The second of two articles

Physicists receive relativity:

Revolution and reaction

JEFFREY CRELINSTEN

Albert Einstein became world-famous in the fall of 1919, when the results of a British eclipse expedition during the previous spring were announced, verifying the prediction of general relativity that light passing near the sun would bend in its gravitational field. Part I of this paper looked at how *The Times* in London and the *New York Times* in America each maintained public interest in the relativity story, the former casting it in terms of Newton versus Einstein, and the latter in terms of scientists whose world had been turned upside down versus commonfolk who wanted to know what was going on. By tracing the press coverage through the first weeks after the story broke, it was shown how very quickly the impression was created that relativity is incomprehensible and that lay people cannot hope to understand it because of its mathematical complexity. The article concluded by showing how the November reporting on scientific opinions regarding the possibility that ordinary refraction might account for the eclipse results, reinforced the impression that in fact, even scientists found the new theory strange and its mathematics difficult. In Part II, we now turn to another story picked up by the journalists at that time.

The case of Sir Oliver Lodge

The myth of incomprehensibility was given a final boost by events in England which surrounded the physicist, Sir Oliver Lodge. From the very beginning of the reporting in *The Times*, Lodge emerged as the antihero, the defender of Newton. In the November 7th report of the joint meeting of the two societies, Lodge was mentioned twice. First, that in February of that year, when the British scientists were still making preparations for the eclipse observations, Lodge had expressed doubts that a deflection would be observed, and that if one was observed, that it would "follow the law of Newton and not that of Einstein." The second mention was quite dramatic. In the middle of the article, a paragraph describes the discussion that followed the announcement of the eclipse results. The president of the Royal Society is quoted, calling the result a "momentous pronouncement of human thought." The three empirical tests of general relativity are outlined, mentioning that the third test, the gravitational redshift, is still uncertain, but the president feels confident that "the Einstein theory must now be reckoned with, and that our conceptions of the fabric of the universe must be fundamentally altered." And then, all by itself, comes the following short paragraph:

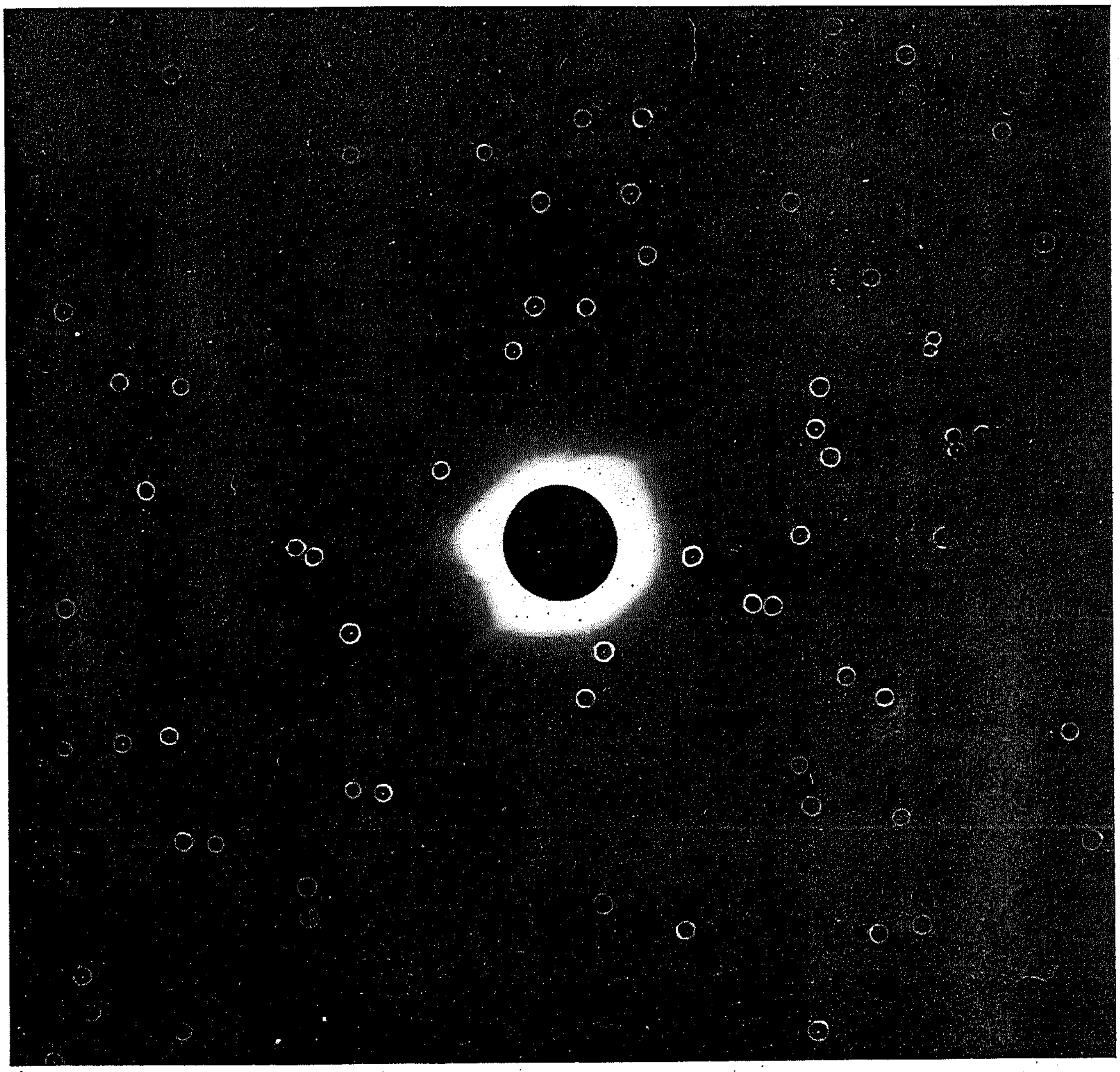
> At this stage Sir Oliver Lodge, whose contribution to the discussion had been eagerly expected, left the meeting.

