Kinematic Definitions

Displacement is a vector quantity that refers to "how far out of place an object is"; it is the object's overall change in position. **Distance** is a scalar quantity that refers to "how much ground an object has covered" during its motion.

Average velocity is often computed using this formula

$$\text{Average Velocity} = \frac{\Delta \text{ position}}{\text{time}} = \frac{\text{displacement}}{\text{time}}$$

Instantaneous Speed - the speed at any given instant in time.

Position-Time Graphs

To determine how far from the detector an object is located, look at the vertical axis of the position-time graph.

To determine how fast an object is moving, look at the steepness (i.e., the slope) the position-time graph.

To determine which way an object is moving, look at which way the position-time graph is sloped.

A position-time graph slope like a front slash, /, means an object is moving away from the detector.

A position-time graph slope like a back slash, \, means an object is moving toward the detector

Velocity-Time Graphs

To determine how fast an object is moving, look at the vertical axis of the velocity-time graph.

To determine which way an object is moving, look at whether the velocity-time graph is above or below the horizontal axis.

An object is moving away from the detector if the velocity-time graph is above the horizontal axis.

An object is moving toward from the detector if the velocity-time graph is below the horizontal axis.

To determine how far an object travels, determine the area between the velocity-time graph and the horizontal axis.

On a velocity-time graph, it is not possible to determine how far from the detector the object is located.

Most everyday motion can be represented with straight segments on a velocity-time graph.

Acceleration

Acceleration tells how much an object's speed changes in one second.

When an object speeds up, acceleration is in the direction of motion.

When an object slows down, its acceleration is opposite the direction of motion.

Objects in free fall gain or lose 10 m/s of speed every second.

Algebraic Kinematics

You must follow these steps to solve an algebraic kinematics calculation.

1. Define a positive direction, e.g., the direction "Away from the detector."
2. Indicate in words what portion of motion you are considering, e.g., "motion from launch to peak flight."
3. Fill out a chart, *including signs and units,* of the 5 kinematic variables:
   a. v_o initial velocity
   b. v_f final velocity
   c. Δx displacement
   d. a acceleration
   e. t time for the motion
4. If three of the five variables are known, the problem is solvable; use the kinematics equation to solve

$$d = v_i{*}t + \frac{1}{2}{*}a{*}t^2 \qquad v_f^2 = v_i^2 + 2{*}a{*}d$$

$$v_f = v_i + a{*}t \qquad d = \frac{v_i + v_f}{2}{*}t$$

Projectile Motion

When an object is in free fall,

- Its *vertical* acceleration is always 10 m/s per second
- Its *horizontal* acceleration is always zero.

Velocities in perpendicular directions add just like perpendicular forces.

The magnitude of an object's velocity is known as its speed.

To approach a projectile problem, make two kinematics charts: one vertical, one horizontal.

Definition of Equilibrium

An object is in equilibrium if it is moving in a straight line at constant speed. This includes an object remaining at rest.

The net force on an object in equilibrium is zero.

Force and Net Force

A force is a push or a pull that acts on an object.

Force is measured with a spring scale or a platform scale.

The units of force are newtons.

Forces acting in the same direction add together to determine the net force.

Forces acting in opposite directions subtract to determine the net force.

The net force is always in the direction of acceleration.

Newton's Second Law

Forces acting in the same direction add together to determine the net force.

Forces acting in opposite directions subtract to determine the net force.

The net force is always in the direction of acceleration.

An object's acceleration is given by $a = F_{net}/m$.

Mass and Weight

Mass tells how much material is contained in an object.

The units of mass are kilograms.

Weight is the force of a planet acting on an object.

On Earth's surface, the gravitational field is 10 N/kg. This means that on Earth, 1 kg of mass weighs 10 N.

Normal Force

A normal force is the force of a surface on an object in contact with that surface.

A normal force acts perpendicular to a surface.

A platform scale reads the normal force.

Adding Perpendicular Forces

When two concurrent forces act perpendicular to one another, the resultant force is

- Greater than if the forces acted in opposite directions
- Less than if the forces acted in the same direction
- At an angle, but closer to the larger force

To determine the resultant force, draw the forces to scale. Create a rectangle, and then measure the diagonal of the rectangle and its angle.

The "magnitude" of a force means the amount of the resultant force.

Using *x*- and *y*-Components

Any diagonal force can be written in terms of two perpendicular force components, called the *x*- and –*y*-components.

To determine the amount of each component, draw the diagonal force to scale. Draw dotted lines from the tip of the force arrow directly to the *x*- and *y*-axes. Measure each component.

When the angle θ of the diagonal force is measured from the horizontal,

- The horizontal component of the force is the magnitude of the force times cos θ.
- The vertical component of the force is the magnitude of the force times sin θ.

Solving Problems with Forces

1. Draw a free-body diagram.
    a. Break angled forces into components, if necessary.
2. Write two equations, one for Newton's second law in each direction:
   (up forces) – (down forces) = *ma*
   (left forces) – (right forces) *ma*

A free-body diagram includes:

1. A labeled arrow representing each force. Each arrow begins on the object and points in the direction in which the force acts.
2. A list of the forces, indicating the object applying the force and the object experiencing the force.

