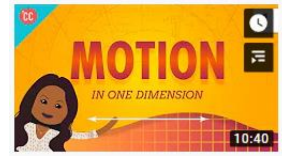


Crash Course Physics: This is a series of YouTube videos produced by certified scientists and educators. It is suggested viewing material to complement many of the concepts introduced in Physics 112. The digital version of this document contains a link to the video, otherwise a search of YouTube will easily find the video or related videos.

Kinematics Concepts & Definitions


The Moving Man

Kinematics: The study of *how* objects move. That is, analyzing motion relating to an object's current motion. The analysis is often a mathematical approach to solving for quantities such as position, final or initial velocity or acceleration at an instant in time. Investigate this with the PhET simulation *The Moving Man.*

Motion: An object is said to be in motion when its position changes.

Frame of Reference: Something not moving with respect to an observer that can be used to detect motion; it is the "point-of-view" of the observer. For example, suppose someone is watching another person walking on a train. The person on the train has a velocity *relative* to the ground or *relative* to the train. Both situations are correct but will yield different numerical results when analyzed.

Coordinate System: The mathematical reference from which to measure quantities. It provides a reference for defining *direction* – up, down, left, right, north, west, east, south, etc. Solving problems in physics requires measurements to be positive or negative and it is the coordinate system that defines the positive direction.

Scalar: Measurements that are independent of direction and always positive in value. It's not that you choose not to communicate a direction, but rather, stating a direction *doesn't make sense*. For example, you would not tell someone their body temperature is 38 ^{o}C East. Other scalar quantities include time, mass, distance and speed.

Vector: Measurements that have a magnitude *and* a direction (magnitude is the numerical value of the measurement). All vectors must be used relative to the positive direction as determined in the coordinate system. Vector quantities can be positive or negative, depending on the coordinate system and are communicated in writing by being bold font or with an arrow above them. For example, the variable for force could be written as ***F*** or $\vec{F}$. Visually, in diagrams, vectors quantities are represented by arrows. The length represents magnitude and the way it points is the direction. Examples of vectors include position, displacement, velocity and acceleration.

Distance: The length of the route between two points. Measurements of distance can never decrease. That is, you can't take away the fact an object moved a certain distance. The odometer of a car, for example, measures a car's total distance traveled.

Position: An object's distance and direction from a reference point (within a coordinate system) at an instant in time. The change in position is called *displacement*.

Average Speed: An object's *total distance* traveled per time interval.

Instantaneous Speed: The speed of an object at an instant in time. Determining this usually requires data to be analyzed. One example is the speedometer of a car.

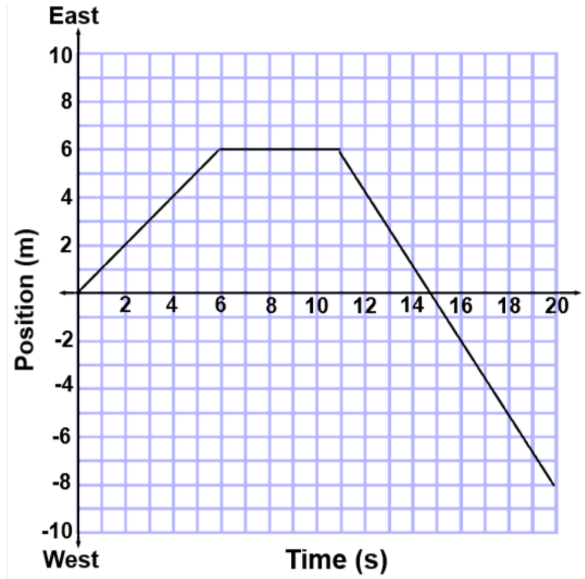
Average Velocity: An object's *change in position* per time interval. Changes in direction average out so the path taken does not matter. It is possible to have a value of zero.

Instantaneous Velocity: The velocity of an object at an instant in time (usually requiring data analysis). It is the object's instantaneous speed *and* direction.