. . . After that brief comment, the article continued . . . .

The next day, a letter to the editor from Sir Oliver Lodge was printed. In it, Lodge dismissed his early departure from the meeting attributing it to a previous engagement, and he also denied ever predicting a result in February. However, he admitted that he "was rash enough to express a hope for a result equal to half Einstein's value." But, he continued, "the double-valued result can be assimilated and specified in various ways." He mentioned two ways, one being the "ponderability of light coupled with a definite effect of motion on the

Lodge

For a picture and biography of the author see the first article of the series [Phys. Teach. 18, 115 (1980)].



This photograph was taken by the Lick Observatory eclipse expedition headed by William Wallace Campbell to test Einstein's theory at the total solar eclipse of 1922 in Wallal, Australia. The stars in the vicinity of the eclipsed sun have been circled. Campbell's measurements of the star positions confirmed that they had been displaced by the amount predicted by Einstein's theory, and in agreement with the British results of 1919. Nonetheless, the "Einstein Problem" continued to be included in the observational programs of eclipse expeditions throughout the twenties.

Lick Observatory Archives, Courtesy AIP Niels Bohr Library

Newtonian constant of gravitation," and the other that "one of the two etherial constants, responsible for the velocity of light, is affected by a gravitational field, so as to cause a kind of refraction." Lodge then went on to caution against "a strengthening of great and complicated generalizations concerning space and time on the strength of the splendid result" which he believed "may be accounted for with reasonable simplicity in terms of the ether of space." As described in Part I, the layout of the letter clearly set up Lodge as the defender of Newton. It appeared second in a series of three items: the main headline, "Newton v. Einstein," then Lodge's letter, and finally the short biography of Einstein discussed in Part I. Both sides of the debate were represented, with Lodge on the side of Newton.

Two weeks later, Newton's defender capitulated in the pages of *The Times* in dramatic fashion, and in such a way as to emphasize the mathematical incomprehensibility of Einstein's theory. On Monday evening, November 24, Lodge gave a lecture on the theory at the residence of Lord Glenconner. The next day *The Times* reported the meeting under the subheading "A Terrible Time for Physicists." The article stated that Lodge "defended the existence of aether against the assaults made upon it by the apparent corroboration of Einstein's theory of relativity." In his view, it claimed, the great achievement of Einstein was that "gravitation had been related to the aether force for the first time" and had "nothing to do with space or time as such." Toward the end of the article, Lodge's position deteriorated.

> Newton, as was known, did not understand the nature of gravitation. We do not understand it now. Einstein's theory would not help us to understand it. If Einstein's third prediction were verified, Einstein's

theory would dominate all higher physics and the next generation of mathematical physicists would have a terrible time. Such things as university courses for all practical purposes would be continued upon Galilean and Newtonian dynamics, but the Einstein school could not fail to interest, sooner or later, every intelligent man.

