MOMENTUM

The faster an object is moving—whether it be a baseball, an automobile, or a particle of matter—the harder it is to stop. This is a reflection of momentum, or specifically, [linear](http://www.scienceclarified.com/knowledge/Linear.html) momentum, which is equal to mass [multiplied by](http://www.scienceclarified.com/knowledge/Multiplication.html) velocity. Like other aspects of matter and motion, momentum is conserved, meaning that when the vector sum of outside forces equals zero, no net linear momentum within a system is ever lost or gained. A third important concept is impulse, the product of force multiplied by [length](http://www.scienceclarified.com/knowledge/Length.html) in time. Impulse, also defined as a change in momentum, is reflected in the proper methods for hitting a baseball with force or surviving a car crash.

[Concept](http://www.scienceclarified.com/everyday/Real-Life-Chemistry-Vol-3-Physics-Vol-1/Momentum-Concept.html)

Like many other aspects of physics, the word "momentum" is a part of everyday life. The common meaning of momentum, however, unlike many other physics terms, is relatively consistent with its scientific meaning. In terms of formula, momentum is equal to the product of mass and velocity, and the greater the value of that product, the greater the momentum.

Consider the term "momentum" outside the world of physics, as applied, for example, in the realm of politics. If a presidential candidate sees a gain in public-opinion polls, then wins a [debate](http://www.scienceclarified.com/knowledge/Debate.html) and embarks on a [whirlwind](http://www.scienceclarified.com/knowledge/Whirlwind.html) speaking tour, the media comments that he has "gained momentum." As with momentum in the framework of physics, what these commentators mean is that the candidate will be hard to stop—or to carry the analogy further, that he is doing enough of the right things (thus gaining "mass"), and doing them quickly enough, thereby gaining velocity.

Momentum - How it works . . . . Momentum and Inertia

It might be tempting to confuse momentum with another physical concept, [inertia](http://www.scienceclarified.com/knowledge/Inertia.html). Inertia, as defined by the second law of motion, is the tendency of an object in motion to remain in motion, and of an object at rest to remain at rest. Momentum, by definition, involves a body in motion, and can be defined as the tendency of a body in motion to continue moving at a constant velocity.

Not only does momentum differ from inertia in that it relates exclusively to objects in motion, but (as will be discussed below) the component of velocity in the formula for momentum makes it a vector—that is, a quantity that possesses both magnitude and direction. There is at least one factor that momentum very clearly has in common with inertia: mass, a measure of inertia indicating the resistance of an object to a change in its motion.

Mass and Weight

Unlike velocity, mass is a scalar, a quantity that possesses magnitude without direction. Mass is often confused with weight, a vector quantity equal to its mass multiplied by the downward acceleration due to gravity. The weight of an object changes according to the [gravitational force](http://www.scienceclarified.com/knowledge/Newton_s_law_of_universal_gravitation.html) of the planet or other celestial body on which it is measured. Hence, the mass of a person on the Moon would be the same as it is on Earth, whereas the person's weight would be considerably less, due to the smaller gravitational pull of the Moon.

Given the unchanging quality of mass as opposed to weight, as well as the fact that scientists themselves prefer the much simpler metric system, [metric units](http://www.scienceclarified.com/knowledge/International_System_of_Units.html) will generally be used in the following discussion. Where warranted, of course, conversion to English or British units (for example, the pound, a unit of weight) will be provided. However, since the English unit of mass, the slug, is even more unfamiliar to most Americans than its metric equivalent, the kilogram, there is little point in converting kilos into slugs.

Velocity and Speed

Not only is momentum often confused with inertia, and mass with weight, but in the everyday world the concepts of velocity and speed tend to be blurred. Speed is the rate at which the position of an object changes over a given period of time, expressed in terms such as "50 MPH." It is a scalar quantity.

