Resource Letter SRT 1 on Special Relativity Theory

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NOTES AND DISCUSSION

Resource Letter SRT 1 on Special Relativity Theory ✩

(September 1962)

Prepared by Gerald Holton, Department of Physics, Harvard University, at the request of the Commission on College Physics.

This is one in a series of Resource Letters on different topics, intended to guide college physicists to some of the literature and other teaching aids (e.g., films, educational apparatus) that may help them to improve course contents in specified fields of physics. No Resource Letter is meant to be exhaustive and complete; in time, there may be more than one on each of the main subjects of interest. Your suggestions and comments will be welcomed.

Terminology: The letter E after the consecutive item number (e.g., 2.E) means the items should be mainly useful for elementary (freshman liberal arts through sophomore physics) courses; the suffix I (e.g., 7.I) indicates intermediate (junior, senior) courses; and the suffix A indicates advanced (senior, graduate) courses. An asterisk (*) signals items particularly recommended for introductory study.

Additional copies: Available from American Institute of Physics, 335 East 45 Street, New York 17, New York. When ordering, request Resource Letter SRT-1, and enclose a stamped return envelope.

I. INTRODUCTION

Over the next few years, a good deal more SRT (special relativity theory) will find its way into introductory and intermediate college physics courses. With this aim in view, plans for writing and for equipment development are at last under way in several colleges. Instructors everywhere should seriously think now of participating in this effort, or at least of getting themselves and their classes ready to use more teaching material on SRT. For this purpose, the present Resource Letter, the first one on this subject, takes a selective look at certain helpful resources that are now available on some of the main topics in SRT. It is intended to be used by instructors, but may also be useful to students doing a course essay on a specific subtopic.

The instructor interested in introducing more SRT in his course faces at least five problems: (1) The amount of publication is immense, but its usefulness for the classroom is usually low. (2) Very little equipment or other aids exist to help the man behind the empty lecture bench make his points. (3) Enough time must be made for SRT in the course if it is to have any meaning to the student. (4) A clear line of argument for getting through SRT (and possibly to introductory GRT) must be selected from among several possibilities. (5) Enough integration with other topics (e.g., QM, nuclear physics) must be achieved to do justice to the full power of SRT.

This Resource Letter should help to deal with the first of these problems, that of the huge bulk of publications. No doubt the best way to begin using the Resource Letter is to find among the next eight sections one on which to concentrate.

II. BOOKS: SOURCES AND TEXTS

Seven books are so good, so basic, and so widely used that nothing new need be said about them. They are, so to speak, double-starred, and must be nearby and accessible if one teaches SRT: A. S. Eddington, The Mathematical Theory of Relativity; A. Einstein, Relativity, the Special and General Theory; A. Einstein, The Meaning of Relativity; M. von Laue, Die Relativitätstheorie; C. Müller, The Theory of Relativity; R. C. Tolman, Relativity, Thermodynamics, and Cosmology; H. Weyl, Space, Time, Matter.


*2.E La Cinématique relativiste. H. Arzelès. (Gauthier-Villars, Paris, 1955), 228 pp. Among the most careful and readable works, with extensive bibliography for each chapter. This book and item 3 should be a major new resource for instructors.


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Thoroughly works out everything, from how to plot graphs through Maxwell, Minkowski, to GRT, with very few rabbits being pulled out of the hat. Leaving it so long out of print is a black mark against the world of publishing, but a paperback edition is now said to be planned.

5.1 La Théorie de la relativité restreinte. O. COSTA DE BEAUREGARD. (Masson et Cie, Paris, 1949), 174 pp. Bibliography develops and uses tensors from the beginning.

*6.1 Introduction to the Theory of Relativity. P. G. BERGMANN. (Prentice-Hall, Englewood Cliffs, New Jersey, 1942), 287 pp. Long a standard text. Introduces tensor calculus but uses it sparingly in Part I (SRT). With problems. Bergmann has been announced to have written the section on SRT in the new Handbuch der Physik, IV, which may turn out to be useful in place of a new edition of this book.


*8.1 Theory of Relativity. W. PAUL. (Pergamon Press, New York, London, 1958), revised ed., 241 pp. Originally “a complete review of the whole literature on relativity theory” up to 1921, it was brought up to date by 26 supplementary pages written in 1956 (though these are mostly on GRT). This book still functions as a major Handbuch for its field.


