Weight – An Official Definition

Mario Iona, Department of Physics, University of Denver, Denver, CO 80208

The opinion paper by Richard C. Morrison [*Phys. Teach.* **37**, 51 (Jan. 1999)] asks why there is such a variety of definitions of weight. The first hurdle of establishing the meaning of weight is to make it clear that we are dealing with a force and not a synonym for mass. We should also realize that the authors are trying to describe a common but rather complicated experience, and not a simple textbook concept of a fundamental nature such as force or energy. It should therefore not be surprising that many definitions are simplifications and are attempts to make the term meaningful at a particular point in a textbook. Unfortunately, such an idealized initial definition often remains the only one given, in spite of other uses of the term and resulting inconsistencies.

There exists, however, a definition that is not influenced by attempts to simplify, that seems to be in agreement with most practices, and that has the support of physicists and engineers in many countries. The International Organization for Standardization (ISO)[1] 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." This is further explained in a note: "When the reference system is the Earth, the quantity defined here has commonly been called the local force of gravity on the body. It is noteworthy that this weight comprises not only the results of the gravitational forces existing at the place where the body is, but also the local centrifugal force due to the rotation of the Earth." (Buoyancy, for which experimental, local corrections can be applied, is not included as affecting the weight.)

Although the usual observation of weight on the rotating Earth is emphasized, the definition allows us to use the surface of the Moon or other planets, or falling elevators, or spacecraft as reference system; in the latter two cases we see that the meaning of weightlessness becomes an obvious extension. This definition allows the unqualified use of the equation $W = mg$, with the free-fall acceleration, g, being the quantity observed in the chosen reference system. It shifts the burden of explaining the variation with location, or reference system, to the discussion of the free-fall acceleration. Unfortunately, taking into account the effect of the reference system on the observed free-fall acceleration is even more often ignored in textbooks than considering the effect on weight.

In looking at the implications of this definition, it becomes clear why many authors use simplifications when first introducing the concept of weight. Accelerated reference systems are seldom discussed, although the dependence of g on the latitude, which is only about one-third gravitational, is often mentioned. We also find that authors change their views as certain terminology becomes better established. Geophysicists are directly concerned with the effects of Earth's rotation and their vocabulary reflects this. They usually distinguish between "gravity" (the gravitational effects as they are observed on the rotating Earth) and "gravitation," when the theoretically simpler, but not observable, purely gravitational interactions are discussed. This subtle distinction is only occasionally found in physics texts.[2]

References

1. ISO 31-3, "Quantities and units. Part 3, Mechanics," 1992.
2. H. Goldstein, *Classical Mechanics* (Addison-Wesley, 1980), p. 178.

Weight – An Accurate, Up-to-Date, Layman's Definition

Roy Bishop, Physics Department, Acadia University, Wolfville, NS, Canada B0P 1X0; roy.bishop@acadiau.ca

One of the enduring debates among physics instructors concerns weight. In the January 1999 issue of *The Physics Teacher* (page 51), Richard Morrison gives an overview of the variety of definitions of weight to be found in a selection of introductory physics textbooks. Morrison states: "My strong preference is for what seems to be the majority view: that weight is the local force of gravity on the object." By "majority" Morrison is referring to the few dozen authors of introductory physics texts, or possibly to a few tens of thousands of physics instructors. I prefer the operational definition of weight used by a much larger majority, namely hundreds of millions of our fellow citizens:

Weight is what bathroom scales read.

Since bathroom scales measure the force they exert on our feet, these scales should be calibrated in newtons (N), but I shall say nothing more about units. An equivalent definition, not specific to bathroom scales, is:

Weight is the force required to support a body.

This definition is essentially the same as that given by Kirkpatrick and Wheeler, and by Hewitt (authors of texts cited in Morrison's article), and I claim no credit for it. The purpose of this note is to point out the merits of this definition of weight as compared with the usual textbook definition. To be concise, I shall designate the definition of weight based on force required to support by "WFS," and the usual textbook definition based on force of gravity as "WFG." WFS has three advantages over WFG:

1. WFS is what weight means to people, be it the reading on their bathroom scales or the force sensed by their aching feet. Even if WFG is qualified to mean the gravitational force exerted only by a local body (usually Earth), centrifugal effects associated with Earth's rotation ensure that neither in magnitude nor in line of action is the force in WFG the same as the force that bathroom scales measure or people feel (see Fig. 1).