In replying to questions, Lodge was reported as admitting that if all the implications of Einstein's theory turned out to be true, then it would have to be left "to the younger men" to deal with them, and that "he himself would not be competent to do so," being content to "leave the transcendental methods to others."

The *New York Times* picked up the story on the same day. In the multiheadline that was so typical of their style, the reader learned among other things of a "New Physics Based on Einstein," and that "Sir Oliver Lodge Says it Will Prevail, and Mathematicians Will Have a Terrible Time." The article informed its readers that "so complicated has this revolutionary theory proved that even some of the most learned have been confounded." Most of the article repeated what *The Times* reported, and then the details of the eclipse observations were given in a secondary report. It is interesting that this story appeared almost a week after the *New York Times* editors had published their double editorial that had abandoned the refraction story and relinquished to mathematical experts all authority to judge the theory. And now here was a report that one of the British experts was ready to throw in the towel as well. The next day, November 26th, the editors responded with an editorial entitled "Bad Times For the Learned." After stirring up the old complaints of incomprehensibility ("one refrains with difficulty from suspecting a cable operator of having edited the dispatch") the editors deemed it completely understandable, and even pleasant, that "Sir Oliver" admits "his personal inability to conceive of space either as having a boundary or as not having one."

> Thoroughly human was his prophecy that as a result of the Einstein discoveries "terrible times" are coming for the mathematicians – at any rate the tone of satisfaction in which he said it was thoroughly human. Mathematicians have caused so many other people to have terrible times so often and so long that it's only fair for them to have their own troubles at last.

The tone was unmistakably hostile towards the mathematicians who have given everyone such a hard time for so long. ("Not one woman in a hundred will give them any sympathy . . . and innumerable boys and girls will simply gloat if the mathematicians are forced to admit the wrongness of their haughty pronouncements.") Though Lodge had said that it would be the "physicists" that would have a hard time due to the mathematics, and not the "mathematicians," the message that due to mathematics, science would become complicated for most experts, let alone the general public, was loud and clear.

And so we see how in both countries Sir Oliver Lodge became a symbol of the old giving way to the new, at the same time sanctioning the belief that Einstein's theory of relativity was characterized by complicated mathematics that made it inaccessible to experts and lay people alike. In the popular press, Lodge represented the old school who valiantly resisted to the end. And though he finally admitted defeat due to the new complexities, he continued to urge caution against going too far. On November 29, the day after Einstein's article was published by the *Times*, the voice of Lodge appeared again, under the plaintive subheading, "A Plea for the Aether." Lodge was quoted as accepting the verification of the Einstein prediction and ruling out refraction once and for all. Half the predicted result would have fit Newtonian conceptions, but the actual observation was "pure Einstein." Nonetheless, though Lodge hailed Einstein's theory as "a brilliant piece of mathematical analysis," he continued to caution against "extending the consequences of the verification of Einstein's theory beyond physics." He also continued to suggest aetherial explanations of the result. And in a December 13 *Times* report of an address on relativity given by Eddington to the Royal Astronomical Society, Lodge was quoted at the end of the lengthy article, saying that he was not prepared "to accept the whole of the theory on time and space," and that "one of the things that astonished him was that Professor Eddington thought that he understood it. (Laughter.)" The article concluded with Lodge expressing surprise that such a complicated theory had arrived at results, saying that it was "marvellous" to him, and that "there had been some very brilliant mathematical work."

And so the point was driven home. In the English context, one of Newton's generals capitulated; in the American context one of the experts admitted that he too was hopelessly confused. In both cases the message was clear: the theory of relativity is incomprehensible to the average person. The mathematics is too difficult.

Persistence of the phenomenon

Relativity continued to be much discussed and written about during the twenties. In 1921 a bibliography of almost 650 books, pamphlets, papers, and other publications was compiled by the International Catalogue of Scientific Literature,[1] and by the middle of the decade, a more comprehensive list was published, including over 3000 titles.[2] During this period Einstein was in demand everywhere – being invited to give lectures, receive degrees, to give interviews[3] – and this personal fame helped keep the relativity story alive in the press. Political events continued to play a role as well. In 1920 Einstein and his theory became targets for nationalist, anti-Semitic sentiments in Berlin; in 1921 a fund-raising tour to the U.S. for the Hebrew University in Jerusalem introduced Einstein to Americans for the first time as well as associating his name with Zionism; in the same year a lecture tour in England broke the anti-German ice in that country; and in 1922 a lecture at the Collège de France was hailed as an epochmaking step toward reconciliation between two bitter enemies.[4] Through it all, Einstein continued to "whistle his relativity tune,[5] and though he was loved and admired most everywhere, people still found his theory incomprehensible.[6]