Exercises.


14.A Relativity: The Special Theory. J. L. SYNGE. (North-Holland Publishing Company, Amsterdam, 1956), 450 pp. “... the essentials of relativity from the Minkowskian point of view. ... My ambition has been to make space-time a real workshop for physicists, and not a museum visited occasionally with a feeling of awe.” Hence original and stimulating. Bibliography. See also his similar but shorter treatment, “Relativistic Dynamics,” in Vol. III, Part I (pp. 198–225) of Handbuch der Physik, S. Flügge, editor (Springer-Verlag, Berlin, 1960). Extensive bibliography of books on mechanics which treat SRT.

III. BOOKS: POPULAR


Note: See also M. Born, item 4, and Einstein, Relativity, the Special and General Theory.

IV. BOOK CHAPTERS

A few introductory general texts and most intermediate-level general texts have a section on SRT. Necessarily, most of these sections are rather similar to one another. The following list contains mostly recent, largely intermediate-level books that have been selected as being among those that it would be profitable to look through, particularly for illustrations and problems.


33.A The Theory of Space, Time, and Gravitation. V. Fock. (Pergamon Press, London and New York, 1959), 411 pp. "The main purpose of this book was to develop the theory of gravitation from a new point of view," but even Chapter 1, on the special theory of relativity, is stimulatingly different from usual treatments.


Note: Useful chapters dealing with special topics exist also in other general texts such as Panofsky-Phillips (item 44); Shankland (item 36); R. B. Lindsay and H. Margenau, Foundations of Physics; W. Band, Introduction to Mathematical Physics; and A. Sommerfield, Lectures on Theoretical Physics.

V. SELECTED EXPERIMENTAL WORK

The fundamental significance of SRT does not depend on any one of the many experiments to "prove" SRT. Still, the larger part of contemporary physics, from spectroscopy to accelerator design, is concerned with experiments and theoretical arguments that do rest at some point on SRT. For introductory purposes, one may well discuss a few experiments, one or two each from, say, optics and particle dynamics.

It will be helpful to keep in mind a classification of the various experiments having a bearing on SRT, and to be aware of their chronological sequence. One such scheme (based in part on a suggestion by D. L. Livesey) follows here. In searching for more complete listings of original papers, see the bibliographical citation in Whittaker (item 34), Pauli (item 8), Arzeti (items 2, 3), von Laue's Relativitätstheorie, Thirring (item 38). A magnificent listing of all work prior to 1924, ordered by author's name as well as chronologically, is Bibliographie de la relativité, Maurice Lecat (Lamertin, Brussels, 1924).

Aether-Drag in Dense Media: (a) Convection effects (e.g., Arago, 1818; Fizeau, 1859; MM, 1866; Zeeman, 1914). (b) Null experiments (Hock, 1868; Airy, 1871). (c) Drag by large bodies (Lodge, 1893; Michelson, 1897).
Aether-Drift Experiments (Air or Vacuum): (a) First-order effects (Cedarholm et al., 1958). (b) Second-order effects (Michelson, 1881; MM, 1887; Kennedy-Thorndike, 1932; Essen, 1955). (c) Indirect aether-drift effects (Double refraction: Rayleigh, 1902; Brace, 1904. Torque on condensor: Trouton-Nobel, 1903; Chase, 1926-27; Tomaschek, 1925-27).

Effects of Moving Source or Mirror: (de Sitter, 1913; Michelson, 1913; Majorana, 1917-19; Tomaschek, 1924).

Rotating Frame Experiments: (Sagnac, 1913-14; Michelson, 1925; Ditchburn-Heavens, 1952).

Time Dilation: (a) Transverse Doppler effect (Ives-Stilwell, 1938, 1941; Otting, 1939) (b) Lifetime of mesons (Rossi-Hall, 1941; Durbin-Loar-Havens, 1952).


Mass-Energy Equivalence in Nuclear Physics: (a) Mass defect (Cockcroft-Watson, 1932; Bainbridge, 1933). (b) Pair production (Anderson, 1933; Blackett and Ochialini, 1933). (c) Annihilation radiation (Klemerer, 1934; DuMond et al., 1949). (d) Decay schemes of elementary particles (Marshak, 1955). (e) Other (e.g., Linac limiting velocity, Mössbauer effect).

