

## Putting to Rest Mass Misconceptions

Wolfgang RindlerMichael A. VandyckPoovan MurugesanSiegfried RuschinCatherine SauterLev B. Okun

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## PUTTING TO REST MASS MISCONCEPTIONS

I am disturbed by the harm that Lev Okun's earnest tirade (June 1989, page 31) against the use of the concept of relativistic mass ("It is our duty . . . to stop this process") might do to the teaching of relativity. It might suggest to some who have not thought these matters through that there are unresolved logical difficulties in elementary relativity or that if they use the quantity  $m = \gamma m_0$  they commit some physical blunder, whereas in fact this entire ado is about terminology. There are perhaps 40% of us who find it useful occasionally to write  $m$  for  $E/c^2$  and 60% who don't. But why the latter should try to coerce the former beats me.

One can perhaps understand a desire that everyone should use the term "mass" in the same sense. I myself have never found this a stumbling block, since the context tells me which mass the author means. Nevertheless, if I am told by the particle physicists—and they are the largest user group of special relativity these days—that henceforth I must use the symbol  $m$  for rest mass and call it mass, so be it. But I refuse to stop using the concept of relativistic mass, which I would then denote by  $m_r$ .

I know a man who can drive a shift car without ever using the clutch—it's a question of timing. The ingenious Ernest Vincent Wright in 1939 wrote a 50 000-word novel, called *Gadsby*, in all of which the letter *e* never occurs. Its sentences look like this: "A busy day's traffic had had its noisy run." Sure, such feats can be performed. But to what end? I like using my clutch, the letter *e* and the relativistic mass.

To me,  $m = \gamma m_0$  is a useful heuristic concept. It gives me a feeling for the magnitude of the momentum  $\mathbf{p} = m\mathbf{v}$  at various speeds. The formula  $E = mc^2$  reminds me that energy has mass-like properties such as inertia and gravity, and it tells me how energy varies with speed. I will confess to even occasionally using the heuristic concepts of longitudinal mass  $\gamma^3 m_0$  and transverse mass  $\gamma m_0$

to predict how a particle will move in a given field of force.

WOLFGANG RINDLER

9/89 University of Texas at Dallas

I read with great interest the article "The Concept of Mass" by Lev B. Okun. As the author points out, the notion of "relativistic mass" is both unnecessary and confusing, and should therefore be avoided.

In this note I would like to go even one step further and suggest that one should also avoid equations such as  $d\mathbf{p}/dt = \mathbf{f}$  and  $\mathbf{p} = m\gamma\mathbf{v}$ , which obscure the Lorentz covariance of the theory because of the appearance of the operator  $d/dt$ . Their use is, however, common practice, even in the best textbooks.<sup>1</sup>

The well-known manifestly Lorentz-covariant treatment employs the equation  $d\mathbf{P}/d\tau = \mathbf{F}$ , where  $\mathbf{P} \equiv m d\mathbf{X}/d\tau$ ,  $\tau$  denoting the proper time and the capitals representing four-vectors. Not only is the Lorentz-covariant formulation conceptually clearer; it is also simpler to use in practice due to its geometrical significance.

These points are made clearly in a book by John L. Synge,<sup>2</sup> to which the reader is referred for more details, in particular for an enlightening discussion of the concept of "rest mass."

### References

1. See, for example, R. Feynman, R. Leighton, M. Sands, *The Feynman Lectures on Physics*, vol. I, Addison-Wesley, Reading, Mass. (1966), ch. 15.8.
2. J. Synge, *Relativity: The Special Theory*, North-Holland, Amsterdam (1965), ch. VI.