In the U.S. particularly, the press continued to harp on the difficulty in understanding his theory. During the stormy antirelativity period in Berlin, the international press picked up the story that Einstein might leave Germany and move to America. Across the Atlantic, the *New York Times* commented in an editorial entitled "Disturber of Minds Unpopular." Ignoring the political implications of the antirelativity campaign, they chose rather to attribute the incident to the antagonism "that most human beings feel for him who says that what they long and firmly have believed is wrong."

> This antagonism will be particularly strong in the case of Dr. Einstein, for he has explicitly admitted, *or at any rate others, uncontradicted, have proclaimed for him*, that his disproof of the old beliefs, and his demonstration of the soundness of the substitutes he offers, are incomprehensible to any except a small and rather haughty minority of Superior Persons. (italics added)

The italicized clause is typical of statements made in the press which in essence demanded that Einstein answer to what others had said, and one begins to understand the aversion to journalists and interviewers that Einstein developed during this period.[7]

It has been pointed out that the popular press in America, having no means to discriminate between responsible and irresponsible science, felt called upon to report both sides of any debate which surfaced about relativity, regardless of whether initiated by serious scientists or cranks.[8] Thus when Charles Lane Poor of Columbia University, whom we discussed in Part I, continued his attacks on relativity through the twenties, and another American astronomer, Thomas Jefferson Jackson See, launched a less scrupulous campaign against Einstein and his ideas, the *New York Times* covered it all in their pages, adding editorial musings such as "The Declaration of Independence itself is outraged by the assertion that there is anything on earth, or in interstellar space, that can be understood only by the chosen few."[9]

Such examples make it easy to conclude with Oppenheimer that the shroud of incomprehensibility that surrounds relativity even today, is largely due to the sensationalism of the press. However, we must not ignore the fact that alongside the cranks and politically motivated mongerers there were serious scientists like Newall and Lodge in England and Millikan in the U.S. who were publicly demonstrating resistance to the theory. Even those scientists who supported the theory and attempted to explain the theory to the public, failed on the whole. One major complication was that there was generally no clear distinction between the special theory and the general theory. It was the astronomical verification of the latter that initiated Einstein's world-fame, and attempts to explain the new theory were plagued with confusion as to which theory, the special or the general, was being discussed. For example, often the fantastic implications of special relativity, slowing clocks and shrinking lengths, were stated with no explanation and no indication of the fact that they did not directly connect to the British eclipse observations.[10] Whether such confusion was due to journalistic sensationalism or whether it came more directly from the scientists' own understanding or lack of it, is not immediately obvious. We need to look more closely at the scientific response to relativity before we can answer such a question. An analysis of the press coverage of the relativity story can lead to an understanding of how contemporary popular myths surrounding Einstein and his theories were generated and propagated. We must look to the scientists themselves, in their own professional context, to decide whether such myths are purely media-generated phenomena, or whether they reflect real tensions that existed within the scientific community.

The scientists' response

There are indications that the situation was somewhat more complex than Oppenheimer's simple indictment of laziness on the part of scientists who understood relativity but couldn't be bothered to explain their specialty to the lay public. V. V. Raman has looked at reactions to relativity in the twenties, and points out that the scientific response was a multi-faceted one.[11] Though there was enthusiastic support for the theory in many quarters, there were many scientists who bitterly opposed it. Much of the criticism was directed against the "abstract mathematical reasoning" and the fact that relativity was baffling to common sense. In 1920, Alfred North Whitehead wrote:[12]

> It is not going too far to say, that the announcement that physicists would have in the future to study the theory of tensors created a veritable panic among them when the verification of Einstein's predictions was first announced.

The tensor calculus was used by Einstein in his general theory, and it was precisely this that Lodge predicted would give physicists a "terrible time."