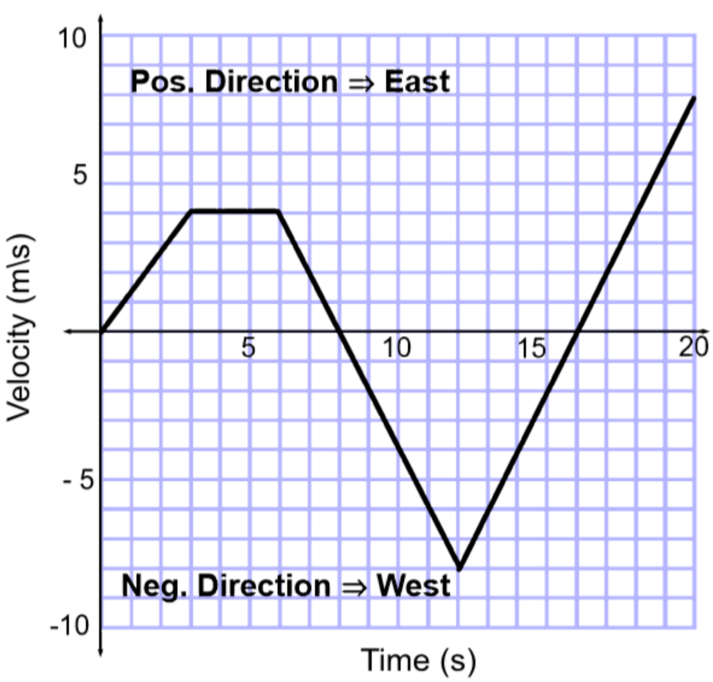
Acceleration: The change in an object's velocity per unit time. That means if an object's speed changes then it undergoes an acceleration. It also means that if only the object's direction changes then it accelerates! When an object changes direction it has an instantaneous velocity of zero, but its acceleration is not zero.

Analyzing Position – Time Graphs

- **Position**: Read from the position axis for the given time. It is how far and in what direction from a starting point.
- **Distance**: Add up all the motion using positive numbers. Follow the graph counting squares up and down until you get to the desired time. It is the total length an object traveled.
- **Direction Change**: When the velocity goes from positive to negative or vice versa.
- **Average Speed**: Distance (see above) divided by the time given in the question.
- **Instantaneous Speed**: Positive value of the slope of the line at the time given (find two points on the line and calculate rise/run).
- **Average Velocity**: Position (see above) divided by the time given in the question.
- **Instantaneous Velocity**: Slope of the line at the time given (find two points on the line and calculate rise/run). Can be positive or negative.

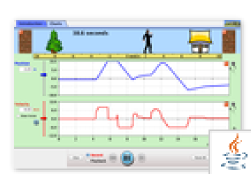


Analyzing Velocity – Time Graphs



- **Velocity**: Read it from the velocity axis for the given time. It communicates the direction of travel, not the position.
- **Instantaneous Acceleration**: The slope of the line at the time given (find two points on the line and calculate rise/run). Can be positive or negative and the sign is the direction of the acceleration, not the object.
- **Distance**: For a certain time-interval, the distance is the area contained between the graph and the time axis (always use positive numbers when calculating).
- **Position**: For a certain time-interval, it is the area contained on the top minus the area contained on the bottom.
- **Direction Change**: When the velocity goes from positive to negative or vice versa.
- **Average Speed**: Total distance divided by the time.
- **Average Velocity**: Final position divided by the time.

Check out the PhET simulation again, but now make use of the graphical functions. Create a position-time and velocity-time graph to review the above concepts.

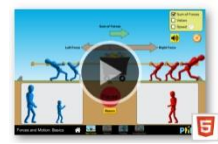


The Moving Man

Dynamics Concepts and Definitions

Dynamics: The study of *why* objects move. When all the forces acting on an object add to be greater than zero, then there is a *net force*. This will cause the object to accelerate, after which we apply kinematic concepts for an analysis.

Force: ***F***, a vector quantity that is a push or a pull on and object. The unit of force is the Newton, N (pounds, or lb, in the United States). Many different forces can act on an object at the same time. The unit of a Newton breaks down into component units: $N = kg \cdot m/s^2$ (investigate forces using the PhET simulation to the right).