A. General Surveys


37.1 “Quelques vérifications expérimentales récentes de la théorie de la relativité restreinte.” Robert Lennier. Rev. Sci. (Paris) 85, 740-748 (1947). A good, brief survey, with main results. The partial list, showing size of field to chose from, includes fine structure of hydrogen lines, Ives-Stilwell experiment, lifetime of mesons measured by Rossi et al., effects of particle speed on inertia and on scattering angle (details of Leprince-Ringuet’s work), and Q values.


40.1 Kritik und Fortbildung der Relativitätstheorie. Karl Sapper, editor. (Akademische Druck-u. Verlagsanstalt, Graz, Austria, 1958), 283 pp. Essays by Benedicks, Giese, Golling, Grünbaum, Mohorovičić, Moon, Saper, Spencer, Tonini, Wenzl, and Zinsen. “Agreement on the need for rejecting dogmatism unites the otherwise widely differing points of view of the authors.” Chosen here to stand for the many books critical of Einstein’s RT; contains attacks on the usual interpretation of experimental results and on “the dangerous influence of positivism in physics.”

Note: In addition, surveys of the main experiments are given in some of the more general books, particularly Arzéliès (items 2, 3), Tonnellat (item 12), Panofsky-Phillips (item 44), Stephenson and Kilminster (item 11), and Rindler (item 10).

B. Optical Experiments: Reviews


44.1 Classical Electricity and Magnetism. Wolfgang K. H. Panofsky and Melba Phillips. (Addison-Wesley Publishing Company, Inc., Reading, Massachusetts, 1955), 400 pp. Chapter 14, pp. 230-242, “The Experimental Basis for the Theory of Special Relativity,” is as pithy and useful a treatment as exists. Includes the table comparing trials of the MM experiment, from R. S. Shankland et al. (item 53) and a discussion of Kennedy-Thorndike experiment. Bibliographies to original experimental papers. (See also the chapters from 15 on—for other valuable teaching resources on SRT.)

C. Optical Experiments: Largely on MM

*46.E Light Waves and Their Uses. A. A. Michelson. (University of Chicago Press, Chicago, 1903), 166 pp. Describes his experiments to 1899. Note: Bibliographies for the various M and MM experiments and discussions concerning them are given, e.g., in Whittaker (item 34); M. von Laue, Relativitätspathie; Lecat, Bibliographie de la relativité; Jaife (item 48).


Note: See also items: 1 (Lorentz on M experiment, pp. 1-7), 25, 34 (Vol. I, 390-2, 404-5), 49, 39, 43, 44, 45, 28.

D. Variation of Electron Mass with Velocity


58.E "A Determination of the Masses and Velocities of Three Ra-B Beta-Particles." M. M. Rogers, A. W. McReynolds, and F. T. Rogers. J. Phys. Rev. 57, 379-383 (1940). Check of relativistic formula to speeds up to 0.75 c, to distinguish between Abraham and Lorentz models of electron.


Useful graphs giving values of m/m and β versus accelerating potential are given in S. Dushman, "Mass-Energy Relation," Gen. Elec. Rev. 47, 6-13 (1944).

Note: See also theoretical papers in Section VI below.

E. Some Other Representative Experiments


61.I "Nuclear Dynamics, Experimental." M. Stanley Livingston and Hans A. Bethe. Revs. Modern Phys. 9, 245-390 (1937). While most of the experimental data and procedures have, of course, been improved (e.g., see K. T. Bainbridge, in E. Segré, editor, Experimental Nuclear Physics, Vol. 1), this historically valuable article gives full references and, for example, comparisons of calculated and experimental Q values.

For earliest good application of SRT to data on nuclear disintegration, see discussion of Cockcroft-Walton experiment by K. T. Bainbridge, "The Equivalence of Mass and Energy," Phys. Rev. 44, 123
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Note: For experiments involving time dilation, see Sec. VII below.

VI. MORE ON INERTIA OF ENERGY


VII. TIME DILATION AND CLOCK PROBLEMS

From the earliest days of SRT, much attention has been paid to time dilation and the clock problem, or twin “paradox,” or ‘voyageur de Langevin.” By now, far too much seems to have been written on this. But students are intrigued by it as much as ever, and if the discussion is kept in bounds, it can serve a useful function.


