Momentum & Impulse

An object in motion has momentum. Momentum does not have a word definition. The definition of momentum is an equation. The momentum of an object is given by the following equation:

 **Momentum = mass X velocity or p = mV**

The symbol for momentum is a lower case “p” and the units of momentum are kg•m/s.

The mass of an object is how much matter is in the object. The mass is determined by the kinds of atoms in the object and how many of those atoms are in the object. The velocity of the object is the speed and direction of the object. The SI unit of mass is the kilogram, kg, and the unit of velocity is meters per second, m/s.

A large object moving at a certain speed has more momentum than a small object moving at the same speed. Doubling the mass of an object doubles the magnitude of the momentum.

If an object moves faster, the momentum of the object increases. Doubling the speed of an object doubles the magnitude of the momentum.

Mass is a scalar quantity but velocity is a vector quantity. The product of a scalar and a vector is a vector quantity. Momentum is a vector quantity so momentum has direction as well as magnitude. **The direction of the momentum is the same as the direction of the velocity of the object.**

Newton’s laws of motion

In 1667, Isaac Newton identified three laws of motion which are the basis of our study of mechanics which is often call Newtonian mechanics. “Mechanics” refers to the motion of objects larger than atoms moving at speeds much less than the speed of light far from large gravitational fields like that of stars.

When Isaac Newton used the word “motion” he meant the idea we call momentum.

The **first law of motion** is sometimes called the law of inertia. It states: An object at rest will remain at rest and an object in motion will move in a straight line at constant speed unless an unbalanced force acts on the object. This tendency of an object to resist a change in its motion is referred to as inertia. The measure of the inertia of an object is the mass of the object.

**Newton’s interpretation of this law would be more like: The momentum of an object will not change unless a force acts on the object.**

A vector quantity changes when either its magnitude (number part) or its direction changes. The momentum of an object will change if the object’s speed changes and/or its direction changes.

Newton’s first law identifies the condition necessary for the momentum of an object NOT to change. Newton’s second and third laws describe conditions during which the momentum of an object DOES change.

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One statement of **Newton’s second law of motion**: For the momentum of an object to change an unbalanced force must act on the object. The change in momentum (also called the impulse) is directly proportional to the change in velocity of the object if the mass of the object does not change. A nonzero NET force on the object produces a change in momentum.

 **Δp = mΔV or Δp = m(Vafter – Vbefore)**

Δp – change in momentum, in kg•m/s

m - mass in kilogram, kg

ΔV – change in velocity, in m/s

Vafter – velocity after the change, in m/s

Vbefore – velocity before the change, in m/s

Velocity is a vector quantity. It must have a directional sign, either + or -. You must include the signs to get the correct sign for Δv.

Another statement of **Newton’s second law of motion**: **The change in momentum of an object is directly proportional to the size of the force on the object and directly proportional to the amount of time the force acts on the object.**

 **Δp = Ft or Δp = force • time**

Δp – change in momentum, in kg•m/s

F – force on the object, in newtons, N

t – time, in seconds

Force is a vector quantity and time is a scalar quantity. Force must has a directional sign, either + or -. The sign for Δp will be the same as the sign for force.

The two previous equations describe the same property; change in momentum, but in terms of different properties. We can combine the two equations to get a third equation:

 **Ft = mΔV or Ft = m(Vafter – Vbefore) or F = m(ΔV/t)**

The ratio ΔV/t is given a special name and a special symbol. The ratio of change of velocity to change in time is called average acceleration and is given the symbol, a. An object accelerates if the object speeds up OR slows OR changes direction. We then can rewrite the equation above:

# F = ma or a = F/m

This is the equation for Newton’s second law, called the law of acceleration. The law is usually stated: The acceleration of an object is directly proportional to the force acting on the object and is inversely proportional to the mass of the object.

**Newton’s second law is the most important single idea in all of mechanics, if not all of Physics.**

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**Newton’s third law of motion** also describes conditions necessary for a change in momentum of an object. The third law is usually called the law of action/reaction or the law of paired forces. This law is often stated: For every action there is an equal reaction in the opposite direction.

By “action” and “reaction”, Newton meant impulse or change in momentum. **The law states, when the** **momentum of one object changes, there must be an equal change in momentum in the opposite direction of at least one other object.** When two objects interact, the two objects experience the same impulse but in opposite directions.

A better way to state the third law: IF object A applies a force on object B, THEN object B applies an equal force on object A but in the opposite direction.

## Conservation of Momentum

Newton’s three laws lead to the law of conservation of momentum: **The total momentum of all objects in a closed system after an event is equal to the total momentum of the objects in the closed system before the event.**

A “system” is an object or group of objects whose motion you choose to examine. An object that is not in the system is an external object.

A closed system is one in which no external objects apply forces on objects in the system AND objects in the system do not apply forces on external objects. A better description of a closes system may be **a system where there is no NET force on the system by external forces.** There CAN be external forces on the system as long as the sum of these external forces is zero.

Conservation of momentum is the basic principle that describes collisions between objects. This is the most common type of situation we will encounter that involves conservation of momentum.

A quantity is “conserved” if the total amount of this quantity for a system after an event is equal to the total amount of the quantity before the event.

**Collisions**

When two objects collide and stick together, the two objects will have the same velocity after the collision.

When an object breaks into pieces, the sum of the masses of the pieces will equal the mass of the original object.

A collision can be described as **elastic** or **inelastic**. Momentum is conserved in both types of collisions. An elastic collision is one in which the total kinetic energy of the objects after the collision is equal to the total kinetic energy of the objects before the collision. Kinetic energy is conserved in an elastic collision. An inelastic collision is one in which the total kinetic energy after the collision is not equal to the total kinetic energy before the collision. Kinetic energy is not conserved. Inelastic collisions are far more typical but much harder to investigate using kinetic energy. Any collision in which an object is permanently deformed (e.g. between automobiles) is inelastic. Also any collision that produces heat or sound is inelastic. Collisions between gas molecules are considered elastic.

**Remember**: Momentum is conserved in ALL collisions!

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IMPULSE

Impulse is the change in momentum of an object. We can calculate impulse in several ways. Impulse is represented by the symbol ***J***.

 *J* = Δp or *J* = mΔV or *J* = FΔt or *J* = Δ(mV)

Impulse can be expressed in kg•m/s or in N•s. Impulse is a vector with its direction in the same direction as the force that produced the impulse.

When object A interacts with object B, the impulse experienced by A (the action) will be equal in magnitude to the impulse experienced by B (the reaction) but in the opposite direction.

The word definition of impulse is **change in momentum**. We can calculate impulse impressed on an object in several ways:

 impulse = Δp

 impulse = Δ(mV)

 impulse = mΔV (if the mass of the object does not chance due to the

 force acting on the object)

 impulse = Ft

 impulse on A = - impulse on B (if objects A and B are the only

 objects that collide)

The symbol ***F*** in the equations above can be misleading. This is the force **on the object whose momentum changes!** Since there is a force, there must be an object which produces the force. The symbol ***F*** can also mean the force **by the agent which CAUSES the momentum of the object to change.**

Anytime the momentum of an object changes the object experiences an impulse. For a closed system, individual objects usually will experience an impulse but the NET impulse for the system is zero.