It is instructive also to look at the early reception of general relativity.[13] H. Levy, a student at Göttingen University from 1912 to 1914, witnessed a lecture Einstein gave there on relativity. The final 1915 version of general relativity had not yet been developed, but Einstein had been trying to generalize his special theory for some time, and had already developed much of the mathematics in collaboration with his friend, the mathematician Marcel Grossman. Levy recalls the lecture.[14]

> I remember watching the engineering professors who were present and who were, of course, horrified by his approach, because to them reality was the wheels in machinery – really solid entities. And here was this man talking in abstract terms about space-time and the geometry of space-time, and the curvature of space-time; and showing how you could explain gravitation by the way in which a body moves in space-time along a geodesic – namely the shortest curve in space-time. This was all so abstract that it became unreal to them. I remember seeing one of the professors getting up and walking out in a rage, and as he went out I heard him say, 'Das ist absolut Blödsinn' (That is absolute nonsense). Well, that really reflected the attitude of most of the engineers of the time . . . . There were others, of course, who simply thought that here was a very clever mathematician talking and after all you can expect anything from a mathematician!

It is ironic that the attitude of the Göttingen engineers towards Einstein's mathematics echoed Einstein's own attitude of several years earlier. Even as a student, at the Zurich Polytechnic, he had not attended the mathematics seminars, and during his early professional career, he felt that mathematics tended to be formalistic and to complicate physical ideas.[15] However, by 1912-1913 Einstein had been imbued with a great respect for mathematics, acquired through intense work on general relativity. This respect was dramatically vindicated in 1915 when he completed the theory, and it never left him.[16] This conversion on Einstein's part was obviously not shared by the Göttingen engineers.

Einstein's mathematical evolution as he developed his general theory of relativity can be viewed against a general background of changing attitudes toward the role of mathematics in physics. Russell McCormmach has pointed out that the period from the last decade of the 19th century to World War I saw an increasing role of new mathematical tools in physical theory. When Einstein was a student at the Zurich Polytechnic in the years before the turn of the century, a strong movement existed in which professors of engineering and applied science berated their colleagues in mathematics for teaching abstruse mathematics to students interested more in application. Einstein's early attitudes towards mathematics, though not necessarily shaped by these influences, was definitely consonant with them. However, by the end of the century physicists had accepted the importance of vectors for electromagnetic theory. In developing vector analysis to formulate electromagnetic and gravitational field theories during the first decade of the new century, physicists came increasingly into contact with the theories of invariants, groups, tensors, matrices, and the absolute differential calculus. On the other hand, this trend was by no means universal. Theoretical physics was a fairly recent specialty within the overall physics discipline.[17] When Einstein published an early version of his general theory in 1913, his collaborator, Marcel Grossman, included a section elucidating the basics of tensor calculus,[18] so new was this branch of mathematics to the majority of physicists.

There is very little reason to believe that the general population of physicists had been enlightened much in these matters by 1919, when the world at large first heard about general relativity. Einstein's full-fledged theory had been published during the war in 1915, and few scientists outside Germany had heard about it.[19] The panic described by Whitehead on the part of physicists contemplating tensors was probably quite real, and we can reasonably conclude that newspapers' seizure upon Lodge's brooding about coming "terrible times" was not merely journalistic hype.

There is also evidence that on the experimental side, general relativity encountered early opposition. In Germany, the astronomer Erwin Freundlich, one of Einstein's early collaborators, required funds to finance an expedition to observe the 1914 solar eclipse in Russia in order to test Einstein's prediction that light would bend in the gravitational field of the sun. Both his superior at the Berlin Observatory, Hermann Struve, and the Berlin Academy, refused to put up the money, and Freundlich had to raise the funds himself.[20] In fact, Einstein later stated that German astronomers had been generally uncooperative regarding general relativity. In the twenties, many scientists were reluctant to accept general relativity on experimental grounds, claiming insufficient evidence, or insisting on more classical interpretations (like Newall's refraction or Lodge's ether-based explanations), or even refusing to accept the readings obtained.[21]

The astronomer S. Chandrasehkar has recently reminded Einsteinophiles celebrating Einstein's centenary year that many eminent scientific contemporaries of Einstein viewed his general theory of relativity with distant respect, admiring the "abstruse mathematics" with artistic appreciation if not complete understanding. This "work of art" assessment, he points out, sounds like faint praise offered in order to try not "to dissociate oneself from the general acclaim that is accorded Einstein."[22] He is not even sure "how well the principles of general relativity, as laid by Einstein, are appreciated by physicists of today," pointing out the fact that in spite of its widespread acclaim, general relativity was ignored or neglected as a discipline in physics until as late as 1950.[23]