MICHAEL A. VANDYCK

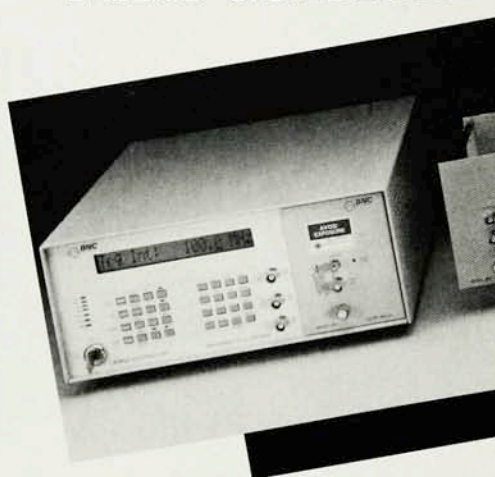
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7/89

Lev Okun's article on the concept of mass, despite the apologetic tone, is an important one. Many introductory physics and physical science

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texts include the erroneous concept implied in the equation

$$m = \frac{m_0}{\sqrt{1 - v^2/c^2}}$$

Students are taught that as the velocity of an object of "rest mass"  $m_0$  gets close to  $c$ , the velocity of light, its mass becomes extremely large. The argument is extended to explain why an object of "rest mass"  $m_0$  cannot reach the velocity of light: If  $v = c$ , then the mass becomes infinite! The same students are also told that particles in cosmic rays could have velocities greater than  $0.9c$  without any change in their masses. It is about time we eliminate such contradictory and confusing statements from our textbooks.

Okun's definition,  $E_0 = mc^2$ , may not eliminate the confusion, as  $m$  could still be interpreted as "rest mass" since  $E_0$  is rest energy. To avoid that confusion, I recommend that the mass-energy relation be stated as  $E = \gamma mc^2$ , where

$$\gamma = \frac{1}{\sqrt{1 - v^2/c^2}}$$

For the special case of a reference frame at rest,  $v = 0$ ,  $\gamma = 1$  and  $E_{\text{rest}} = mc^2$ . Let us eliminate the subscript "0" altogether.

This definition may not gain popularity among the public. On the other hand, physics students will learn the correct concepts of special relativity.

POOVAN MURUGESAN  
Stetson University  
DeLand, Florida

6/89

The article "The Concept of Mass" contains, in my opinion, a curious mistranslation of Einstein's letter of 19 June 1948 to Lincoln Barnett.

The pertinent part in the caption on page 32 reads:

It is not good to introduce the concept of the mass  $M = m/(1 - v^2/c^2)^{1/2}$  of a moving body for which no clear definition can be given. It is better to introduce no other mass concept than the "rest mass"  $m$ . Instead of introducing  $M$  it is better to mention the expression for the momentum and energy of a body in motion.

The German word *daneben* does not mean "instead of," but rather "besides," "in addition to" or "moreover." I would therefore translate the passage:

It is not proper to speak of the mass  $M = m/(1 - v^2/c^2)^{1/2}$  of a moving body, because no clear definition can be given for  $M$ . It is preferable to restrict oneself to the "rest mass"  $m$ . Besides, one may well use the expression for

momentum and energy when referring to the inertial behavior of rapidly moving bodies.

It should be noted that according to Einstein's letter, the expression for momentum and energy may be used to describe the inertial behavior of rapidly moving bodies, not the motion as such.

I am unqualified to evaluate the article. But it seems to me that the inaccurate translation may not be irrelevant to the argument.

SIEGFRIED RUSCHIN  
Linda Hall Library  
Kansas City, Missouri

8/89

I found many of the remarks in the article "The Concept of Mass" thought provoking and interesting. This past semester I took a course where we discussed some of Einstein's theory of special relativity. My professor wished for us to use  $m_0$  as the rest mass and  $m = \gamma m_0$  as the relativistic mass in our equations. Our text,<sup>1</sup> however, did not show this notation. This conflict between my professor and the text was a source of great confusion for me. One of my main concerns was that my professor had probably been taught about relativistic mass and then passed the idea along to his students like so many other teachers. Why is it that the academic system has been able to pass along information like this for so long?

Everyone should now fully realize what terminology one should use in explaining mass, and the reasons behind it. The article was a source of greater understanding for me and, I hope, for other readers. There are still concepts in physics that confuse me: Does mass truly depend on velocity?