Velocity, by contrast, is a vector. If one were to say "50 miles per hour toward the northeast," this would be an expression of velocity. Vectors are typically designated in bold, without italics; thus velocity is typically [abbreviated](http://www.scienceclarified.com/knowledge/Abbreviation.html) **v** . Scalars, on the other hand, are rendered in italics. Hence, the formula for momentum is usually shown as *m* **v.**

Linear Momentum and Its Conservation

Momentum itself is sometimes designated as *p.* It should be stressed that the form of momentum discussed here is strictly [linear](http://www.scienceclarified.com/knowledge/Linear.html), or straight-line, momentum, in contrast to angular momentum, more properly discussed within the framework of rotational motion.

Both angular and linear momentum abide by what are known as conservation laws. These are statements concerning quantities that, under certain conditions, remain constant or unchanging. The conservation of linear momentum law states that when the sum of the external force vectors acting on a physical system is equal to zero, the total linear momentum of the system remains unchanged—or conserved.

The conservation of linear momentum is reflected both in the [recoil](http://www.scienceclarified.com/knowledge/Recoil.html) of a rifle and in the propulsion of a rocket through space. When a rifle is fired, it produces a "kick"—that is, a sharp jolt to the shoulder of the person who has fired it—corresponding to the momentum of the bullet. Why, then, does the "kick" not knock a person's shoulder off the way a bullet would? Because the rifle's mass is much greater than that of the bullet, meaning that its velocity is much smaller.

As for rockets, they do not—contrary to popular belief—move by pushing against a surface, such as a launch pad. If that were the case, then a rocket would have nothing to propel it once it is launched, and certainly there would be no way for a rocket to move through the vacuum of outer space. Instead, as it burns fuel, the rocket expels exhaust gases that exert a backward momentum, and the rocket itself travels forward with a corresponding degree of momentum.

Systems

Here, "system" refers to any set of physical interactions isolated from the rest of the universe. Anything outside of the system, including all factors and forces irrelevant to a discussion of that system, is known as the environment. In the pool-table illustration shown earlier, the interaction of the billiard balls in terms of momentum is the system under discussion.

It is possible to reduce a system even further for purposes of clarity: hence, one might specify that the system consists only of the pool balls, the force applied to them, and the resulting momentum interactions. Thus, we will ignore the [friction](http://www.scienceclarified.com/knowledge/Friction.html) of the pool table's surface, and the assumption will be that the balls are rolling across a frictionless plane.

Impulse

For an object to have momentum, some force must have set it in motion, and that force must have been applied over a period of time. Likewise, when the object experiences a collision or any other event that changes its momentum, that change may be described in terms of a certain amount of force applied over a certain period of time. Force multiplied by time interval is impulse, expressed in the formula *F* · *Δ* *t,* where **F** is force, *Δ* (the Greek letter delta) means "a change" or "change in…"; and *t* is time.

As with momentum itself, impulse is a vector quantity. Whereas the vector component of momentum is velocity, the vector quantity in impulse is force. The force component of impulse can be used to derive the relationship between impulse and change in momentum. According to the second law of motion, **F** = *m* **a** ; that is, force is equal to mass multiplied by acceleration. Acceleration can be defined as a change



When parachutists land , they keep their knees bent and often roll over — all in an effort to lengthen the time of impact , thus reducing the effect of the force.

in velocity over a change or interval in time. Expressed as a formula, this is *Δ* **v /** *Δ* **t.**

Thus, force is equal to an [equation](http://www.scienceclarified.com/knowledge/Equation.html) that can be rewritten as **F** *Δ* *t* = *m Δ* **v** . In other words, impulse is equal to change in momentum.

This relationship between impulse and momentum change, derived here in [mathematical](http://www.scienceclarified.com/knowledge/Mathematics.html) terms, will be discussed below in light of several well-known examples from the real world. Note that the metric units of impulse and momentum are actually interchangeable, though they are typically expressed in different forms, for the purpose of convenience. Hence, momentum is usually rendered in terms of kilogram-meters-per-second (kg · m/s), whereas impulse is typically shown as newton-seconds (N · s). In the English system, momentum is shown in units of slug-feet per-second, and impulse in terms of the pound-second.



