

Pieces of Einstein's 1905 Puzzle

In their article "A Small Puzzle from 1905" in the March 2005 issue of *PHYSICS TODAY* (page 34), Alex Harvey and Engelbert Schucking express surprise that the relevant literature contains no commentary about Albert Einstein's one erroneous prediction in his 1905 paper on relativity: He predicted a rate difference between Earth-based equatorial and polar clocks. The earliest reference given to demonstrate that the behavior of clocks on the geoid has been widely known among physicists is from 1975. The earliest account of which I am aware is from 1957.¹

Harvey and Schucking describe the similar rates of a polar clock and an equatorial clock in two ways:

► The gravitational blueshift of a clock on the equator precisely cancels the time dilation associated with its motion.

► Relative to a frame attached to Earth, neither clock is moving and both are at the same effective gravitational potential; thus their rates are identical.

A third way to view this situation is closely related to the second. By the principle of equivalence, a clock at rest in a gravitational field is equivalent to a clock being accelerated in a field-free space. As described by general relativity, gravitation is geometry, not a force, which is why no one has ever felt a force of gravity. The only force acting on the Earth-based clocks, or on any stationary Earth-based objects, is the electromagnetic contact force supporting them. Any two nearby clocks located on the same surface perpendicular to the direction of this contact force (the plumb-bob direction) will have identical rates. Thus all clocks on the geoid run at the same rate.

A popular-level description of time that includes this elegant behavior of clocks on the geoid appears in the an-

nual *Observer's Handbook* of the Royal Astronomical Society of Canada. Although the handbook began publication in 1907, a description of this feature of Earth-based clocks first appeared in the 2003 edition.

Reference

1. B. Hoffman, *Phys. Rev.* **106**, 358 (1957).

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There is a small error in "A Small Puzzle from 1905" about Einstein's prediction error regarding time dilation: The caption under the illustration on page 36 says clock rates increase with gravitational potential. Of course the authors meant "decrease."

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Although I am flattered by the reference to me in Alex Harvey and Engelbert Schucking's article, I need to correct the record. Sometime in the late 1970s, while giving a lecture at the University of Maryland, I innocently stated Einstein's prediction about the polar and equatorial clocks. It had not occurred to me that the prediction was wrong. After the lecture Carroll O. Alley came up to me and pointed out the error. He also gave me some reprints in which he presents the correct theory and gives results that prove it with atomic clocks flown in airplanes.¹ Alley is the hero of this tale and should be credited.

Reference

1. C. O. Alley, in *Quantum Optics, Experimental Gravity, and Measurement Theory*, P. Meystre, M. O. Scully, eds., Plenum Press, New York (1983), p. 363.

Jeremy Bernstein

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Alex Harvey and Engelbert Schucking make repeated references in their article to the "erroneous prediction" in Albert Einstein's 1905 paper on electrodynamics. The point of the article seems to be

amazement that neither Einstein nor "numerous historians of science" have focused attention on the "erroneous" calculation of time dilation, which did not take into account gravitational effects. However, historians of science do not, in general, attempt to judge the work of scientists by the standard of later developments.

In the case at hand, Einstein himself found a theory of greater generality than special relativity, on which the 1905 calculation was based. But that later discovery does not ex post facto make the earlier calculation an error. In fact, it was a correct calculation based solely on special relativistic ideas. How would Einstein's contemporaries have reacted if he had scattered throughout the 1905 paper numerous references to Isaac Newton's "errors"? Einstein recognized that special relativity modified Newton's ideas, and of course general relativity was an even greater modification. Einstein did not go back to correct his 1905 mistake, because he had made none.

The history of science is endless and fascinating, but it should not be told in terms of errors and wrong predictions. That approach suggests that science is a progression of correcting errors from the past rather than the acquisition of deeper understanding. Some day decades or more in the future, much of what we believe today of quantum theory and gravitation will be regarded as special cases of a broader, more comprehensive theory. Let us hope that the historians of that day will not reflect on the inexplicable errors of those who paved the way.

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Harvey and Schucking reply:

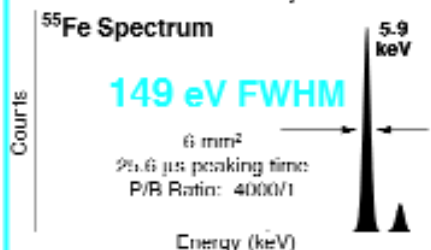
Roy Bishop is right to mention the 1957 paper by Banesh Hoffman. We are not entirely happy with Bishop's derivation of the null effect: Einstein's equivalence principle of 1907 refers to a constant field of acceleration, with the pole and equator points accelerating in different directions. However, we are also not

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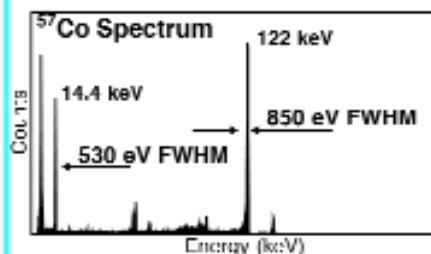
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pleased with the “derivations” we gave in our paper, derivations that used the crutches of Newtonian gravity and special relativity. In Einstein’s theory, the exact derivation using a stationary Killing vector is very simple but deemed to be beyond the comprehension of physics undergraduates. It is a scandal that, despite this year’s monumental Einstein lip service, his greatest achievement of 80 years ago, his theory of gravitation, has not become a regular part of the undergraduate physics curriculum.

David Taylor contends that clock rates do not increase with gravitational potential. We understand clock rates to be the number of ticks per second. An increased clock rate means a “blueshifted” clock. We also define the gravitational potential as increasing with distance from Earth. Thus, our clock rates increase with gravitational potential.

However, the gravitational potential introduced by Joseph Louis Lagrange was defined with the opposite sign, so that its gradient gave the acceleration. After the conservation of energy was discovered, physicists redefined the gravitational potential with the opposite sign while as-

tronomers and geophysicists often stayed with the old definition.

We are grateful to Jeremy Bernstein for pointing to the work of professor Carroll O. Alley. Unfortunately, we did not know that he had experimentally confirmed Einstein’s theory of gravitation by studying clock rates at different latitudes. In addition to the reference Bernstein quotes, a talk by Alley appears in the *Proceedings of the Thirteenth Annual Precise Time and Time Interval Application and Planning Meeting, 1982* (NASA Conference Publication 2220). Referring to that talk, Alley writes in a letter to Bernstein: “When I told the audience of physicists about the required understanding of relativistic time in the engineering of modern timekeeping systems, Eugene Wigner was so pleased that he interrupted my talk to beat his hands on the table in front of him in the European fashion!”

We do not agree with the views of Bill Shields on the history of science. Although they may be valid for a history of religion, science—unlike religion—can be tested against experiment and observation of nature. Mismatches between theory and observation are the germs for exciting new developments. To keep histori-

ans of science from discussing the truth seems absurd to us. If they discuss a flat-earth theory, are they not allowed to mention that the theory has a problem?

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Pursuit Nontrivial

Thanks to Matt Landreman for his Opinion piece (PHYSICS TODAY, March 2005, page 52). I have shared his sentiments since I was a student. The one bit of condescending jargon I disliked most was, “It is obvious to the alert student that . . .” It was never obvious to this alert student. The longer I studied and read and taught, the more obvious it became that it was not obvious and usually involved many complicated steps.

Two things helped me deal with such presumptions. First, my father taught me that anything is easy when you know how, and I was determined to learn how. Second, many of my early students were mature US Army aviation warrant officers who would not let me get away with such statements. Their comment was, “I’ll