Friction Force

The force of friction is the force of a surface on an object acting along the surface.

The force of friction acts in the opposite direction of an object's motion.

The coefficient of friction μ (Gk. mu) is not a force.

The coefficient of friction is a number that tells how sticky two surfaces are.

The force of friction is equal to the coefficient of friction times the normal force $F_f = \mu F_n$.

The coefficient of kinetic friction is used when an object is moving; the coefficient of static friction is used when an object is not moving. Both types of coefficient of friction obey the same equation.

The coefficient of static friction can take on any value up to a maximum, which depends on the properties of the materials in contact.

Gravitation

All massive objects attract each other with a gravitational force.

The **gravitational force** F_G of one object on another is given by $F_G = G\frac{M_1 M_2}{d^2}$

The **gravitation field** g near an object of mass M is given by $g = G\frac{M}{d^2}$, where d represents the distance from the object's center to anywhere you're considering.

The **weight** of object near a planet is given by mg, where g is the gravitational field due to the planet at the object's location.

The gravitational field near a planet is always equal to the free-fall acceleration.

Gravitational mass is measured by measuring an object's weight using *weight* = *mg*.

Inertial mass is measured by measuring the net force on an object, measuring the object's acceleration, and using $F_{net} = ma$.

Inclined Planes

When an object is on an inclined plane, break the object's weight into components parallel to and perpendicular to the incline. Do not use x- and y-axes.

The component of the object's weight parallel to the incline is $mg\sin(\theta)$.

The component of the object's weight perpendicular to the incline is $mg\cos(\theta)$.

Newton's Third Law

Newton's third law says that the force *of* object A *on* object B is **equal** to the force *of* object B *on* object A.

A "third law force pair" is a pair of forces that obeys Newton's third law.

Two forces in a third law force pair can never act on the same object.

Circular Motion

An object moving at constant speed v in a circle of radius r has an acceleration of magnitude v^2/r, directed toward the center of the circle.

Rotational Kinematics—Definitions

Angular displacement θ indicates the angle through which an object has rotated. It is measured in radians.

A radian is an angle, equal to just under 60 degrees.

Average angular velocity ω (Greek letter omega) is angular displacement divided by the time interval over which that angular displacement occurred. It is measured in rad/s.

Instantaneous angular velocity is how fast an object is rotating at a specific moment in time.

Angular acceleration α (Greek letter alpha) tells how much an object's angular speed changes in one second. It is measured in rad/s per second.

Angular acceleration and centripetal acceleration are independent. Angular acceleration changes an object's rotational speed, while centripetal acceleration changes an object's direction of motion.

Relationship Between Angular and Linear Motion

The linear displacement of a rotating object is given by $r\theta$, where r is the distance from the rotational axis.

The linear speed of a rotating object is given by $v = r\omega$.

The linear acceleration of a rotating object is given by $a = \alpha r$.

Torque

The torque provided by a force is given by τ (Greek tau) = $Fd_{\perp}$, where $d_{\perp}$ refers to the "lever arm."

Rotational Inertia

Rotational inertia I represents an object's resistance to angular acceleration.

For a point particle, rotational inertia is MR^2, where M is the particle's mass, and R is the distance from the axis of rotation.

For a complicated object, its rotation inertia may be given by an equation relating its mass and radius. These equations will be given as needed.

Rotational inertia of multiple objects add together algebraically.

Newton's Second Law for Rotation

An angular acceleration is caused by a net torque: $\alpha = \tau_{net}/I$.

II. Conservation Laws

What is conserved?

Mechanical energy is conserved when there is no net work done by external forces (and when there's no internal energy conversion).

Angular momentum is conserved when no net external force acts in that direction.

Momentum in a direction is conserved when no net external force acts in that direction.

Momentum

Momentum is equal to mass times velocity: $p = mv$.

The standard units of momentum are newton-seconds, abbreviated N s.

The direction of an object's momentum is always the same as its direction of motion.

Impulse

Impulse J can be calculated in either of two ways:

1. Impulse is equal to the change in an object's momentum.
2. Impulse is equal to the force experienced multiplied by the time interval of collision, $J = Ft$.

Impulse has the same units as momentum, N·s.

Impulse is the area under a force vs. time graph.

Conservation of Momentum in Collisions

When no external force act on a system of objects, the system's momentum cannot change.

The total momentum of two objects before a collision is equal to the object's total momentum after the collision.

Momentum is a vector: that is, the total momentum of two objects moving in the same direction adds together; total momentum of two objects moving in opposite directions subtracts.

A system's center of mass obeys Newton's second law: that is: the velocity of the center of mass changes only when an external net force acts on the system.

Definition of Work

The amount of work done by a steady force is the amount of force multiplied by the distance an object moves parallel to that force: $\mathbf{W = F \cdot \Delta x_{\parallel}}$.

Positive work is done by a force parallel to an object's displacement.

Negative work is done by a force antiparallel to an object's displacement.