## Reference

1. R. Serway, *Physics for Scientists and Engineers*, 2nd ed., Saunders, Philadelphia (1987).

CATHERINE SAUTER  
Baltimore, Maryland

7/89

OKUN REPLIES: I fully agree with Siegfried Ruschin that the English text of Einstein's letter does not correspond exactly to the German original. Moreover, I was aware of this circumstance when I published my article. However, both the German manuscript and a copy of the English typescript that Einstein sent to Lincoln Barnett are in the same file of the Einstein archives, and I did not and do not think that an inaccurate translation that did not bother Einstein was worth remarking on in the article.

continued on page 115

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continued from page 15

I agree with Michael A. Vandyck that the most adequate way of presenting special relativity is by writing manifestly Lorentz-covariant equations. However, the connection with Newtonian mechanics is also essential. Nonrelativistic physics is an important (and correct within its realm) part of physics. And it would be a kind of "relativistic extremism" always to start from four-dimensional coordinates and momenta when considering everyday phenomena.

It is not quite clear to me why Poovan Murugesan believes that the equation  $E_0 = mc^2$ , where  $E_0$  is the rest energy and  $m$  is the mass, would provoke a student to call  $m$  the rest mass. But I don't think we have a real disagreement here.

In connection with Catherine Sauter's letter I would like to point out that the textbook by Raymond Serway to which she refers contains a modern and concise essay on relativity written by George O. Abel. Curiously, the chapter on relativity in a more recent book cowritten by Serway<sup>1</sup> is based entirely on  $m = \gamma m_0$ .

Sauter wonders why "the academic system has been able to pass along information like [the idea of relativistic mass] for so long." A partial answer is given by Wolfgang Rindler, who has written an eloquent letter defending the notion of velocity-dependent mass.

My article cannot suggest that there are unresolved logical difficulties in elementary relativity, as Rindler worries, because I stressed that the matter is absolutely clear to all specialists. What is unresolved is the way the subject is treated in many textbooks. I do insist that by using  $m = \gamma m_0$  the authors of these textbooks commit a "physical blunder" because they use misleading and confusing terminology.

Rindler writes, "One can perhaps understand a desire that everyone should use the term 'mass' in the same sense." I appreciate his understanding that terms in physics should mean the same thing to everyone and his readiness to "use the symbol  $m$  for rest mass and call it mass." However, the equations  $m = \gamma m_0$ ,  $\mathbf{p} = m\mathbf{v}$  and  $E = mc^2$ —the heuristic value of which Rindler praises—preclude uniform usage of the word "mass." (By the way, it seems to me that  $E = \gamma mc^2$  tells how energy varies with speed much better than the "heuristic"  $E = mc^2$ .)

As for Rindler's statement that understanding the term "mass" in various senses never was a stumbling block for him, it would be extremely

strange if it were otherwise. Rindler is not a student, but an expert in relativity. I have seen three editions of his book *Essential Relativity: Special, General and Cosmological* (Springer-Verlag, New York, 1969, 1977, 1979). It is a nice introduction to the subject, except for the sections where the so-called relativistic mass and the whole bunch of other masses are introduced at length. I believe that these sections do present a "stumbling block" to students. If Rindler uses the term "mass" in only one sense in the fourth edition of his book, it will not contain such misleading statements as one that accompanies the equation  $m = \gamma(v)m_0$  in section 5.3 of the last edition—"This conclusion is inevitable if momentum is conserved"—or the whole paragraph about "mass-energy equivalence according to the formula  $E = mc^2$ " in the same section.

The relativistic mass is dear to Rindler's heart. For him not to use it is like driving a car without using the clutch, or writing a novel without using the letter  $e$ . But the fact is that most leading physics journals, such as *Physical Review*, *Physical Review Letters* and *Physics Letters*, don't use relativistic mass. You will not find it in professional books on particle physics. Are all these cars without clutches? To me, texts using the letter  $m$  in many senses look like a novel where  $m$  stands for  $e, m, n, \dots$

It is obvious that Rindler is simply accustomed to the archaic language. But is that enough to justify the promotion of this language to new generations of students?

I would like to use this opportunity to make some remarks concerning equation 16 of my article for gravitational force:

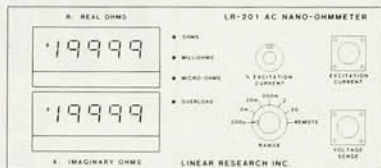
$$\mathbf{F}_g = -\frac{G_N M(E/c^2)}{r^3} \times [\mathbf{r}(1 + \beta^2) - \beta(\boldsymbol{\beta} \cdot \mathbf{r})]$$

According to this equation the force acting on a horizontally moving photon is twice as large as that on a vertically moving one. This factor of 2 explains the famous extra factor of 2 in Einstein's expression for the angle of light bending by the Sun. Equation 16 needs some comments, which unfortunately were missing from my article.