As Sammy Sosa's bat hits this ball , it applies a tremendous momentum change to the ball. After contact with the ball , Sosa will continue his swing , thereby contributing to the momentum change and allowing the ball to travel farther .

Momentum - Real-life applications

When Two Objects Collide

Two moving objects, both possessing momentum by virtue of their mass and velocity, collide with one another. Within the system created by their collision, there is a total momentum *M* **V** that is equal to their combined mass and the vector sum of their velocity.

This is the case with any system: the total momentum is the sum of the various individual momentum products. In terms of a formula, this is expressed as *M* **V** = *m* 1 **v** 1 + *m* 2 **v** 2 + *m* 3 **v** 3 +… and so on. As noted earlier, the total momentum will be conserved; however, the actual distribution of momentum within the system may change.

Two Lumps Of Clay (INELASTIC COLLISION)

Consider the behavior of two lumps of clay, thrown at one another so that they collide head-on. Due to the properties of clay as a substance, the two lumps will tend to stick. Assuming the lumps are not of equal mass, they will continue traveling in the same direction as the lump with greater momentum.

As they meet, the two lumps form a larger mass *M* **V** that is equal to the sum of their two individual masses.

Once again, *M* **V** = *m* 1 **v** 1 + *m* 2 **v** 2 .

The *M* in *M* **V** is the sum of the smaller values *m,* and the **V** is the *vector sum* of velocity. Whereas *M* is larger than *m*1 or *m*2 —the reason being that scalars are simply added like ordinary numbers— *V* is smaller than **v**1 or **v**2 . This lower number for net velocity as compared to particle velocity will always occur when two objects are moving in opposite directions. (If the objects are moving in the same direction, *V* will have a value between that of **v** 1 and **v** 2 .)

To add the vector sum of the two lumps in collision, it is best to make a diagram showing the bodies moving toward one another, with arrows illustrating the direction of velocity. By convention, in such diagrams the velocity of an object moving to the right is rendered as a positive number, and that of an object moving to the left is shown with a negative number. It is therefore easier to interpret the results if the object with the larger momentum is shown moving to the right.

The value of **V** will move in the same direction as the lump with greater momentum. But since the two lumps are moving in opposite directions, the momentum of the smaller lump will cancel out a portion of the greater lump's momentum—much as a negative number, when added to a positive number of greater magnitude, cancels out part of the positive number's value. They will continue traveling in the direction of the lump with greater momentum, now with a combined mass equal to the arithmetic sum of their masses, but with a velocity much smaller than either had before impact.

BILLIARD BALLS (ELASTIC COLLISION)

The game of pool provides an example of a collision in which one object, the cue ball, is moving, while the other—known as the object ball—is stationary. Due to the [hardness](http://www.scienceclarified.com/knowledge/Hardness.html) of [pool balls](http://www.scienceclarified.com/knowledge/Billiard_ball.html), and their tendency not to stick to one another, this is also an example of an almost perfectly elastic collision—one in which [kinetic energy](http://www.scienceclarified.com/knowledge/Kinetic_energy.html) is conserved.

The colliding lumps of clay, on the other hand, are an excellent example of an inelastic collision, or one in which kinetic energy is not conserved. The total energy in a given system, such as that created by the two lumps of clay in collision, is conserved; however, kinetic energy may be transformed, for instance, into heat energy and/or sound energy as a result of collision. Whereas inelastic collisions involve soft, sticky objects, elastic collisions involve rigid, non-sticky objects.

Kinetic energy and momentum both involve components of velocity and mass: **p** (momentum) is equal to *m* **v** , and KE (kinetic energy) equals ½ *m* **v** 2 . Due to the elastic nature of pool-ball collisions, when the cue ball strikes the object ball, it transfers its velocity to the latter. Their masses are the same, and therefore the resulting momentum and kinetic energy of the object ball will be the same as that possessed by the cue ball prior to impact.

