LETTERS TO THE EDITOR

Letters are selected for their expected interest for our readers. Some letters are sent to reviewers for advice; some are accepted or declined by the editor without review. Letters must be brief and may be edited, subject to the author's approval of significant changes. Although some comments on published articles and notes may be appropriate as letters, most such comments are reviewed according to a special procedure and appear, if accepted, in the Notes and Discussions section. (See the "Statement of Editorial Policy" in the January issue.) Running controversies among letter writers will not be published.

ON WEIGHTLESSNESS

It will be surprising if the letter from Frank Goodman[1] about weightlessness does not elicit a number of responses. This is a topic that turns physicists into enthusiastic advocates of conflicting positions. It is a classic Humpty Dumpty situation ("When *I* use a word, it means just what I choose it to mean..."), for it is ultimately a question of opinion and definition. However, I find myself siding with Robert Ehrlich,[2] not with Frank Goodman, in this matter.

I would claim that "weight" and "weightlessness" have as much to do with physical sensations as they do with physics. The whole concept of weight is rooted in the feeling that some force is always trying to drag us downward, and does so unless an upward supporting force is supplied to prevent it. Our only *direct* measure of weight, in fact, is the magnitude of this supporting force. With the help of Newton's second law we have an indirect measure, based on the observed magnitude of our downward acceleration if the support is removed. We recognize, however, that weight is not an intrinsic property of a body; it depends on the body's location and state of motion. For an object at rest with respect to the Earth, what we call its weight is, as we know, the resultant of the true gravitational force and a centrifugal force. Weight is thus a curious hybrid, the combination of a true force arising from fundamental interactions and what is often called a fictitious force—even though in the framework of the rotating Earth it is very real. Perhaps because of this, the International Bureau of Weights and Measures (BIPM) does not baldly say that weight is a force; it says "The word *weight* denotes a quantity of the same nature as a *force* [my underline]; the weight of a body is the product of its mass and the acceleration due to gravity."[3]

What does all this have to do with weightlessness? The connection appears when we consider other possible frames of reference. The International Standards Organization expands somewhat on the BIPM statement and defines weight as follows: "The weight of a body in a specified reference system is that force which, when applied to the body, would give it an acceleration equal to the local acceleration of free fall in that reference system."[4] This corresponds precisely to a definition of our own weight as what we would measure, under any circumstances, if we stood on a bathroom scale. Our weight (let us not muddy the issue by calling it "apparent weight") increases when we are in an elevator with an upward acceleration, and decreases when the elevator has a downward acceleration. By this definition, an astronaut in a spacecraft orbiting the Earth has zero weight—i.e., is weightless. But so also, I contend, is a penny or a human being in free fall at the Earth's surface, because their actual physical states are equivalent to that of the astronaut. To see this, consider the internal stresses acting on a given object. For the astronaut in a spacecraft, raising the arms is effortless; the subjective effect of what we commonly call gravity has vanished. But the same holds for a person in free fall anywhere, for whom the arms cease to tug on the shoulders, and so on. It manifestly holds, too, for any deformable object. A liquid drop, which is flattened when sitting on a horizontal surface, becomes spherical when falling, because it is no longer sensitive to the particular combination of gravitational and centrifugal forces that defines the local value of g. And although the effect may not be visible for more rigid objects, it is certainly there.

I think that this vanishing of internal stresses is the most logical criterion for defining what we mean by weightlessness in any circumstances—not just in a spacecraft that itself provides a freely falling reference frame in which g is zero. By the same token, the *increase* of internal stresses if we are in an elevator accelerating upward—the increased force with which the rest of our body presses down on our feet, the sinking feeling in the stomach, etc.—corresponds precisely to an increase in what we would colloquially and subjectively call our weight and the weight of our internal organs. With special regard to an object that is released from rest to fall vertically near the Earth's surface, I would argue that it has weight W, measurable on a balance, before it is released, but also becomes weightless once it is falling, with an acceleration g relative to the Earth equal to W/m. In this transition there has been a major change in the physical condition of the object.

Have I put myself into a logical contradiction? I do not think so. I cannot deny, of course, that the gravitational force and the centrifugal force (supplemented now by a Coriolis force) continue to act on the body as it falls. But I think that if I define weightlessness in terms of the physical state of the object, my position is justified. What I am in effect arguing is that the body itself defines the reference frame within which its weight should be measured. I am sure that many others will see the situation differently, but I urge such people to imagine what it *feels* like to be in free fall, and to consider seriously the merits of the above discussion. I admit that it *is* all a matter of definition. But since I began with Humpty Dumpty, let me end with what a distinguished philosopher once said about him: "[He] must take an honourable place among those who have attempted to free us from the bondage of symbols which are our own creation."[5]

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[1]Frank O. Goodman, "Weightful versus weightless," Am. J. Phys. **62**, 775 (1994).
[2]R. Ehrlich, "Ruler physics: Thirty-four demonstrations using a plastic ruler," Am. J. Phys. **62**, 111–120 (1994).
[3]*SI: The International System of Units*, edited by R. J. Bell [translated from 6th ed. (1991) of *SI: Le Système International d'Unités* (BIPM, Sèvres, France)] (HMSO, London, 1993), p. 27.
[4]International Organization for Standardization, *International Standard ISO 31-3, Quantities and Units, Part 3: Mechanics* (ISO, Geneva, Switzerland, 1992).
[5]R. B. Braithwaite, "Lewis Carroll as Logician," Math. Gazette **16**, 174–178 (1932).