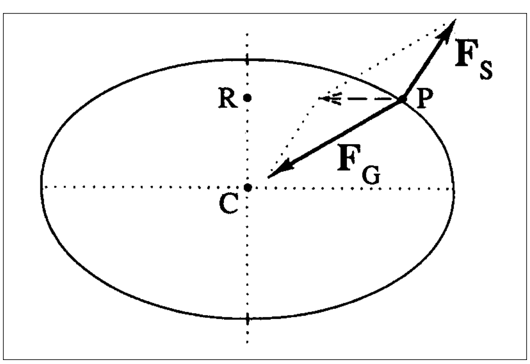

Fig. 1. A person P located at an intermediate latitude on the rotating Earth is supported by an electromagnetic contact force F_S directed vertically upward (along a plumb line), and is attracted toward Earth's center C by Newton's gravitational force F_G. The vector sum (resultant) of F_S and F_G is directed toward the center of rotation R. (The rotation rate and hence equatorial bulge of Earth are exaggerated to emphasize the dissimilar magnitudes and non-collinear nature of the two forces.) Textbooks usually equate weight with F_G, whereas bathroom scales and aching feet measure F_S. For an astronaut in an orbiting space shuttle, $F_S = 0$.

2. "Weightlessness" as used in the popular press and by NASA is consistent with WFS, but not with WFG. If we insist on using WFG, then we have to confuse understanding further by saying that an orbiting astronaut may be "effectively weightless" but that he really has weight. The accusation that the nonscientific media misuse the term "weightlessness" only compounds the confusion. Students get "used to the idea that weight is a force caused by the gravitational pull of the planet" (Morrison's words) because that is what most textbooks and instructors tell them, and students want to optimize their academic grade. No wonder then that when faced with an orbiting spacecraft within which they *know* weightlessness occurs, "at least seven out of ten [students] will answer that [the spacecraft is] outside the Earth's gravity"!

3. WFG is a creature of Newtonian physics. In order to force the world into an Euclidean straightjacket, Newton had to treat gravity as if it were a force. In 1915 Einstein replaced Newton's mysterious force of gravity with a non-Euclidean spacetime. WFS is consistent with general relativity, but WFG is not. WFS is based upon a real force, the electromagnetic interaction. WFG is based upon a non-existent force, a force that is as fictional as centrifugal and Coriolis forces, a force that no one has ever felt. (Many a time when speaking on the topic of gravity I have offered \$50 to anyone who can describe even one instance in which they have felt the force of gravity. I still have my \$50.)

Regarding item 3, I am not proposing that general relativity replace Newton's gravitational force in introductory physics. This would be didactically unsound, for we cannot begin to appreciate Einstein without first understanding Newton's vision of the world. My point is simply that definition WFG is based upon a ghost that vanished more than 80 years ago.

To lay to rest decades of confusion surrounding the formal definition of weight, it is necessary, but not sufficient, for physics educators to use a consistent definition. Also necessary is a definition of weight that matches the popular meaning of this everyday term. Surely even a majority of physics instructors cannot expect the rest of the world to adopt a definition that is not what people mean by weight (what bathroom scales or aching feet sense), that causes needless confusion in weightless situations, and that is based upon a pre-1915 theory of gravitation.

Weight – A Pictorial View

Andrzej Sokolowski, Rogue Community College, Medford Campus, 3345 Redwood Highway, Grants Pass, OR 97527-9298, and St. Mary's School, 816 Black Oak Drive, Medford, OR 97504; ASokol7668@aol.com

Here is a demonstration method that I have used to teach the difference between force of gravity and weight. Let F_G be the force of gravity, which includes the local effects of gravitational attraction and centrifugal effects. $F_G = mg$, where g is the local field strength or, equivalently, the acceleration of the object in free fall. Let F_W be the weight, which will be defined in terms of the reading on a force scale.

A. *Object is on a horizontal surface. The angle of inclination of the support is* $\alpha = 0°$.

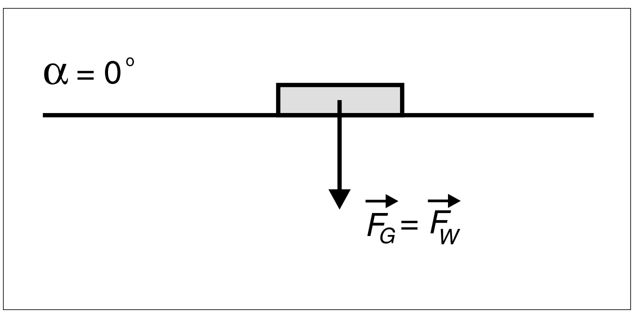

Fig. 1.

Students can easily draw the vector of the force of gravity. To find the vector of weight, I ask: What would be the reading of the scale on which the block rests? Evidently, the scale would show the value of F_G. So in this case, $F_W = F_G$.

B. *Increase the inclination of the support to an angle* $\alpha > 0°$.

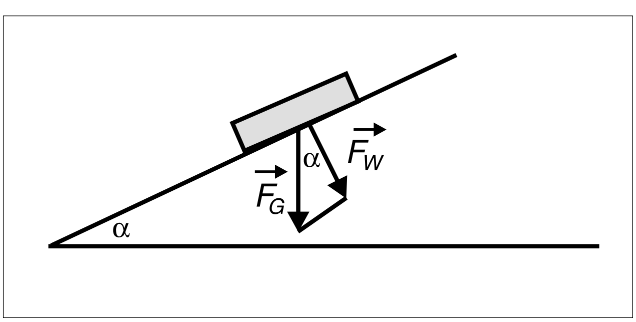

Fig. 2.

