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:

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

(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.[2] 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.[3]

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)].

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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.[1]

Reference

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

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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,[1] 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 Symmetry, and Correlation Functions*, W. A. Benjamin, Reading, Mass. (1975).

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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 Λ 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 Λ term in his paper "Zum kosmologischen Problem der allgemeinen Relativitätstheorie."[1] There we read, "Unter diesen Umständen muss man sich die Frage vorlegen, ob man den Tatsachen ohne die Einführung des theoretisch ohnedies unbefriedigenden Λ-Gliedes gerecht werden kann" ("Under these circumstances, the question should be raised of whether one can satisfy the facts without introducing the Λ term, which anyway is theoretically unsatisfactory"), and, in the conclusion, "Bemerkenswert ist vor allem, dass die allgemeine Relativitätstheorie Hubbels neuen Tatsachen ungezwungener (nämlich ohne Λ-Glied) 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 Λ term, than the empirical postulate of a quasistatic space, now set aside"). One year later, in a paper with Willem de Sitter,[2] 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 Λ."

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-