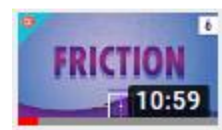

Forces and Motion: Basics

Types of Forces: Forces a grouped in to two categories – contact and noncontact forces. Contact forces require direct physical contact between objects (such as friction, applied and tension forces). Noncontact forces exert their forces on objects over a distance and create *fields* (such as gravity, magnetic and electric forces).

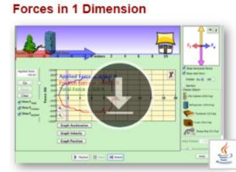
Applied Force: F_a, this is usually a force created by a person or machine acting on an object.

Normal Force: F_N, a force that acts perpendicular to a surface. For example, the stool you sit on provides a normal force upwards, equal to the magnitude of gravity's pull on you, your weight. The concept of normal force is prominent in our investigations and understanding of the force of friction.

Force of Friction: F_f, this *electromagnetic* force acts between surface atoms of two objects in direct contact. These bonds must be broken to move the objects. The greater the normal force the more the objects are pushed together, so the stronger the bonds. The force of friction always acts opposite the direction of motion of the object or, if it is not moving, the direction of the net force acting on it. There are two types of frictional forces: static and kinetic.



Static Friction: A frictional force that must be overcome to get an object moving. Think of pushing a massive object, it does not move unless you apply a large force. That is because the force of friction is very strong due to a high normal force.


Forces in 1 Dimension

Kinetic Friction: A frictional force that must be overcome to keep an object moving. Kinetic friction is lower than static friction for any two surfaces. The electromagnetic bonds have less time to strength as they continually form and break due to the object's motion.

Coefficient of Friction: μ. Think of this as the "*electromagnetic stickiness*" between any two surfaces. It is unique for any two objects, and for our course, it is independent of surface area or location. All that matters are the two objects. Each type of friction has its own coefficient value. The symbol is the Greek letter mu, μ.


Forces and Motion

Force of Gravity: F_g, Aa attractive force that acts over a distance between masses because of their warping of spacetime. For situations on Earth, it is the pull on objects towards the center of the Earth. It is often calculated by $\vec{F_g} = m\vec{g}$, where $\vec{g} = 9.81\, m/s^2$, the average acceleration due to gravity for the Earth. Another term for force of gravity is an object's *weight*.

Net Force: F_{net}, is the vector sum of all the forces acting on an object. Vector sum means that only forces acting in the same *dimension* can be added together. For example, forces acting left or right are not added with forces acting up or down – they are separate calculation. Objects accelerate in the direction of the net force.

Equilibrium: An object in equilibrium means that the net force acting on it is *zero*. This can happen is the object is a rest (a velocity of zero) or is moving with a constant velocity (an acceleration of zero).

Classical Mechanics: Developed in the late 1600s by Sir Isaac Newton. This system of physics treats matter and energy as separate entities, but it can predict the motion and interactions of objects. Such objects need to be much larger than an atom and traveling much slower than the speed of light.

Quantum Mechanics: Developed in the early 1900s, spearheaded by Albert Einstein, treat matter and energy as one and the same through the famous equation $E = mc^2$. This system of physics can model the motion and energy of subatomic particles and objects traveling near the speed of light, $c \approx$ 300 000 000 m/s as well as all classical physical systems.

Newton's 1st Law: An object at rest or in uniform motion will remain at rest or in uniform motion unless acted on by an external force. An external force brings an object out of equilibrium. For example, when traveling in a car and it takes a sharp turn you get squished into the door or another passenger. What is happening is that you are trying to continue uniform motion, but the car gets in your way.

Newton's 2nd Law: The net (average) force acting on an object is equal to the product of the object's mass and (average) acceleration, $\boldsymbol{F} = m\boldsymbol{a}$. This force has the same direction as the acceleration. This mathematically relates concepts of dynamics and kinematics.

Newton's 3rd Law: For every action there is an opposite and equal reaction. Forces act in pairs, called action-reaction pairs. Thus, if you punch a wall the wall "punches" back with the same force, possibly breaking your hand. Walking on the floor is possible because the floor pushes you forward (if you were to push the floor, the floor would move).

Inertial Frame of Reference: One in which Newton's Laws of motion are valid and can be applied. Every force can be explained. This frame of reference must be in equilibrium.

