

## 5.4 Mass and Weight

### Mass and Weight

#### Key Ideas

- Mass and weight are different concepts. Mass is related to an object's inertia, while weight is the gravitational force on an object.
- Weight is the mass times the acceleration due to gravity, or the magnitude of the gravitational field.
- All objects in free-fall accelerate at the same rate because mass cancels out of Newton's second law of motion.
- Acceleration can cause an object's apparent weight to be different from its actual weight.

#### Learning Objectives

After completing this section, you should be able to...

- explain the difference between mass and weight,
- calculate the weight of an object, given its mass,
- explain the difference between weight and "apparent weight," and
- relate the "apparent" weight of an object to its acceleration using Newton's second law of motion.

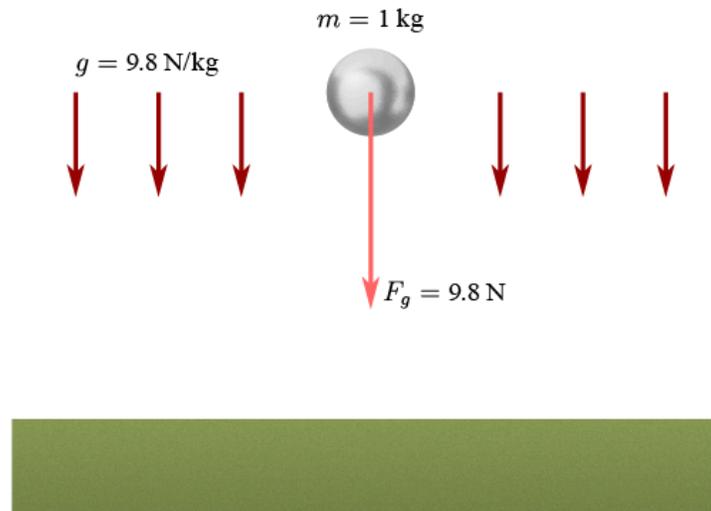
The terms "mass" and "weight" are often used interchangeably in everyday language, but in physics, they have very different definitions. As we have previously discussed, mass is a measure of the "amount of matter" in an object. Most objects are composed of countless numbers of atoms, each of which is composed of smaller, subatomic particles. Measuring an object's mass by directly relating it to the masses of its constituent particles is therefore very difficult. However, as we stated in Section 5.2 ([Newton's First Law of Motion](#)), mass can also be thought of as the amount of inertia of an object. Newton's second law gives us a practical way to measure an object's mass: subject it to a net force and measure its acceleration. The magnitude of the net force on an object divided by its acceleration magnitude gives its mass. Provided it does not lose or gain matter, an object's mass, measured in this way, always remains the same. Mass is therefore an intrinsic property of the object that depends on the object itself and not on any interaction with its environment. Weight, on the other hand, is not an intrinsic property of the object, as we will discuss below.

#### Gravity and Weight

**Gravity** is a fundamental interaction that affects all matter in the universe. All matter exerts an attractive **gravitational force** (or **force of gravity**) on all other matter. Gravitational forces are **long-range**, that is, objects exert gravitational forces on each other over great distances without having to be in contact. The magnitude of the gravitational force that objects exert on each other depends on their masses; larger masses exert larger forces. Also, the force depends on the distance between objects, with the force weakening with greater distance. Gravity is a relatively weak interaction when compared to other naturally occurring forces, so only objects with very large masses, like planets and stars, can exert gravitational forces large enough to produce appreciable effects.

The gravitational forces exerted by a large body like a star or planet are often described in terms of the **gravitational field** created by and surrounding that body. Gravitational fields will be discussed further in Chapter 13 ([Section not found](#)). The more general concept of fields will be further explored in the chapters on electricity and magnetism. A **field** is a quantity that has a value at any point in space. The gravitational field produced by the body is a vector quantity that points toward the center of that body, with a magnitude that gets smaller with greater distance from the body. We can think of the gravitational field at a point as the gravitational force that the body exerts on a mass of one kilogram. So, for example, on

the Earth's surface, as shown in [Figure 5.12](#), the gravitational force that Earth exerts on a 1-kg object is about 9.8 N. We therefore say the magnitude of the gravitational field near the Earth's surface is 9.8 N/kg.



