5.3: Mass and inertia

Mass is a property of an object that quantifies how much matter the object contains. In SI units, mass is measured in kilograms. One kilogram is defined to be the mass of a cylinder that is made of a platinum-iridium alloy that is kept at the international Bureau of Weights and Measures, in France. All other masses are obtained by comparison to this standard. In 2019, all base S.I. quantities (such as the kilogram) were redefined based on constants of nature (for example, the kilogram is now defined such that Planck's constant has the exact value $h = 6.62607015 \times 10^{-34}\mathrm{kg} \cdot \mathrm{m}^2 \cdot \mathrm{s}^{-1}$).

Newton's Second Law introduces the concept of mass as that property of the object that determines how large of an acceleration it will experience given a net force exerted on that object. In principle, one can compare the accelerations of different bodies to that of the international standard to determine their mass in kilograms. For example, under a given net force, if an object's acceleration is half of that of the standard kilogram, the object has a mass of $2\mathrm{kg}$.

In the context of Newton's Second Law, mass is a measure of the inertia of an object; that is, it is a measure of how that particular object resists a change in motion due to a force (we can think of a large acceleration as a large change in motion, as the velocity vector of the object will change more). For this reason, the mass that appears in Newton's Second Law is referred to as "inertial mass".

As you recall, the weight of an object is given by the mass of the object multiplied by the strength of the gravitational field, $\vec{g}$. There is no reason that the mass that is used to calculate weight, $F_g = mg$, has to be the same quantity as the mass that is used to calculate inertia $F = ma$. Thus, people will sometimes make the distinction between "gravitational mass" (the mass that you use to calculate weight and the force of gravity) and "inertial mass" as described above. Very precise experiments have been carried out to determine if the gravitational and inertial masses are equal. So far, experiments have been unable to detect any difference between the two quantities. As we will see, both Newton's Universal Theory of Gravity and Einstein Theory of General Relativity assume that the two are indeed equal. In fact, it is a key requirement for Einstein's Theory that the two be equal (the assumption that they are equal is called the "Equivalence Principle"). You should however keep in mind that there is no physical reason that the two are the same, and that as far as we know, it is a coincidence!

Unless stated otherwise, we will not make any distinction between gravitational and inertial mass and assume that they are equal. We will simply use the term "mass" and only clarify the type of mass when relevant (e.g. when we cover gravity).