I mentioned earlier that one of the confusing aspects of the popularization attempts after 1919 was the lack of any clear distinction between the special and general theories. The public, and most physicists, heard about relativity for the first time in 1919, and tended to lump the two together. We need more studies on the early reception and development of both theories to understand how the later generation of scientists who inherited the theories in 1919 interpreted them. For instance, except for a few physicists around Max Planck,[24] Einstein's 1905 theory was hardly discussed at all, until the Göttingen mathematician, Hermann Minkowski, developed his well-known space-time formalism and presented it to a wider scientific audience in his famous "Space and Time" lecture of 1908. Only after that did many physicists begin to realize the fundamental implications of Einstein's work.[25] In spite of this, Einstein disagreed with Minkowski's physical understanding of the theory,[26] and only later did he use the space-time formalism to produce the general theory. Most physicists probably never went through Einstein's elementary and profound considerations of how we make fundamental measurements, having been first introduced to the subject in the form given by Minkowski.

Similarly, for years physicists on the whole thought that H. A. Lorentz's 1904 theory of electrons and Einstein's 1905 special theory of relativity were the same theory, because they both used the Lorentz transformations. However, Lorentz's theory was primarily motivated by the observed fact that the effect of motion through the ether on the speed of light was indetectable (e.g., Michelson-Morley) and he postulated an interaction between electrons and ether to account for the null result. Einstein *postulated* the constancy of light velocity, combined it with the principle of relativity, and built a new kinematics.[27] Physicists tended to think primarily in Lorentzian terms,[28] generally working on the nature of the electron and of ether, and except for a few, they could not understand Einstein's new insights about measurement, preferring to think in terms of matter-ether interactions. In Britain particularly, physicists had been educated so universally in ether mechanics and in mechanical modelling generally, that expositors of special relativity had to translate Einstein's theory into ether terms in spite of his abolishment of the need for such an ether.[29] This confusion reappeared in the twenties when the reality of the relativistic effects of length contraction and time dilation were debated hotly. Some commentators, Lorentz included, believed in a real shrinking, whereas more Einsteinian interpreters such as Eddington insisted that the effects are only apparent.[30]

A similar situation likely occurred with general relativity. Einstein viewed it as a generalization of the special theory, motivated by an extension of the principle of relativity from uniform to arbitrary motions. However, specialists in spectroscopy or celestial mechanics for example, probably encountered the theory first in connection with specific problems such as the gravitational redshift, or the motion of Mercury's perihelion, and were unprepared at first to accept all the fundamental implications.[31]

Thus we see that the problem of reception is integrally connected to that of popularization. Until we understand some of the problems scientists faced when they first encountered and developed relativity, we will not be able to assess their attempts to explain the theory to the public.

Conclusion

Einstein gives us a unique opportunity to study the various levels of interaction between science and general culture. On one hand, this is because his name has become such a major symbol in today's popular culture. A vast literature has been generated, not only about his science, but about Einstein, the archetypical scientist as well. On the other hand, his career covers a crucial period in the history of modern science. It is a period of revolution in thought, characterized by the emergence of relativity and quantum mechanics; it is also a period of precipitous social change in science, characterized by increased institutional specialization and increased involvement with public affairs.

The post-war schism between scientists and the rest of modern culture, characterized by C. P. Snow in the fifties,[32] has its perfect representation in popular attitudes toward Einstein and his theory of relativity. The overwhelming interest that the public has for Einstein as a scientific genius and a symbol of 20th-century greatness stands in stark contrast with the universally accepted belief that his theory of relativity is incomprehensible. From the historical account given here, we can understand how this belief developed during the years after the 1919 eclipse observations. However, 60 years later, the belief is as strong as ever, and we must understand this as well.

References:

1. Excerpts from this list appeared in "Relativity," *Nature* **106**, No. 2677, 781-813 (February 17, 1921), pp. 811-813.
2. Maurice Lecat, *Bibliographie de la Relativite* (Brussels, 1924).
3. Einstein was so deluged with letters that he had a recurring nightmare: "I am burning in Hell and that the postman is the Devil roaring at me, throwing new bundles of letters at my head because I have not yet answered the old ones." Quoted in Carl Seelig *Albert Einstein: A Documentary Biography* (Staples Press, Ltd., London, 1956), p. 163.
4. Banesh Hoffmann and Helen Dukas, *Albert Einstein: Creator and Rebel* (New American Library, New York, 1972), pp. 141-149.
5. *Ibid.*, p. 152.
6. See for example, Paul A. Carter, "Science and the Common Man," *The American Scholar* 45, 778-794 (1975-76), p. 780.
7. "To be called to account publicly for everything one has said, even in jest, an excess of high spirits, or momentary anger, fatal as it must be in the end, is yet up to a point reasonable and natural. But to be called to account publicly for what others have said in one's name, when one cannot defend oneself, is indeed a sad predicament." Albert Einstein, "Interviewers," in *The World As I See It*, translated by Alan Harris (Wisdom Library, New York, 1949), p. 32.
8. Ronald C. Tobey, "The Einstein Controversy, 1919-1924," in *The American Ideology of National Science, 1919-1930* (Univ. of Pittsburgh Press, 1977), 96-132, esp. pp. 108-111.
9. Quoted in Paul A. Carter, *op. cit.* (note 6), p. 782.
10. The best example is R. D. Carmichael, "Given the Speed, Time is Naught," *The New York Times*, December 7, 1919, 18; see also, "How Tall Are You Einstein Measure?" *The New York Times*, December 5, 1919, 19 and the editorial response "Relation of Motion to Stature," *The New York Times*, December 5, 1919, 14; in England, a widely read explanation of the theory was published in *The Times Educational Supplement*, and later published separately as a pamphlet because of popular demand. Algebra was included in the exposition. The article concentrated on special relativity, stressing the Michelson-Morley experiment, and relying on ether pictures to explain the details. The general theory was touched upon, but clearly the author was not favorably inclined to it. See F. M. Denton, "The Modern Theory of Relativity," *The Times Educational Supplement*, December 4, 1919, 605-606.
11. V. V. Raman, "Relativity in the Twenties: Many-Sided Reactions to a Great Theory," *Indian Journal for the History of Science* 7, 119-145 (1972), esp. pp. 123-129.
12. A. N. Whitehead, *The Concept of Nature* (Cambridge University Press, 1920), p. 182, quoted in H. Dingle, *Science at the Crossroads* (Martin Brian & O'Keeffe, London, 1972), p. 178.
13. Compared to studies of the early reception of special relativity, little work has been done with the general theory. Notable exceptions are Lewis Pyenson, *The Göttingen Reception of Einstein's General Theory of Relativity* (diss. Johns Hopkins University, 1973); "La réception de la relativité généralisée: disciplinarité et institutionalisation en physique," *Revue d' histoire des sciences* 28, 63-73 (1975).
14. Quoted in G. J. Whitrow (ed.), *Einstein: the man and his achievement* (Dover, New York, 1973), p. 43.
15. Thus his famous statement in reaction to Hermann Minkowski's mathematical development of special relativity, "Since the mathematicians have invaded the theory of relativity, I do not understand it myself anymore." Quoted in Arnold Sommerfeld, "To Einstein's 70th Birthday," in *Albert Einstein: Philosopher-Scientist*, ed. P.A. Schilpp (Open Court, La Salle, 111., 1949), 99-105, p. 102.
16. Russell McCormmach, "Editor's Foreword," *Historical Studies in the Physical Sciences* 7 xi-xxxv (1976).
17. For a discussion of the emergence of theoretical physics as a distinct subspecialty in physics, see Russell McCormmach, "Editor's Foreword," Hist. Stud. Phys. Sci. 3, ix-xxiv (1971) esp. pp. xvii-xxi.
18. Albert Einstein and Marcel Grossmann, "Entwurf einer verallgemeinerten Relativitätstheorie und einer Theorie der Gravitation," *Zeitschrift für Mathematik und Physik* 62 (1913), 225-261.
19. The British astronomers, Frank Dyson and Arthur Eddington, received word of it through their Dutch colleague, Willem de Sitter in neutral Holland.
20. Lewis Pyenson, "Einstein's Early Scientific Collaboration," Hist. Stud. Phys. Sci. 7, 83-123 (1976), pp. 109, 104, 117-118. Later Freundlich got into a theoretical debate with the astronomer Hugo von Seeliger over anomalous perihelion precession and relativistic calculations of stellar densities, and Struve had him removed from his post at the observatory. *Ibid.*, pp. 114-117.
21. V. V. Raman, *op. cit.* (note 11), pp. 129-130.
22. S. Chandrasehkar, "Einstein and general relativity: Historical perspectives," Am. J. Phys. 47, 212-217 (1979), p. 213.
23. ". . . from 1936 . . . to 1961, no courses in general relativity, not even for one single quarter, were given at the University (of Chicago)", *ibid*, p. 214. John Archibald Wheeler has told me that in 1952 he gave the first course on general relativity ever to be given at Princeton University.
24. Stanley Goldberg, "Max Planck's Philosophy of Nature and His Elaboration of the Special Theory of Relavitiy, Hist. Stud. Phys. Sci. 7, 125-160 (1976).
25. Tetu Hirosige, "Origins of the Theory of Relativity, Hist. Stud. Phys. Sci. 7, 3-82 (1976), pp. 77-79.
26. Lewis Pyenson, "Hermann Minkowski and Einstein's Special Theory of Relativity," *Archives for History of Exact Sciences* 17, 70-95 (1977); see also his "Einstein's Early Scientific Collaboration," *op. cit.* (note 20), p. 95.
27. Stanley Goldberg, "The Lorentz Theory of Electrons and Einstein's Theory of Relativity," Am. J. Phys. 37, 982-994 (1969), "In Defense of Ether: The British Response to Einstein's Special Theory of Relativity, 1905-1911," Hist. Study. Phys. Sci. 2, 89-125 (1970), esp. pp. 91-96; Russell McCorm-

