, NJ, 1987), Chapters 5 and 6, ISBN 0-691-08472-6.

4. Einstein – The Man and His Thoughts

Einstein was, of course, much more than the author of the special and the general theories of relativity. As a scientist, he contributed to many areas of physics. (His Nobel prize wasn't even awarded for the theory of relativity!) As a citizen of the world community, he played a much larger role in science and, for that matter, in world affairs than we have had time to explore in this course. A paper on this topic might briefly identify several of Einstein's contributions to twentieth-century physics and then discuss one or two contributions (excluding relativity) in greater detail; or it might identify and explore some of Einstein's positions and actions on political issues; or it might examine Einstein's religious beliefs and/or his lifelong sense of wonder at the behavior of the physical world; or, taking Einstein as an example, it might examine in broad terms wherein lies genius and how genius is best nurtured.

Beginning sources:

- [QC16.E5 B45] Jeremy Bernstein, *Einstein* (Viking Press, New York, 1973) ISBN 670-01959-3.
- [DMC] Banesh Hoffman, *Albert Einstein: Creator and Rebel* (Viking Press, New York, 1972).
- [DMC] G. J. Whitrow (editor), *Einstein: The Man and his Achievement* (Dover, New York, 1967) ISBN 0-486-22934-3.

- [QC16/E5P26] A. Pais, *Subtle is the Lord* (Clarendon Press, Oxford, 1982) ISBN 0-19-853907-X.
- [QC16/E5P25] A. Pais, *Einstein Lived Here* (Clarendon Press, Oxford, 1994) ISBN 0-19-853994-0.
- Mendel Sachs, "Space, Time, and Elementary Interactions in Relativity", *Physics Today*, February, 1969, pp 51–60.
- Robert S. Shankland, "Conversations with Albert Einstein", *American Journal of Physics* **31**, 37–47 (1963).
- [QC16/E5I5] Leopold Infeld, *Albert Einstein: His Life and Its Influence on Our World* (Scribner, New York, 1950).
- [QC16/E5A3] Albert Einstein, *Out of My Later Years* (Philosophical Library, New York, 1950).