Since the mass of the object and the place of the experiment do not change, the force of gravity does not change either. How about the value of the weight of the object? Since the support surface is no longer horizontal, the component of the force of gravity perpendicular to the surface is no longer equal to the force of gravity. Therefore the weight of the object is not equal to the force of gravity. Instead, $F_W = F_G \cos\alpha$. The object weighs less now!

C. *Increase the inclination of support to 90°.*

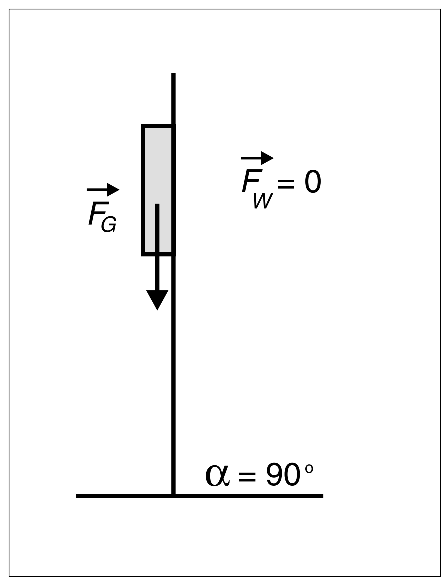

Fig. 3.

Now I ask the students: What is the value of the component of F_W perpendicular to the support? The force of gravity has no component perpendicular to the board, so the weight of the object is zero! We say that the object is *weightless*.

Further Questions

1. Can the weight of an object exceed the force of gravity on it?

2. Under what conditions are objects in the gravitational field of Earth weightless?

Weight – Don't Use the Word at All

Ronald Brown, Physics Department, Cal Poly, San Luis Obispo, CA 93407; rfbrown@calpoly.edu

I strongly agree with Richard Morrison[1] that at the end of the twentieth century, the physics teaching community should at least agree on a definition of the word "weight." That we do not is very strong evidence to me that the word should simply never appear in the literature or textbooks. It should be expunged from our vocabulary—*except* as a substitute for the word "object," as in "A weight was suspended from a string." I have said this for years: Every single time the word "weight" is used, it could be replaced by the phrase "force due to gravity" and the clarity would improve. Notice that the phrase is consistent with every definition used in the listing of textbooks in the Morrison article and *always* avoids the basic confusion between "mass" and "weight" that so many of our students struggle with. That is, a mass can never be confused with a force due to gravity. Mass can be thought of as a property of an object whereas forces act on objects, hence the confusion becomes moot. The use of the words "weight" and "mass" become essentially interchangeable in so many people's minds because they seem to both be identifying the same property of the objects themselves.

The word "weight" is inherently ambiguous. It is not clear when it is used whether it is a measure of the actual force that is exerted on the object by Earth, or whether it is what would be measured when weighing the object. But those two forces are never the same. On Earth, the buoyant force on a normal sized person simply due to the air is nearly half a pound (in barbaric units) or about 2 newtons (in SI). And of course some of the authors mentioned are also fond of such concepts as "apparent weight" when you ride an elevator, as if that were a fundamentally new concept. (Has no one noticed this is just the normal force of the elevator floor on the person inside?) And if we then worry that Earth is also rotating, what we measure must be corrected once again (and depends on latitude). The force due to gravity is not a constant either, but still does not include the other ambiguities.

In addition to reducing the confusion between mass and force, the notation becomes clearer as well if "weight" is never used. The symbol w is unlikely to ever be used for "force due to gravity," hence will never be confused (a couple of chapters later in most textbooks) with W for work. Do we *really* want to ever say "The work done by the weight as an object falls a distance h is $W = wh$"? Halliday et al.[2] entitle Sect. 7.4 "Work Done by Weight," which will suggest to some students that objects do work on themselves. Is that the message we are trying to teach? Does that not lead directly to a number of common difficulties for beginning students even though it correctly uses the definitions of "weight" presented in most of the listed texts?

The solution to this problem is trivial. Never use the word "weight." Always use "force due to gravity" when what you mean is "force due to gravity"—an expression that is as valid on some unknown planet around some distant star as it is here on Earth.

References

1. R. C. Morrison, "Weight and gravity—the need for consistent definitions" In My Opin., *Phys. Teach*. **37**, 51 (Jan. 1999).
2. D. Halliday, R. Resnick, and J. Walker, *Fundamentals of Physics*, 5th Ed., (Wiley, New York, 1997), Sect. 7.4

Cartoon by Chris Silverman