# Newton’s Laws of Motion

## Introduction

what causes bodies to move the way that they do

For example, how can a tugboat push a cruise ship that’s much heavier than the tug?

Why is it harder to control a car on wet ice than on dry concrete? The answers to these and similar questions take us into the subject of dynamics, the relationship of **motion** to the **forces** that cause it.

In this lecture we will use two new concepts, **force** and **mass**, to analyse the principles of dynamics. These principles were clearly stated for the first time by Sir Isaac Newton (1642–1727); today we call them **Newton’s laws of motion**.

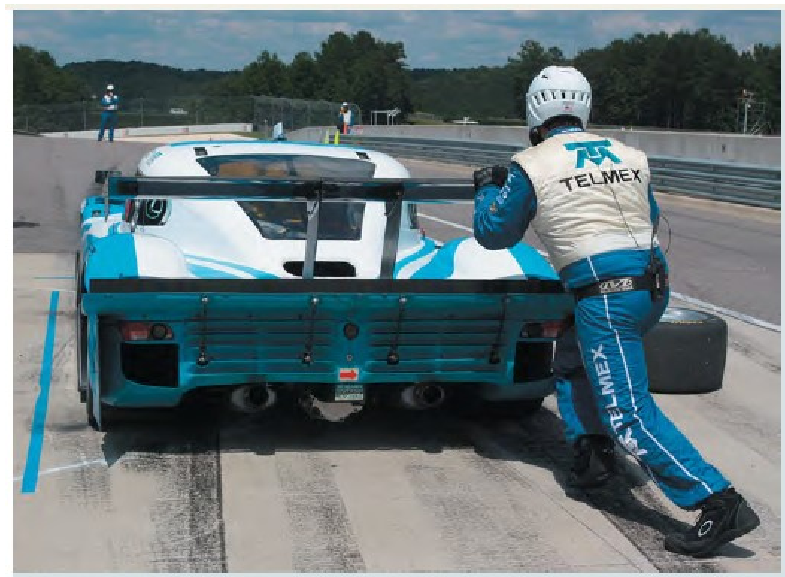


Figure 1: This pit crew member is pushing a race car forward. Is the race car pushing back on him? If so, does it push back with the same magnitude of force or a different amount?

**The first law** states that when the net force on a body is zero, its motion doesn’t change. In other .words, *an object will not change its motion unless a force acts on it*

**The second law** relates force to acceleration when the net force is not zero. In other words, *the* . *force on an object is equal to its mass times its acceleration*

**The third law** is a relationship between the forces that two interacting bodies exert on each other. In other words, *when two objects interact, they apply forces to each other of equal magnitude and opposite direction*

## Newton’s First Law

Newton’s first law is used to define what we mean by an ***inertial frame*** . of reference, it is sometimes called the ***law of inertia***

$\vec{F} = \vec{F}_1 + \vec{F}_2 = \vec{F}_1 + (-\vec{F}_1) = 0$

$\sum \vec{F} = 0,$ (body in equilibrium) (3)

For this to be true, each component of the net force must be zero, so

$\sum F_x = 0, \quad \sum F_y = 0,$ (body in equilibrium) (4)

## Newton’s Second Law, (Mass and Force)

The *ratio* of the magnitude $\left|\sum \vec{F}\right|$ of the net force to the magnitude $a = |\vec{a}|$ . We call this ratio the *inertial mass*, or simply the **mass**, of the body and denote it by $m$.

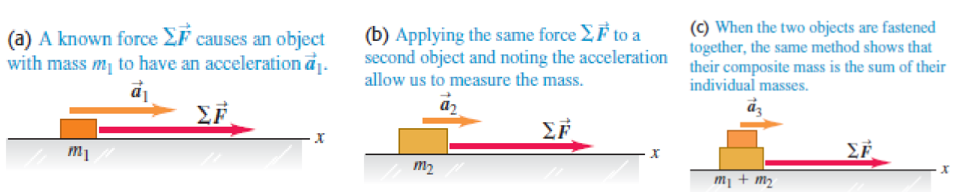
$m = \frac{\left|\sum \vec{F}\right|}{a},$ or $\left|\sum \vec{F}\right| = m\,a,$ or $a = \frac{\left|\sum \vec{F}\right|}{m}$ (5)

*We can also use Eqs. (5) to compare a mass with the standard mass and thus to measure masses.* Suppose we apply a constant net force $\left|\sum \vec{F}\right|$ to a body having a known mass $m_1$ and we find an acceleration of magnitude $a_1$ (Fig. a). We then apply the same force to another body having an unknown mass $m_2$and we find an acceleration of magnitude $a_1$ (Fig. b).

Then, according to Eqs. (5),

$m_1 a_1 = m_2 a_2,$ thus $\frac{m_2}{m_1} = \frac{a_1}{a_2},$ (same net force) (6)

*For the same net force, the ratio of the masses of two bodies is the inverse of the ratio of their accelerations.*




$\sum \vec{F} = m\,\vec{a},$ (Newton’s second law of motion) (7)

The Component form,

$\sum F_x = ma_x \quad \sum F_y = ma_y \quad \sum F_z = ma_z$ (Newton’s second law of motion) (8)

## Mass and Weight

One of the most familiar forces is the weight of a body, which is the gravitational force that the earth exerts on the body. (If you are on another planet, your weight is the gravitational force that planet exerts on you).

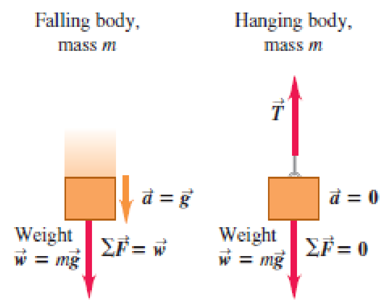
Newton’s second law tells us that a force must act to produce this acceleration. If a 1-kg body falls with an acceleration of 9.8 m/$s^2$ the required force has magnitude

$F = ma = (1\,kg)(9.8\,m/s^2)$ =9.8 kg.m/$s^2$=9.8 N

*The force that makes the body accelerate downward is its weight.*

$w = mg,$ (Magnitude of the weight of a body of mass $m$ (9)

The weight of a body is a force, a vector quantity, and we can write Eq. (9) as a vector equation (see the Figure):




- The relationship of mass to weight: $\vec{w} = m\vec{g}$.
- This relationship is the same whether a body is falling or stationary.

$$\vec{w} = m\vec{g}$$

*Example 6*: A (2.49 *$10^4$) Rolls-Royce Phantom traveling in the +$x$–direction makes an emergency stop; the $x$-component of the net force acting on it is ( -1.83*$10^4$ ). What is its acceleration?

$$m = \frac{w}{g} = \frac{2.49 \times 10^4\ \text{N}}{9.80\ \text{m/s}^2} = \frac{2.49 \times 10^4\ \text{kg}\cdot\text{m/s}^2}{9.80\ \text{m/s}^2}$$
$$= 2540\ \text{kg}$$

Then $\sum F_x = ma_x$ gives

$$a_x = \frac{\sum F_x}{m} = \frac{-1.83 \times 10^4\ \text{N}}{2540\ \text{kg}} = \frac{-1.83 \times 10^4\ \text{kg}\cdot\text{m/s}^2}{2540\ \text{kg}}$$
$$= -7.20\ \text{m/s}^2$$

Newton’s Third Law

If body A exerts a force on body B (an “action”), then body B exerts a force on body A (a “reaction”). .These two forces have the same magnitude but are opposite in direction

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$\vec{F}_{A\ on\ B} = -\vec{F}_{B\ on\ A}$, (Newton’s third law of motion) (11)