If the cue ball has transferred all of its velocity to the object ball, does that mean it has stopped moving? It does. Assuming that the interaction between the cue ball and the object ball constitutes a closed system, there is no other source from which the cue ball can acquire velocity, so its velocity must be zero.

It should be noted that this illustration treats pool-ball collisions as though they were 100% elastic, though in fact, a portion of kinetic energy in these collisions is transformed into heat and sound. Also, for a cue ball to transfer all of its velocity to the object ball, it must hit it straight-on. If the balls hit off-center, not only will the object ball move after impact, but the cue ball will continue to move—roughly at 90° to a line drawn through the centers of the two balls at the moment of impact.

Impulse: Breaking or Building the Impact

When a cue ball hits an object ball in pool, it is safe to assume that a powerful impact is desired. The same is true of a bat hitting a baseball. But what about situations in which a powerful impact is not desired—as for instance when cars are crashing? There is, in fact, a relationship between impulse, momentum change, transfer of kinetic energy, and the impact—desirable or undesirable—experienced as a result.

Impulse, again, is equal to momentum change—and also equal to force multiplied by time interval (or change in time). This means that the greater the force and the greater the amount of time over which it is applied, the greater the momentum change. Even more interesting is the fact that one can achieve the same momentum change with differing levels of force and time interval. In other words, a relatively low degree of force applied over a relatively long period of time would produce the same momentum change as a relatively high amount of force over a relatively short period of time.

The conservation of kinetic energy in a collision is, as noted earlier, a function of the relative [elasticity](http://www.scienceclarified.com/knowledge/Elasticity.html) of that collision. The question of whether KE is transferred has nothing to do with impulse. On the other hand, the question of how KE is transferred—or, even more specifically, the interval over which the transfer takes place—is very much related to impulse.

Kinetic energy, again, is equal to ½ *m* **v** 2 . Ifa moving car were to hit a stationary car head-on, it would transfer a quantity of kinetic energy to the stationary car equal to one-half its own mass multiplied by the square of its velocity. (This, of course, assumes that the collision is perfectly elastic, and that the mass of the cars is exactly equal.) A transfer of KE would also occur if two moving cars hit one another head-on, especially in a highly elastic collision. Assuming one car had considerably greater mass and velocity than the other, a high degree of kinetic energy would be transferred—which could have deadly consequences for the people in the car with less mass and velocity. Even with cars of equal mass, however, a high rate of acceleration can bring about a potentially lethal degree of force.

CRUMPLE ZONES IN CARS.

In a highly elastic car crash, two automobiles would bounce or rebound off one another. This would mean a dramatic change in direction—a reversal, in fact—hence, a sudden change in velocity and therefore momentum. In other words, the figure for *mΔ* v would be high, and so would that for impulse, F*Δ*t.

On the other hand, it is possible to have a highly inelastic car crash, accompanied by a small change in momentum. It may seem logical to think that, in a crash situation, it would be better for two cars to bounce off one another than for them to crumple together. In fact, however, the latter option is preferable. When the cars crumple rather than rebounding, they do not experience a reversal in direction. They do experience a change in speed but the momentum change is far less than if they rebounded.

Furthermore, crumpling lengthens the amount of time during which the change in velocity occurs, and thus reduces impulse. But even with the reduced impulse of this momentum change, it is possible to further reduce the effect of force, another aspect of impact. Remember that *mΔ* **v** = **F** *Δt* : the value of force and time interval do not matter, as long as their product is equal to the momentum change. Because **F** and *Δ* *t* are inversely proportional, an increase in impact time will reduce the effects of force.

For this reason, car manufacturers actually design and build into their cars a feature known as a crumple zone. A crumple zone—and there are usually several in a single automobile—is a section in which the materials are put together in such a way as to ensure that they will crumple when the car experiences a collision. Of course, the entire car cannot be one big crumple zone—this would be fatal for the driver and riders; however, the incorporation of crumple zones at key points can greatly reduce the effect of the force a car and its occupants must endure in a crash.

