Newton's second law can be written as an equation:

$$\vec{\mathbf{a}} = \frac{\Sigma\vec{\mathbf{F}}}{m},$$

where $\vec{\mathbf{a}}$ stands for acceleration, m for the mass, and $\Sigma\vec{\mathbf{F}}$ for the *net force* on the object. The symbol Σ (Greek "sigma") stands for "sum of"; $\vec{\mathbf{F}}$ stands for force, so $\Sigma\vec{\mathbf{F}}$ means the *vector sum of all forces* acting on the object, which we define as the **net force**.

Net force

We rearrange this equation to obtain the familiar statement of Newton's second law:

NEWTON'S SECOND LAW OF MOTION

$$\Sigma\vec{\mathbf{F}} = m\vec{\mathbf{a}}. \tag{4–1}$$

Newton's second law relates the description of motion to the cause of motion, force. It is one of the most fundamental relationships in physics. From Newton's second law we can make a more precise definition of **force** as *an action capable of accelerating an object.*

Force defined

Every force $\vec{\mathbf{F}}$ is a vector, with magnitude and direction. Equation 4–1 is a vector equation valid in any inertial reference frame. It can be written in component form in rectangular coordinates as

$$\Sigma F_x = ma_x, \qquad \Sigma F_y = ma_y, \qquad \Sigma F_z = ma_z.$$

If the motion is all along a line (one-dimensional), we can leave out the subscripts and simply write $\Sigma F = ma$.

Unit of force: the newton

In SI units, with the mass in kilograms, the unit of force is called the **newton** (N). One newton, then, is the force required to impart an acceleration of $1\ \mathrm{m/s^2}$ to a mass of 1 kg. Thus $1\ \mathrm{N} = 1\ \mathrm{kg \cdot m/s^2}$.

In cgs units, the unit of mass is the gram (g) as mentioned earlier.[†] The unit of force is the *dyne*, which is defined as the net force needed to impart an acceleration of $1\ \mathrm{cm/s^2}$ to a mass of 1 g. Thus $1\ \mathrm{dyne} = 1\ \mathrm{g \cdot cm/s^2}$. It is easy to show that $1\ \mathrm{dyne} = 10^{-5}\ \mathrm{N}$.

In the British system, the unit of force is the *pound* (abbreviated lb), where $1\ \mathrm{lb} = 4.44822\ \mathrm{N} \approx 4.45\ \mathrm{N}$. The unit of mass is the *slug*, which is defined as that mass which will undergo an acceleration of $1\ \mathrm{ft/s^2}$ when a force of 1 lb is applied to it. Thus $1\ \mathrm{lb} = 1\ \mathrm{slug \cdot ft/s^2}$. Table 4–1 summarizes the units in the different systems.

PROBLEM SOLVING

Use a consistent set of units

It is very important that only one set of units be used in a given calculation or problem, with the SI being preferred. If the force is given in, say, newtons, and the mass in grams, then before attempting to solve for the acceleration in SI units, we must change the mass to kilograms. For example, if the force is given as 2.0 N along the x axis and the mass is 500 g, we change the latter to 0.50 kg, and the acceleration will then automatically come out in $\mathrm{m/s^2}$ when Newton's second law is used (we set $1\ \mathrm{N} = 1\ \mathrm{kg \cdot m/s^2}$):

$$a_x = \frac{\Sigma F_x}{m} = \frac{2.0\ \mathrm{N}}{0.50\ \mathrm{kg}} = \frac{2.0\ \mathrm{kg \cdot m/s^2}}{0.50\ \mathrm{kg}} = 4.0\ \mathrm{m/s^2}.$$

TABLE 4–1
Units for Mass and Force

System	Mass	Force
SI	kilogram (kg)	newton (N) $(= \mathrm{kg \cdot m/s^2})$
cgs	gram (g)	dyne $(= \mathrm{g \cdot cm/s^2})$
British	slug	pound (lb)

Conversion factors: $1\ \mathrm{dyne} = 10^{-5}\ \mathrm{N}$; $1\ \mathrm{lb} \approx 4.45\ \mathrm{N}$.

EXAMPLE 4–2 ESTIMATE **Force to accelerate a fast car.** Estimate the net force needed to accelerate (*a*) a 1000-kg car at $\frac{1}{2}g$; (*b*) a 200-g apple at the same rate.

APPROACH We can use Newton's second law to find the net force needed for each object, because we are given the mass and the acceleration. This is an estimate (the $\frac{1}{2}$ is not said to be precise) so we round off to one significant figure.

[†] Be careful not to confuse g for gram with g for the acceleration due to gravity. The latter is always italicized (or boldface when a vector).