It is common knowledge that in a locally inertial frame the gravitational force is equal to zero. That means that equation 16 is valid only for locally noninertial frames, such as the usual laboratory frame. Moreover, it is important to stress that we are considering the static, spherically

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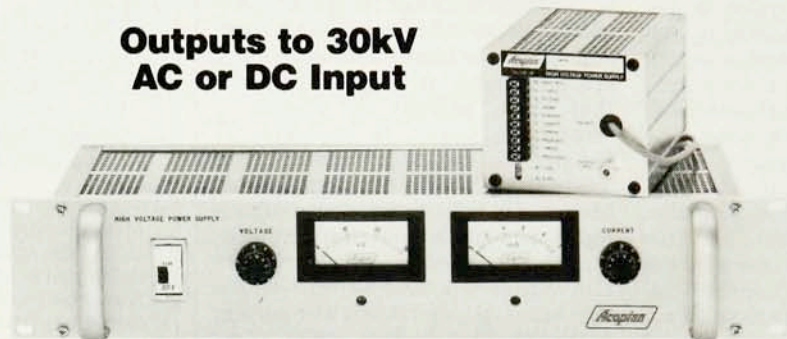
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symmetric gravitational field of the Sun or the Earth (neglecting rotation) and that the metric chosen to obtain equation 16 is isotropic:  $g_{\alpha\beta} = (g_{00}, g_{ik})$ , where  $g_{ik} = -\eta_{ik}f$ , so that  $ds^2 = g_{00}x^0x^0 - f(x^1x^1 + x^2x^2 + x^3x^3)$ . Using this metric, equation 16 is easily derived as a first-order approximation in the gravitational potential  $GMc^2/r$  from equation 87.3 of *Field Theory* by Lev D. Landau and Evgenii M. Lifshitz. As the final step of this derivation one has to change to the frame with the usual local rulers and clocks. The choice of an isotropic metric does not permit us to get rid of our force by using equivalence-principle elevators, and therefore one can say that the result for the light bending angle does arise from the global geometry of the central field—the point that is usually stressed in textbooks on gravity.

Engelbert Schucking from New York University has informed me that he has obtained a generalized exact formula for what he calls “the relativistic apple,” valid in all approximations with respect to the potential  $GMc^2/r$ :

$$\mathbf{F}_g = -\frac{G_N M(E/c^2)}{r^3 \left(1 + \frac{G_N M c^2}{2r}\right)^3} \times \left[ \mathbf{r} \left(1 + \beta^2 + \frac{G_N M c^2}{2r - G_N M c^2}\right) - \beta(\beta \cdot \mathbf{r}) \right]$$

(I'm grateful to Schucking for this communication. I am also grateful to him and to Mikhail Voloshin and Alexander Dolgov for very enlightening discussions.) The first-order approximation in gravitational coupling implicit in equation 16 is very good for the cases of the Sun and the Earth.

I have found equation 16 in only one book.<sup>2</sup> Unfortunately the formula is constructed there semiempirically, and the book itself is full of  $E = mc^2$  and all that.

The lack of space and time didn't allow me to discuss in my article such important questions as the mass of a system of particles. I consider this and some other problems in more detail in an extended version of the article.<sup>3</sup>

I don't think we should try to banish  $E = mc^2$  from T-shirts, badges and stamps. But in the textbooks it should appear only as an example of a historical artifact, with an explanation of its archaic origin.

## References

1. M. G. Bowler, *Gravitation and Relativity*, Pergamon, Elmsford, N. Y. (1976).
2. R. S. Serway, J. S. Faughn, *Physics*, Saunders, Philadelphia (1989).