80 E “The Clock Paradox in Relativity.” C. C. DARWIN. Nature 180, 976-977 (1957). A very simple discussion, showing asymmetry in legs kept by two space ships counting each other's regularly sent light flashes.


83 E “Relativity and Space Travel.” J. R. PIERCE. Proc. IRE 47, 1053-1061 (1959). Discusses quantitatively a clock paradox, a twin problem, frequency shift in gravitational field, clock rate on satellite, speed achievable by photon rocket, and insufficiency of interstellar matter to power a space ship. See also C. Darwin, item 80.

84 I “The ‘Clock Paradox’ and Space Travel.” E. M. McMillan. Science 126, 381-384 (1957). Uses SRT and ordinary case as well as continuously accelerated coordinate system. Examples to show that “relativistic time modifications are negligible for travel within solar system” even for large accelerations, and that necessary energy expenditures to get important effect is “far beyond any foreseeable practical limits.”


Note: Several of the books cited above have good treatments of time dilation and clock problem, e.g., Arzelies (item 2), Born (item 4), Sherwin (item 25), Stephenson and Khilister (item 11), and Pauli (item 8).


Since then the papers in this subject have tended less to be a debate involving Dingle; further bibliography to 1960 is given in footnotes 16 to 23 of item 83 (Tiered). There was also an earlier exchange of articles on the concept; some of these are among H. Dingle, F. S. Einstein, and L. Infeld, in Am. J. Phys. 10 (1942) and 11 (1943).

VIII SOME OTHER CONSEQUENCES OF LT (E.G., VISUAL APPEARANCE)

91 I “Invisibility of the Lorentz Contraction.” JAMES TERRELL. Phys. Rev. 116, 1041-1045 (1959). It is shown—not without embarrassment to some of us—that to a single observer objects in rapid motion at a relatively large distance appear to have undergone rotation, not contraction. See also earlier paper for case of spheres by R. Penrose, Proc. Cambridge Phil. Soc. 55, 137-139 (1959).


For extension of argument to measurement of time intervals by single observer, see see A. D. Crowell, Am. J. Phys. 29, 376-371 (1961).


Another puzzle (will a length-contracted object fall through a grid over which it slides?) is in W. Rindler, Am. J. Phys. 29, 365-366, 839 (1961).


A necessary reminder that even for slow motions, the LT giving charge density cannot be approximated nonrelativistically. Illustrative examples for rotating and nonrotating circuits and magnets.


Kinematic effects of SRT treated by considering iterations of the infinitesimal LT.

IX. OTHER TEACHING AIDS

A. Laboratory and Demonstration Experiments

Almost nothing directly applicable to teaching SRT is now available, and very little that is indirectly applicable. But there is hope for early help with apparatus.


An inexpensive optical interferometer experiment is under design at the MIT Science Teaching Center (directed by F. L. Friedman), and another at Educational Services Incorporated (E.S.I., directed by H. Haber-Schaim), where there is also work on a first-order (null) ether-drift experiment and an acoustical Fizeau experiment analogue.


V. Neher at California Institute of Technology is developing a Busch tube experiment for student laboratory. A number of projects are under way at the Science Teaching Center of M.I.T., involving Professors Frisch, Bertozzi, King, and Smith; they include experiments on limiting velocity of electrons in linear accelerator, time-of-flight measurement of electron beam, and a simplified Bucher-Kaufmann apparatus. Some experiments are to be on film; others also are intended to yield apparatus for students.


A commercial beta-ray spectrometer is sold by Atomic Laboratories, Inc., Model 79641, $295; it requires also Electromagnet Model 79641, $295, and scaler, PSU, vacuum pump, and gauge.

B. Films

Here again, virtually nothing is yet on the market specifically for teaching SRT. The nearest is the 26-minute film "Frames of Reference" (1958), produced by PSSC-ESI and distributed by Modern Talking Picture Service, Inc., 3 East 54 Street, New York 22, New York. Two filmed 50-minute lectures on SRT by G. Gamow are soon to be released by General Dynamics-Convair, San Diego, California.