Another major reason for crumple zones is to keep the passenger compartment of the car intact. Many injuries are caused when the body of the car intrudes on the space of the occupants—as, for instance, when the floor buckles, or when the [dashboard](http://www.scienceclarified.com/knowledge/Dashboard.html) is pushed deep into the passenger compartment. Obviously, it is preferable to avoid this by allowing the fender to collapse.

REDUCING IMPULSE: SAVING LIVES, BONES, AND WATER BALLOONS.

An [airbag](http://www.scienceclarified.com/knowledge/Airbag.html) is another way of minimizing force in a car accident, in this case by reducing the time over which the occupants move forward toward the dashboard or wind-shield. The airbag rapidly inflates, and just as rapidly begins to deflate, within the split-second that separates the car's collision and a person's collision with part of the car. As it deflates, it is receding toward the dashboard even as the driver's or passenger's body is being hurled toward the dashboard. It slows down impact, extending the amount of time during which the force is distributed.

By the same token, a skydiver or paratrooper does not hit the ground with legs outstretched: he or she would be likely to suffer a broken bone or worse from such a foolish stunt. Rather, as a parachutist prepares to land, he or she keeps knees bent, and upon impact immediately rolls over to the side. Thus, instead of experiencing the force of impact over a short period of time, the parachutist lengthens the amount of time that force is experienced, which reduces its effects.

The same principle applies if one were catching a water balloon. In order to keep it from bursting, one needs to catch the balloon in midair, then bring it to a stop slowly by "traveling" with it for a few feet before reducing its momentum down to zero. Once again, there is no way around the fact that one is attempting to bring about a substantial momentum change—a change equal in value to the momentum of the object in movement. Nonetheless, by increasing the time component of impulse, one reduces the effects of force.

In old *Superman* comics, the "Man of Steel" often caught unfortunate people who had fallen, or been pushed, out of tall buildings. The cartoons usually showed him, at a stationary position in midair, catching the person before he or she could hit the ground. In fact, this would not save their lives: the force component of the sudden momentum change involved in being caught would be enough to kill the person. Of course, it is a bit absurd to quibble over scientific accuracy in *Superman,* but in order to make the situation more plausible, the "Man of Steel" should have been shown catching the person, then slowly following through on the [trajectory](http://www.scienceclarified.com/knowledge/Trajectory.html) of the fall toward earth.

THE CRACK OF THE BAT: INCREASING IMPULSE.

But what if—to once again turn the tables—a strong force is desired? This time, rather than two pool balls striking one another, consider what happens when a batter hits a baseball. Once more, the correlation between momentum change and impulse can create an advantage, if used properly.

As the pitcher hurls the ball toward home plate, it has a certain momentum; indeed, a pitch thrown by a major-league player can send the ball toward the batter at speeds around 100 MPH (160 km/h)—a ball having considerable momentum). In order to hit a line drive or "knock the ball out of the park," the batter must therefore cause a significant change in momentum.

Consider the momentum change in terms of the impulse components. The batter can only apply so much force, but it is possible to magnify impulse greatly by increasing the amount of time over which the force is delivered. This is known in sports—and it applies as much in tennis or golf as in baseball—as "following through." By increasing the time of impact, the batter has increased impulse and thus, momentum change. Obviously, the mass of the ball has not been altered; the difference, then, is a change in velocity.

How is it possible that in earlier examples, the effects of force were decreased by increasing the time interval, whereas in the baseball illustration, an increase in time interval resulted in a more powerful impact? The answer relates to differences in direction and elasticity. The baseball and the bat are colliding head-on in a relatively elastic situation; by contrast, crumpling cars are inelastic. In the example of a person catching a water balloon, the [catcher](http://www.scienceclarified.com/knowledge/Catcher.html) is moving in the same direction as the balloon, thus reducing momentum change. Even in the case of the paratrooper, the ground is stationary; it does not move toward the parachutist in the way that the baseball moves toward the bat.