**Figure 5.12** Near the Earth's surface, the Earth produces a gravitational field  $\vec{g}$  pointing downward with uniform magnitude of 9.8 N/kg. An object with a mass of 1 kg placed in this field experiences a gravitational force due to the Earth with a magnitude of 9.8 N.

This value may look familiar. The symbol used for the gravitational field vector is  $\vec{g}$ , magnitude  $g$ . So, on Earth's surface,  $g = 9.8 \text{ N/kg}$ . Using the definition of the newton, where  $1 \text{ N} = 1 \text{ kg} \cdot 1 \text{ m/s}^2$ , we find that  $g = 9.8 \text{ N/kg} = 9.8 \text{ m/s}^2$ . The magnitude of the gravitational field at Earth's surface is equivalent to the more familiar "acceleration due to gravity" introduced in Section 3.5 ([Free Fall](#)). We will use units of  $\text{m/s}^2$  for gravitational field for consistency. The gravitational force on an object is equal to its mass times this gravitational field. We will define **weight** to be the gravitational force on an object.

## Weight

Weight is the gravitational force on an object. The magnitude of the weight  $F_g$  of an object with mass  $m$  in a gravitational field of magnitude  $g$  is:

$$F_g = mg$$

5.6

The SI unit for weight is the newton (N).

As mentioned above, weight, unlike mass, is not a property of an object. Weight depends not only on mass but on the gravitational field, which varies in magnitude depending on location. For example, Earth's gravitational field reduces in magnitude with greater distance from Earth's center. At sea level on Earth,  $g = 9.81 \text{ m/s}^2$ ; at the top of Mount Everest,  $g = 9.77 \text{ m/s}^2$ ; while 400 km above the Earth's surface (the average orbital altitude of the International Space Station),

$g = 8.56 \text{ m/s}^2$ . On another planet or celestial body,  $g$  could have a completely different value. For example, on the Moon,  $g = 1.6 \text{ m/s}^2$  on average, and on Mars,  $g = 3.7 \text{ m/s}^2$  on average. Astronauts on the moon weighed only about 17% of what they weighed on Earth.

## Example 5.8

During the Apollo 14 lunar mission in February 1971, astronaut Alan Shepard famously played golf on the Moon, where the surface gravitational field is  $1.6 \text{ m/s}^2$ . The mass of a typical golf ball is 45 g. What is the golf ball's weight on Earth? What is its mass on the Moon? What is its weight on the Moon?

### Strategize

We will use [Equation 5.6](#) to find the weight of the ball, given different values of  $g$ .

### Develop and Solve

The golf ball's weight  $F_{g,E}$  on Earth is given by its mass and  $g_E = 9.8 \text{ m/s}^2$ .

$$\begin{aligned}F_{g,E} &= mg_E \\ &= (0.045 \text{ kg})(9.8 \text{ m/s}^2) \\ &= 0.44 \text{ N}\end{aligned}$$

The golf ball's mass on the Moon is the same as it is on Earth, 45 g. To find the ball's weight on the Moon,  $F_{g,M}$ , we use the same mass, but now  $g_M = 1.6 \text{ m/s}^2$ .

$$\begin{aligned}F_{g,M} &= mg_M \\ &= (0.045 \text{ kg})(1.6 \text{ m/s}^2) \\ &= 0.072 \text{ N}\end{aligned}$$

### Assess

The mass of the golf ball does not change on the Moon, but its weight does, due to the lower gravitational field magnitude.

## Confusion of Terms and Units

Why are weight and mass commonly confused? The main reason is that we live in a gravitational field on Earth that is essentially uniform in magnitude. Any differences in gravitational force on an object (due to changes in altitude, for example) are therefore negligible on Earth's surface. The weight of an object in a uniform gravitational field scales

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