Force

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Force may be briefly described as that influence on a body which causes it to accelerate. In this way, force is defined through Newton's second law of motion. *See also:* **Acceleration (/content/acceleration/002500)**

This law states in part that the acceleration of a body is proportional to the resultant force exerted on the body and is inversely proportional to the mass of the body. An alternative procedure is to try to formulate a definition in terms of a standard force, for example, that necessary to stretch a particular spring a certain amount, or the gravitational attraction which the Earth exerts on a standard object. Even so, Newton's second law inextricably links mass and force. *See also:* **Mass (/content/mass/408400)**

Many elementary books in physics seem to expect the beginning student to bring to his study the same kind of intuitive notion concerning force which Isaac Newton possessed. One readily thinks of an object's weight, or of pushing it or pulling it, and from this one gains a “feeling” for force. Such intuition, while undeniably helpful, is hardly an adequate foundation for the quantitative science of mechanics.

Newton's dilemma in logic, which did not trouble him greatly, was that, in stating his second law as a relation between certain physical quantities, he presumably needed to begin with their definitions. But he did not actually have definitions of both mass and force which were independent of the second law. The procedure which today seems most free of pitfalls in logic is in fact to use Newton's second law as a defining relation.

First, one supposes length to be defined in terms of the distance between marks on a standard object, or perhaps in terms of the wavelength of a particular spectral line. Time can be supposed similarly related to the period of a standard motion (for example, the rotation of the Earth about the Sun, the oscillations of the balance wheel of a clock, or perhaps a particular vibration of a molecule). Although applying these definitions to actual measurements may be a practical matter requiring some effort, a reasonably logical definition of velocity and acceleration, as the first and second time derivatives of vector displacement, follows readily in principle.

Absolute standards

Having chosen a unit for length and a unit for time, one may then select a standard particle or object. At this juncture one may choose either the absolute or the gravitational approach. In the so-called absolute systems of units, it is said that the standard object has a mass of one unit. Then the second law of Newton defines unit force as that force which gives unit acceleration to the unit mass. Any other mass may in principle be compared with the standard mass (*m*) by subjecting it to unit force and measuring the acceleration (**a**), with which it varies inversely. By suitable appeal to experiment, it is possible to conclude that masses are scalar quantities and that forces are vector quantities which may be superimposed or resolved by the rules of vector addition and resolution.

In the absolute scheme, then, Eq. (**1**)

$$\mathbf{F} = m\mathbf{a} \tag{1}$$

is written for nonrelativistic mechanics; here boldface type denotes vector quantities. The quantities on the right of Eq. (**1**) are previously known, and this statement of the second law of Newton is in fact the definition of force. In the absolute system, mass is taken as a fundamental quantity and force is a derived unit of dimensions MLT^{-2} (M = mass, L = length, T = time).

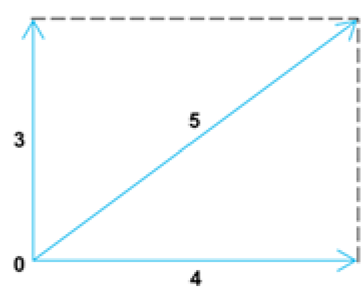
Gravitational standards

The gravitational system of units uses the attraction of the Earth for the standard object as the standard force. Newton's second law still couples force and mass, but since force is here taken as the fundamental quantity, mass becomes the derived factor of proportionality between force and the acceleration it produces. In particular, the standard force (the Earth's attraction for the standard object) produces in free fall what one measures as the gravitational acceleration, a vector quantity proportional to the standard force (weight) for any object. It follows from the use of Newton's second law as a defining relation that the mass of that object is $m = {}^{w}/_{g}$, with g the magnitude of the gravitational acceleration and w the magnitude of the weight. The derived quantity mass has dimensions FT^2L^{-1}.

Because the gravitational acceleration varies slightly over the surface of the Earth, it may be objected that the force standard will also vary. This may be avoided by specifying a point on the Earth's surface at which the standard object has standard weight. In principle, then, the gravitational system becomes no less absolute than the so-called absolute system. *See also:* **Gravitation (/content/gravitation/298900)**

Composition of forces

By experiment one finds that two forces of, for example, 3 units and 4 units acting at right angles to one another at point 0 produce an acceleration of a particular object which is identical to that produced by a single 5-unit force inclined at arccos 0.6 to the 3-unit force, and arccos 0.8 to the 4-unit force (see **illustration**). The laws of vector addition thus apply to the superposition of forces.



Vector addition of forces.

Full-size image

Conversely, a single force may be considered as equivalent to two or more forces whose vector sum equals the single force. In this way one may select the component of a particular force which may be especially relevant to the physical problem. An example is the component of a railroad car's weight along the direction of the track on a hill.

Statics is the branch of mechanics which treats forces in nonaccelerated systems. Hence, the resultant of all forces is zero, and critical problems are the determination of the component forces on the object or its structural parts in static equilibrium. Practical questions concern the ability of structural members to support the forces or tensions. *See also:* **Statics (/content/statics/652100)**

Specially designated forces

If a force is defined for every point of a region and if this so-called vector field is irrotational, the force is designated conservative. Physically, it is shown in the development of mechanics that this property requires that the work done by this force field on a particle traversing a closed path is zero. Mathematically, such a force field can be shown to be expressible as the (conventionally negative) gradient of a scalar function of position *V*, Eq. (**2**).

$$\mathbf{F} = -\nabla V \tag{2}$$

A force which extracts energy irreversibly from a mechanical system is called dissipative, or nonconservative. Familiar examples are frictional forces, including those of air resistance. Dissipative forces are of great practical interest, although they are often very difficult to take into account precisely in phenomena of mechanics.

The force which must be directed toward the center of curvature to cause a particle to move in a curved path is called centripetal force. For example, if one rotates a stone on the end of a string, the force with which the string pulls radially inward on the stone is centripetal force. The reaction to centripetal force (namely, the force of the stone on the string) is called centrifugal force. *See also:* **Centrifugal force (/content/centrifugal-force/119400)**; **Centripetal force (/content/centripetal-force/120000)**

Methods of measuring forces

Direct force measurements in mechanics usually reduce ultimately to a weight comparison. Even when the elastic distortion of a spring or of a torsion fiber is used, the calibration of the elastic property will often be through a balance which compares the pull of the spring with a calibrated weight or the torsion of the fiber with a torque arising from a calibrated weight on a moment arm. *See also:* **Balance (/content/balance/070400)**

In dynamic systems, any means of measuring acceleration—for example, through photographic methods or radar tracking—allows one to calculate the force acting on an object of known mass.

Units of force

In addition to use of the absolute or the gravitational approach, one must contend with two sets of standard objects and lengths, the British and the metric standards. All systems use the second as the unit of time. In the metric absolute system, the units of force are the newton and the dyne. The newton, the unit of force in the International System (SI), is that force which, when applied to a body having a mass of 1 kilogram, gives it an acceleration of 1 m/s^2. The poundal is the force unit in the British absolute system, whereas the British gravitational system uses the pound. Metric gravitational systems are rarely used. Occasionally one encounters terms such as gram-force or kilogram-force, but no corresponding mass unit has been named. *See also:* **Units of measurement (/content/units-of-measurement/721700)**

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Related Primary Literature

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