Weight and Gravity — The Need for Consistent Definitions

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Everyone who teaches introductory physics is used to dealing with the confusion students experience when first confronted with the difference between mass and weight. After a week or two of dealing with force vectors, however, most students are used to the idea that weight is a force caused by the gravitational pull of the planet. But then, in the typical introductory course, a few weeks later they encounter circular motion, gravity, and Earth satellites and confusion returns in force. Even after lengthy discussion of centripetal acceleration and the idea that a central force is required if an object is to move in a circle, ask students why astronauts in the space shuttle float freely about the cabin; at least seven out of ten will answer that "they are outside the Earth's gravity." This misconception is, of course, strongly reinforced by years of the media talking about "weightlessness" and "zero-gravity" of orbital flight. Students are quite shocked to learn, for example, that at a typical shuttle orbit altitude of 250 miles, the force of Earth's gravity on an astronaut is still 88 percent of what it is when he is standing on the ground!

Unfortunately, use of the terms "weightlessness" and "zero-gravity" and the consequent misunderstanding caused by them is not confined to the nonscientific media. Materials published by NASA routinely refer to the "weightless environment" in an orbiting spacecraft, and terminology used in standard basic-physics texts is anything but consistent. It is this last point that this note attempts to address. We would expect that trained physicists at the end of the twentieth century would all give the same definition of the word "weight"—especially when writing for beginning students. Perusal of a selection of standard textbooks, however, quickly shows that this is not the case. The textbooks examined were simply those sitting in my bookshelves, the usual collection of examination copies sent by publishers to college physics departments. These include: *Physics— An Introduction*, Boleman (Prentice-Hall); *Physics*, 5th ed., Giancoli (Prentice-Hall); *Fundamentals of Physics*, 5th ed., Halliday, Resnick, and Walker (Wiley); *Physics: Algebra/Trig*, 2nd ed., Hecht (Brooks/Cole); *Conceptual Physics*, 8th ed., Hewitt, (Addison-Wesley); *Physics A World View*, 3rd ed., Kirkpatrick and Wheeler (Saunders); *Physics The Nature of Things*, Lea and Burke (Brooks/Cole); *Physics*, Ohanian (Norton); *College Physics*, 4th ed., Sears, Zemansky, and Young (Addison-Wesley); *College Physics*, 4th ed., Serway and Faughn (Saunders); *College Physics*, 3rd ed., Wilson and Buffa (Prentice-Hall).

Among these texts, the most common definition of "weight" is the force of gravity on the object produced by the nearest astronomical body. Ohanian (page 122) states "Weight is the pull of the Earth's gravity." In Serway and Faughn (page 90) we find: "The force exerted by the earth on an object is called the weight of the object." In Hecht, "Weight is the downward force experienced by an object as a result of the Earth-object gravitational interaction." Some authors are more careful with their wording to acknowledge that weight exists on other planets. Wilson and Buffa (page 103) state: "The weight of an object is the gravitational force of attraction that a celestial body exerts on an object."

In Sears, Zemansky, and Young, we find a subtly different definition on page 69: "Weight is the resultant gravitational force exerted on a body by all other bodies in the universe." Other authors are less precise, making it unclear which of the above definitions they are using: Lea and Burke (page 127) say "Weight means the gravitational force being exerted on an object." Giancoli (page 80) defines weight as simply "the force of gravity acting on a body."

Things become less simple in Halliday, Resnick, and Walker, where we find (page 87): "The weight of a body is a force that pulls the body directly toward a nearby astronomical body. . . . The force is primarily due to an attraction—called a gravitational attraction—between the two bodies." They don't seem to say just what the rest of this force is.

In general, the differences described above can be considered very minor and really not worth worrying about. When we go to the texts by Hewitt and by Kirkpatrick and Wheeler, however, we find a very different definition. On pages 38-39 of Kirkpatrick and Wheeler we read: "Mass is often confused with weight, which in turn is confused with the force of gravity. . .we measure our weight by how much we can compress a calibrated spring such as a bathroom scale." Similarly, Hewitt (page 149) states: "We define the weight of something as the force it exerts against the supporting floor." This definition then allows Hewitt to state that an astronaut in orbit "is weightless because he is not supported by anything." In contrast, Wilson and Buffa (page 232) say bluntly "'weightlessness' and 'zero gravity' are misnomers."

Most of the texts examined are at least self-consistent. Hecht, for example, calls the force an object exerts on a scale the "effective weight" and states that an object in free fall is "effectively weightless." Giancoli (pages 130-132) does a good job explaining the difference between "real weightlessness" (in deep space, well away from astronomical objects) and "apparent weightlessness." Boleman, on the other hand, compounds the confusion by first stating (page 51) "Your weight is the pull of earth's gravity on your body" and then, on page 143, writing "The first skylab crew was weightless for 29 days."

My strong preference is for what seems to be the majority view: that weight is the local force of gravity on the object. In fact, *The American Heritage Dictionary of the English Language* provides a better wording than any of the cited texts: "The gravitational force exerted by the earth or another celestial body on an object, equal to the product of the object's mass and the local value of gravitational acceleration." (This is actually their second definition; the first is one that no physicist would be happy with—to wit: "a measure of the heaviness or mass of an object").

The purpose of this note, however, is not to argue the relative merits of the different definitions but rather to argue that the physics-teaching community should address the issue and agree on common definitions. Public ignorance and misunderstanding of many common physical phenomena —e.g. "weightlessness" in orbit—is, in part, our own fault. It would be a definite step in the right direction to make sure that we are at least defining our terms in the same way.

A Ripple Tank for Gulliver

Photograph of the beach at Tel Aviv, Israel, dramatically shows single-slit diffraction of ocean waves through the barrier openings. Note that the beach has been shaped by the circular wave fronts.

Photo taken by Sabina Zigman, a sophomore in physics honors class at Benjamin N. Cardozo High School, Bayside, New York.
Photo submitted by her teacher, Sheldon Wortzman.