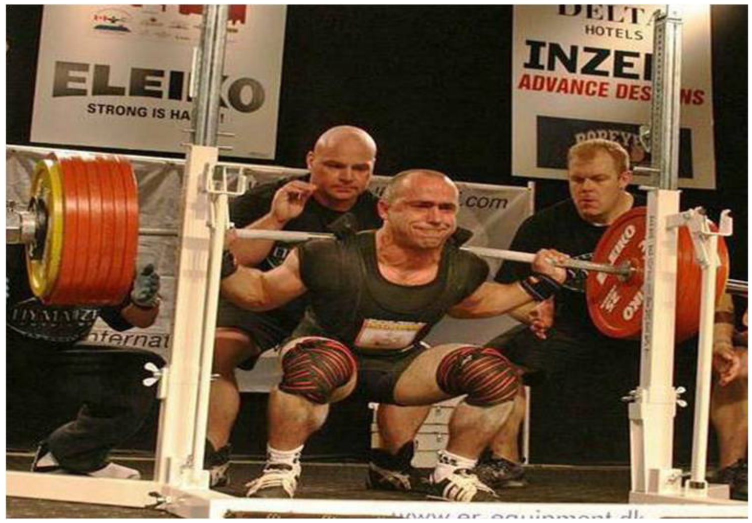

Figure 5.1: In power lifting the force by the muscles of the lifter must balance the force of weight of the lifted object. Photo credit: International Powerlifting Federation, at Wikicommons.

5.1 MEASURING FORCES

5.1.1 Distinction Between Mass and Weight

When you hold a heavy object in your hand, you feel the sensation of a downward force on your hand. The source of the downward force on the hand is the attractive pull of Earth on the object. The force of Earth on an object is called its weight. A power lifter must balance the weight of the load on the barbell. The more you put on the barbell more difficult it gets to lift the barbell.

The pull of Earth on an object is proportional to the amount of matter, but they are not the same quantities and we make a distinction between the mass (m) and the pull of Earth, which we call **weight** (W).

$$\boxed{W = m\ g,} \tag{5.1}$$

where the proportionality constant g is the acceleration due to gravity, the same quantity we have used for the acceleration of an object in the free fall. Although, the value of g is different at different places on Earth, we will use a standard value of 9.81 m/s^2 in our calculations. The SI unit of weight is obtained from multiplying the units of mass and acceleration, the result being kg.m/s^2, which is also called Newton and denoted by the symbol N.

$$1\ N = 1\ kg.m/s^2.$$

Therefore, the weight of 1-kg is equal to a force of magnitude 9.81 N, and a 1-lb weight is equal to 4.54 N.

Weight is a vector quantity while mass is a scalar quantity. Note that Eq. 5.1 gives only the magnitude of the weight vector. The direction of weight vector is towards the center of Earth. It is normally too much to keep writing the phrase "the magnitude of weight" when we refer to mg. Therefore, we will simply drop the qualifier "the magnitude of" and call mg weight, although, we know that we also need the direction for weight.

Because it is relatively easy to set up physical systems that will give a reliable indication of magnitude of weight at a location, such as a spring balance to be described below, it is tempting to use Eq. 5.1 to gain the value of the mass of an object. However, since g varies from place to place, an absolute value of mass cannot be truly obtained by instruments that measure weight. We can only obtain mass of an unknown relative to an arbitrarily chosen standard mass by comparing their weights. This is what we do when we compare two masses on a balance. We compare (magnitudes of) their weights at the same location, and if the (magnitudes of) weights are equal, then masses are equal also.

$$\text{If } W_1 = W_2 \implies m_1 g = m_2 g \implies m_1 = m_2. \tag{5.2}$$

5.1.2 A Method of Measuring Forces

According to Eq. 5.1, if you hold a 2-kg object, then you should feel twice the force as you would experience for a 1-kg object. But, in practice, although a 2-kg object will feel much heavier than a 1-kg object, you can't really say if the 2-kg object is exactly twice as heavy as the 1-kg object reliably and consistently. Therefore, we need a better method for measuring forces than the sensation of a human hand.

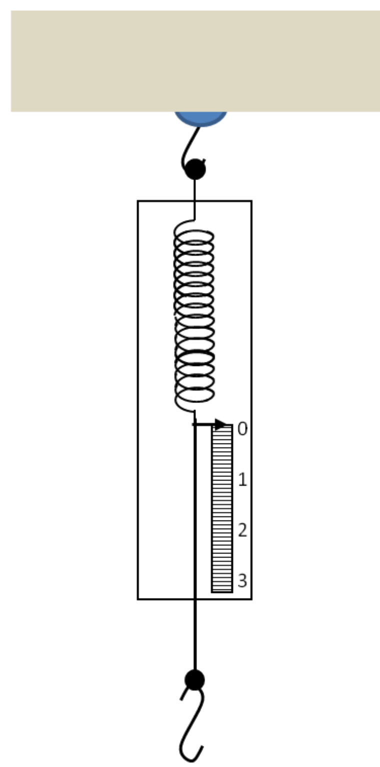

Figure 5.2: A spring balance measures weight. The balance is often calibrated to indicate mass value based on the weight at one location.

The stretching of a simple spiral spring provides a more reliable tool for comparing different pulls. A **spring balance** is constructed by fixing one end of a spring and attaching a pointer to the free end as shown in Fig. 5.2. Once a spring balance is calibrated at a particular location, we can use the spring balance not only for measuring weights but also for measuring other forces as well by comparing them to the force it takes to stretch the spring by a set amount. For instance, if you pull the spring so that the pointer points to 1-kg mark on the scale, then you have applied a force equal to the weight of 1-kg mass, or 9.81 N if g at that site is 9.81 m/s^2. In this way you can measure all other forces with the spring balance after it has been calibrated with reference weights.

Note that a spring balance measures force and not mass. You should be careful in deducing mass from a reading on the spring balance. Suppose you attach a mass to a spring balance and the reading says 1 kg. Would the reading be same if you took the same spring and same mass at another location on Earth? The answer is no. Since spring balance shows force of pull and Earth's pull changes from place to place on Earth, which is reflected in changing value of g, therefore, the spring will show less pull at a place where g is less. It should also be noted that the reading for the weight of an object on the spring balance will go down as you go away from the center of the Earth as the pull of the Earth will decrease then. In a zero gravity situation, the spring balance will read zero no matter the amount of mass attached to the bottom of the spring.