mach, "Einstein, Lorentz, and the Electron Theory," Hist. Stud. Phys. Sci. 2, 41-87 (1970); Kenneth Schaffner, "The Lorentz Electron Theory and Relativity," Am. J. Phys. 37, 498-513 (1969); Tetu Hirosige, *op. cit.* (note 25); Gerald Holton, "On the Origins of the Special Theory of Relativity," in *Thematic Origins of Scientific Thought. Kepler to Einstein* (Harvard Univ. Press, Cambridge, 1973), 165-195, esp. pp. 175-179; Lewis Pyenson, *op. cit.* (note 20), p. 97.

28. Herbert Dingle, *op. cit.* (note 12), pp. 164-167. Dingle primarily wrote this book to convince readers that special relativity is wrong, and that the scientific establishment refuses to consider such a possibility. Though his specific arguments are debatable, some of his observations about different scientists' reactions to relativity are interesting.
29. Stanley Goldberg, "In Defense of Ether," *op. cit.* (note 27), pp. 99-125.
30. Herbert Dingle, *op. cit.* (note 12), pp. 176-179.
31. At the 85th Deutsche Naturforschersammlung, held in Vienna in September 1913, Einstein's new ideas caused such a heated discussion that a Viennese daily picked up the story, announcing "The Minute in Danger, A Sensation of Mathematical Science," See R. W. Clark, *Einstein: The Life and Times* (The World Publishing Co., New York, 1971), pp. 156-157. For an interesting discussion of how the reception of general relativity differed within the subspecialties of theoretical physics and mathematical physics, see Lewis Pyenson, "La réception de la relativité généralisée," *op. cit.* (note 13). I am currently studying the reception of general relativity among astronomers.
32. C. P. Snow, *The Two Cultures* (Cambridge University Press, Cambridge, 1969).

Teachers' pets

Single slit diffraction—A test of the theory

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One PSSC experiment asks students to determine the width of a narrow slit by measuring the central maximum of the interference pattern produced when red light passes through the slit to the student's eye.

A common student response to this experiment is to seek another, more direct, way of measuring the slit width in order to confirm the single-slit interference theory.

One approach that works well is to paint one side of a two-in. glass square with aqua-dag. Once the paint is dry, slits of various widths can be scratched in different glass plates using a razor blade and pins.

Students can then cover the line source in a showcase bulb with a red filter and examine the single slit interference pattern from a distance of several meters while someone else adjusts markers to determine the width of the central maximum.

The width of the slit can be determined by using the familiar equation determined from the theory of single-slit diffraction:

$$w = \lambda L/X = \lambda/\sin\theta$$

To check up on this equation students can place their glass plates in a slide projector and determine the width of the slit projected on a screen. The projector can be placed so as to give a magnification of 50. (This is done by placing a plastic ruler in the projector and moving the projector away from the screen until the images of the one centimeter markings are 50 cm apart when in focus on the screen.) Dividing the measured width of the bright line on the screen by 50 will give a more direct measurement of the slit's width.

When the class data is collected, students can readily see that the widths of the slits are inversely related to the widths of the central maxima.