3. L. B. Okun, *Usp. Fiz. Nauk.* **158**, 511 (1989) [*Sov. Phys. Usp.* **32**, 629 (1989)].

LEV B. OKUN

*Institute of Theoretical and  
Experimental Physics*

1/90

*Moscow, USSR*

## Broken Symmetry Can't Compare with Ferromagnets

I was sorry to see, in the otherwise excellent history of the “standard model” for particle theory by Paul Langacker and Alfred K. Mann (December, page 22), a repetition of the false analogy between broken symmetry and ferromagnetism that is very common among the writings of particle physicists.

In ferromagnetism, specifically, the ground state is an eigenstate of the relevant continuous symmetry (that of spin rotation), and as a result the symmetry is unbroken and the low-energy excitations have no new properties. Broken symmetry proper occurs when the ground state is not an eigenstate of the original group, as in antiferromagnetism or superconductivity; only then does one have the concepts of quasidegeneracy and of Goldstone bosons and the “Higgs” phenomenon. I have discussed the origins of the concept of broken symmetry elsewhere.<sup>1</sup>

## Reference

1. P. W. Anderson, in *Gauge Theories and Modern Particle Theory*, R. Arnowitt, P. Nath, eds., MIT P., Cambridge, Mass. (1975), p. 311.

PHILIP W. ANDERSON

*Princeton University*

12/89

*Princeton, New Jersey*

LANGACKER AND MANN REPLY: Our description of a ferromagnet as an example of a broken symmetry followed the language that is common in many books on condensed matter physics,<sup>1</sup> and the ferromagnet is a valid analog of what is called a spontaneously broken global symmetry in elementary-particle physics. It was not our intention to imply that the ferromagnet is an example of the “Higgs” phenomenon, and we apologize if the wording in the article was not sufficiently clear. We thank Philip Anderson for emphasizing the important distinction between ferromagnets (in which the order parameter commutes with the symmetry generators) and antiferromagnets.

## Reference

1. See, for example, D. Forster, *Hydrodynamics, Fluctuations, Broken Symme-*

*try, and Correlation Functions*, W. A. Benjamin, Reading, Mass. (1975).

PAUL LANGACKER

ALFRED K. MANN

*University of Pennsylvania*

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3/90

## Where Did Einstein Lament Lambda?

We were very interested in the article “Landau's Attitude Toward Physics and Physicists” by Vitaly L. Ginzburg (May 1989, page 54). In the section headed “General Relativity” the author raises the issue of the introduction and renouncement by Einstein of the cosmological constant  $\Lambda$  and mentions that he tried to find an original paper on that subject. We recently tried to trace where and when Einstein gave up the idea of  $\Lambda \neq 0$ : The references can be found in the excellent biography by Abraham Pais, *Subtle Is the Lord...: The Science and the Life of Albert Einstein* (Oxford U. P., New York, 1982, page 288).

Einstein wrote that there is no need for a  $\Lambda$  term in his paper “Zum kosmologischen Problem der allgemeinen Relativitätstheorie.”<sup>1</sup> There we read, “Unter diesen Umständen muss man sich die Frage vorlegen, ob man den Tatsachen ohne die Einführung des theoretisch ohnedies unbefriedigenden  $\Lambda$ -Gliedes gerecht werden kann” (“Under these circumstances, the question should be raised of whether one can satisfy the facts without introducing the  $\Lambda$  term, which anyway is theoretically unsatisfactory”), and, in the conclusion, “Bemerkenswert ist vor allem, dass die allgemeine Relativitätstheorie Hubbles neuen Tatsachen ungezwungener (nämlich ohne  $\Lambda$ -Glieder) gerecht werden zu können scheint als dem nun empirisch in die Ferne gerückten Postulat von der quasi-statischen Natur des Raumes” (“It is remarkable that the theory of relativity seems to satisfy Hubble's new results more naturally [Pais translates this as “in an unforced way”], namely, without the  $\Lambda$  term, than the empirical postulate of a quasistatic space, now set aside”). One year later, in a paper with Willem de Sitter,<sup>2</sup> Einstein wrote (in English), “It now appears that in the dynamical case this end [the existence of a finite mean density in a static universe] can be reached without the introduction of  $\Lambda$ .”

As for the oft-quoted sentence about Einstein that “the introduction of the cosmological term was the biggest blunder he ever made in his life,” it is to be found only in George Gamow's autobiography *My World Line* (Vi-