Non-Inertial Frame of Reference: One in which Newton's Laws of motion are not valid and cannot be applied. The frame of reference is not in equilibrium. In such a frame of reference, some aspects of an object's motion cannot be explained without the use of *fictitious forces*. For example, if a car is the frame of reference and it suddenly slows down, the passengers lunge forward. Relative to the car there was no push or pull to create such motion.

Conservation of Mechanical Energy

Work: In physics, work is done on an object when a force causes a displacement of the object. Work is a measure of energy and uses the unit called Joules, J. For reference, 1 J of work is lifting an apple to the top of your head. The mathematical relationship is $W = \boldsymbol{Fd}$. Only a force parallel to the direction of motion does work on an object. Work is a scalar quantity, but it can be positive or negative. The sign of work is not determined by a coordinate system. If the force and displacement are in the same direction, that is positive work, otherwise, work is negative.

Conservative Force: Does work on an object in such a way that the amount of work done is independent of the path taken. For example, lifting an object 1 meter off the ground will be the same if you lift it straight up or use a ramp (in the absence of friction). A system of only conservative forces will have energy changes that are reversible.

Nonconservative Force: The work done on an object is path dependent. Friction is such a force and removes energy from the system as heat. Such physics systems may not be reversible. In the natural world, most systems involve nonconservative forces. For example, when you bounce a ball it will not return to its original height because energy is lost from the collision with the floor in the form of deformations, heat and sound.

Energy Skate Park: Basics

Kinetic Energy: E_K, is the energy associated with motion. Represented by $E_K = \frac{1}{2}mv^2$, where *m* is the object's mass in *kg* and *v* is the instantaneous speed in *m/s*. Kinetic energy is measured in Joules, J.

Potential Energy: Stored energy, the object has the *potential* to move. Such energy is associated with an object because of the position, shape or condition of the object (e.g. pressing down on a spring or pulling a bow string stores energy because of a change of shape of the object).

Gravitational Potential Energy: E_g, is energy is stored in a gravitational field above a reference, or zero level of a gravitational source. (i.e. the surface of the Earth, but it can be set for each system). Mathematically, $E_g = mgh$, where *g* is the acceleration due to gravity and *h* is the height above a zero level (use only positive values).

Elastic Potential Energy: E_e, the energy stored that depends on the distance an object has been compressed or stretched. Elastic materials can restore its shape by applying a *restoring force*. That ability is summarized numerically by a what is called a spring constant, *k*. Highly flexible materials have a low k-value, whereas stiff materials have high k-values. Mathematically, the stored energy is $E_e = \frac{1}{2}kx^2$ where *x* is the compression or stretch length in meters. If a restoring force calculation is required, *Hooke's Law* is applied to the object: $F_s = -kx$. The expression is negative because it always acts opposite to the compression or stretch direction (this assumes stretch direction is positive).

Work-Energy Theorem: Work must be done on an object to change its position. This theorem states that the work done on an object equals its energy gained or lost. Each form of energy applies its own version of the work-energy theorem: $W = \Delta E_K$, $W = \Delta E_g$, or $W = \Delta E_e$ and remember that $W = \boldsymbol{Fd}$, should force or displacement be part of the analysis. The symbol Δ (capital Greek letter delta) means "change in" so it will be an object's "final" – "initial" energy of that type.

Law of Conservation of Energy: Energy can neither be created nor destroyed, but it can be transformed from one form to another or transferred from one object to another. The total energy of an isolated system, including all forms of energy, always remains constant. Common examples include dropping an object – initially the object has a speed of zero but gravitational potential energy. Once released the gravitational potential energy decreases but its speed increases – gravitational potential energy is transformed into kinetic energy. In the absence of air resistance, the total energy remains constant. Use the PhET simulation on the right to explore energy transformations.

Energy Skate Park: Basics

- If all the forces in the system are conservative, then mathematically $\Delta E_T = 0$ where E_T is the total of all types of energies and is a constant. That means the change in total energy is zero.
- If there exists one or more nonconservative forces, the mathematically $\Delta E_T = W_{nc}$, where W_{nc} is the work done by the nonconservative forces (friction acting over a distance, for example) and will evaluate to a negative value since that energy is lost.