He could, and should, have treated the Michelson-Morley experiment as a friendly witness, giving aid and support to his theory. The evidence from the experiment can actually be exploited in two ways: in the reference frame of the Solar System, the Earth and the experimental apparatus are in motion, and the null result gives evidence for length contraction; but in the reference frame of the Earth, the apparatus is at rest, and the null result gives evidence for equal, constant round-trip speeds of light in the two perpendicular directions.

Einstein's misappreciation of the experiment was a serious mistake. How serious did not become clear until the 1940s, when a new analysis of the implications of the Michelson-Morley experiment by the American physicist H. P. Robertson showed that this experiment, in conjunction with a similar experiment using an interferometer with arms of unequal lengths, can be used to provide an empirical basis for the Lorentz transformation equations and thereby establish the constancy of the one-way speed of light. This means that the constant round-trip speed implies the constant one-way speed.[30] Thus, the experiment provides quantitative confirmation for one of the basic principles of the theory of relativity and for one of its important predictions: the constant speed of light and the length contraction. Until the development of the new experiments in the 1960s, it remained the most precise quantitative evidence for relativity.[31]

EINSTEIN'S THIRD MISTAKE in the 1905 paper is in his calculation of the relativistic mass. He recognized, quite correctly, that the alterations imposed on the acceleration of a particle by length contraction and time dilation alter Newton's Second Law, and effectively make the mass m in the equation $ma = F$ into a variable quantity. The mass increases with the speed of the particle, so a fast-moving particle effectively has more inertia. Einstein also recognized that this inertia depends on the direction of the acceleration: it is larger for a longitudinal acceleration, parallel to the velocity (as in the case of a particle accelerating along a straight line), than it is for a transverse acceleration, perpendicular to the velocity (as in the case of the centripetal acceleration of a particle traveling at constant speed around a circle).

But when Einstein calculated this speed-dependent mass for the transverse case, he made a bizarre misstep. To find the mass, he needed to compare the acceleration and the force. But he compared the acceleration in one reference frame with the force in *another* reference frame: he used the experimenter's reference frame (at rest in the laboratory) for the former and the particle's own reference frame (moving with the particle) for the latter. This gave him a mass that was larger than it actually is. It was a mistake like that of a tailor who interchanges the waist and inseam measurements of a pair of trousers, and presents his customer with trousers wide at the waist and short at the ankles.

Einstein's mistake was not accidental. He knew he was using two different reference frames for acceleration and for force, and he did so deliberately, for some mysterious and perhaps mystic reason of his own. He was dealing with a force that had different magnitudes in different reference frames, and he seems to have thought that the choice between these different magnitudes had to be made by definition, by stipulation. In this rush to stipulation Einstein was making the same kind of mistake he made in the one-way speed of light: instead of relying on measurements he was again relying on his "free will."

When an experimenter measures the inertia of a particle by pushing on the particle with a calibrated force and observing the response, she does not care what the force is in any reference frame other than her own—the force in her reference frame is a measurable quantity, and the force acting on a particle is whatever measurements in her reference frame say it is. There is no freedom of will or of stipulation in this. Years later, Einstein somewhat sheepishly conceded that his calculation of the transverse mass from his definition of force "is not advantageous, as was first shown by M. Planck."[32] This was rather an understatement: Dear customer, I concede that the fit of the trousers I tailored for you is not advantageous.

How did Planck become involved in this miscalculation? Among his other duties as professor at the University of Berlin and president of the German Physical Society, Planck was also an editor of *Annalen,* and Einstein's paper crossed his desk before it appeared in print. Planck immediately perceived that it was an important new contribution to relativity, and he also immediately perceived that the calculation of the mass was wrong.

One reason why this mistake must have been obvious to Planck was that he knew of calculations of the relativistic mass done a year earlier by Lorentz and also of older calculations done by Poincaré and by J. J. Thomson, the discoverer of the electron. These earlier calculations lacked the generality of Einstein's calculations; they applied only to "bodies" made of electric and magnetic fields. The disagreement between Lorentz's formulas and Einstein's set off warning bells in Planck's mind, and when he checked Einstein's calculations he immediately spotted Einstein's mistake.

Planck was the perfect gentleman. Instead of crowing that he had found a mistake in Einstein's calculations, he simply published an entirely new and elegant recalculation of the mass, with which he obtained the correct formula. By rights, this formula should thereafter have been associated with Planck's name. But history often treats scientists unfairly, and today only few physicists are aware that the formula for the relativistic transverse mass in Einstein's paper was wrong, and that the correct formula is due to Planck.

Einstein can be faulted not only for the mistake in his calculation, but also for his ignorance of Lorentz's work. But in this there are some extenuating circumstances: Lorentz published his paper (in English) in the *Proceedings of the Royal Academy of Amsterdam,* a journal that did not enjoy very wide distribution, so Einstein would have found it difficult to locate a copy. It seems he did not get around to reading Lorentz's paper until much later.