KEY TERMS

ACCELERATION:

A change velocity. Acceleration can be expressed as a formula *Δ*v/*Δ*t—that is, change in velocity divided by change, or interval, in time.

CONSERVATION OF LINEARMOMENTUM:

A physical law, which states that when the sum of the external force vectors acting on a physical system is equal to zero, the total [linear](http://www.scienceclarified.com/knowledge/Linear.html) [momentum](http://www.scienceclarified.com/knowledge/Momentum.html) of the system remains unchanged—or is conserved.

CONSERVE:

In physics, "to conserve" something (for example, momentum or kinetic energy) means "to result in no net loss of" that particular component. It is possible that within a given system, one type of energy may be transformed into another type, but the net energy in the system will remain the same.

ELASTIC COLLISION:

A collision in which kinetic [energy is conserved](http://www.scienceclarified.com/knowledge/Conservation_of_energy.html). Typically elastic collisions involve rigid, non-sticky objects such as pool balls.  ***In Elastic collisions, the objects bounce off one another.***

IMPULSE:

The amount of force and time required to cause a change in momentum. Impulse is the product of force [multiplied by](http://www.scienceclarified.com/knowledge/Multiplication.html) a change, or interval, in time ( **F** *Δ*t): the greater the momentum, the greater the force needed to change it, and the longer the period of time over which it must be applied.

INELASTIC COLLISION:

A collision in which kinetic energy is not conserved.(The total energy is conserved: kinetic energy itself, however, may be transformed into heat energy or sound energy.) Typically, inelastic collisions involve non-rigid, sticky objects—for instance, lumps of clay. At the other extreme is an elastic collision. ***In Inelastic collisions, the objects stick together and move as one unit.***

INERTIA:

The tendency of an object in motion to remain in motion, and of an object at rest to remain at rest.

KINETIC ENERGY:

The energy an object possesses by virtue of its motion.

MASS:

A measure of inertia, indicating the resistance of an object to a change in its motion—including a change in velocity. A [kilogram](http://www.scienceclarified.com/knowledge/Kilogram.html) is a unit of mass, whereas a pound is a unit of weight.

MOMENTUM:

A property that a moving body possesses by virtue of its mass and velocity, which determines the amount of force and time (impulse) required to stop it. Momentum—actually linear momentum, as opposed to the angular momentum of an object in rotational motion—is equal to mass multiplied by velocity.

SCALAR:

A [quantity](http://www.scienceclarified.com/knowledge/Quantity.html) that possesses only magnitude, with no specific direction—as contrasted with a vector, which possesses both magnitude and direction. Scalar quantities are usually expressed in italicized letters, thus: *m* (mass).

SPEED:

The rate at which the position of an object changes over a given period of time.

SYSTEM:

In physics, the term "system" usually refers to any set of [physical interactions](http://www.scienceclarified.com/knowledge/Fundamental_interaction.html) isolated from the rest of the universe. Anything outside of the system, including all factors and forces irrelevant to a discussion of that system, is known as the environment.

VECTOR:

A quantity that possesses both magnitude and direction—as contrasted with a scalar, which possesses magnitude without direction. Vector quantities are usually expressed in bold, non-italicized letters, thus: **F** (force). They may also be shown by placing an [arrow](http://www.scienceclarified.com/knowledge/Arrow.html) over the letter designating the specific property, as for instance v for velocity.

VECTOR SUM:

A [calculation](http://www.scienceclarified.com/knowledge/Calculation.html) that yields the net result of all the vectors applied in a particular situation. In the case of momentum, the vector component isvelocity. The best method is to make a [diagram](http://www.scienceclarified.com/knowledge/Diagram.html) showing bodies in collision, with arrows illustrating the direction of velocity. On such a diagram, motion to the right is assigned a positive value, and to the left a negative value.

VELOCITY:

The speed of an object in a particular direction.