Work is a scalar quantity—it can be positive or negative, but does not have a direction.

The area under a force vs. displacement graph is work.

Equations for Different Forms of Energy

All forms of energy have units of joules, J.

- **Kinetic energy:** KE = ½ mv^2. Here, m is the mass of the object, and v is its speed.
- Gravitational potential energy: PE = mgh.
- The term ***mechanical energy*** refers to the sum of a system's kinetic energy and potential energy.
- **Spring potential energy:** PE = ½ kx^2. Here, k is the spring constant, and x is the distance the spring is stretched or compressed from its equilibrium position.
- **Rotational kinetic energy:** KE_r = ½ $I\omega^2$. Here, I, is the rotational inertia of the object, and ω is the angular speed of the object.

Work-Energy Theorem

Before starting a work-energy problem, define the object or system being described.

The work-energy theorem states that the net work done by external forces changes the system's mechanical energy:

$$W_{ext} = (K_f - K_i) + (PE_f - PE_i)$$

Power

Power is defined as the amount of work done in one second, or energy used in one second:

$$power = work / time \text{ or } Force \times distance / time$$

The units of power are joules per second, which are also written as watts.

An alternative way of calculating power when a constant force act is *power = force × velocity*.

Angular Momentum

Before calculating angular momentum, it is necessary to define a rotational axis.

The angular momentum L of an object is given by:

- $I\omega$ for an extended object
- mvr for a point object, where r is the "distance of closest approach"

The "direction" of angular momentum is given by the right-hand rule.

Conservation of Angular Momentum

When no torques act external to a system, angular momentum of the system cannot change.

Angular momentum is a vector—angular momentum in the same sense add; angular momentum in the opposite senses subtract.

Angular momentum is conserved *separately* from linear momentum. Do not combine them in a single equation.

Angular Impulse

The impulse-momentum theorem can be written for angular momentum, too.

$$\tau \Delta t = \Delta L$$

A change in angular momentum equals the net torque multiplied by the time the torque is applied.

III. (a) Electricity

Non-Rigorous Definition of Voltage, Current, Resistance

Voltage is provided by a battery. Voltage is measured in units of volts.

Resistance is provided by a resistor, a lamp, or any electronic device. The units of resistance are ohms (Ω).

Current relates to the amount of charge flowing through a resistor. The units of current are amps.

Ohm's law states that voltage is equal to current multiplied by resistance: **V = IR.**

Rigorous Definitions of Voltage, Current, Resistance

Voltage is energy per charge. **E**(joules)/**Q**(coulombs)

Current is charge per time. I = Q/time

Power is energy per time. P(watts) = E(joules)/time

Potential difference is a synonym for voltage. $\Delta V = V_a - V_b$

Vertical Springs

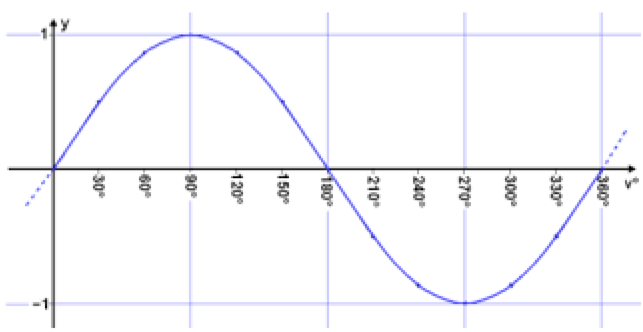
When dealing with an object hanging vertically from a spring, it's easiest to consider the spring-Earth-object system.

The potential energy of the spring-Earth-object system is PE = ½ kx^2, where x is measured from the position where the object would hang in equilibrium.

Simple Harmonic Motion

Many objects that vibrate back and forth exhibit simple harmonic motion. The pendulum and the mass on a spring are the most common examples of simple harmonic motion.

An object in simple harmonic motion makes a position-time graph in the shape of a sine function.



An object in simple harmonic motion experiences a net force whose

- magnitude increases a linear function of distance from equilibrium position.
- direction always points toward the equilibrium.

Definitions involving simple harmonic motion:

- Amplitude (A): the maximum distance from the equilibrium position reached by an object in simple harmonic motion.
- Period (T): the time for an object to complete one entire vibration
- Frequency (*f*): how many entire vibrations an object makes each second

The period of a mass on a spring is given by the equation $T = 2\pi\sqrt{\frac{m}{k}}$. The mass attached to the spring is *m*, the spring constant is *k*.

The period of a pendulum is given by the equation $T = 2\pi\sqrt{\frac{L}{g}}$. The length of the pendulum is L; the gravitational field is *g*.

Equations Relating Frequency, Period, Wavelength, Wave Speed

Frequency and period are inverses of each other: $f = 1/T$, and $T = 1/f$.

You can calculate the speed of a wave by multiplying the wavelength by the frequency: $v = \lambda f$.

You can calculate the speed of a wave by dividing the wavelength by the period. $v = \lambda / T$.

Transverse/Longitudinal Waves

Whenever the motion of a material is at right angles to the direction in which the wave travels, the wave is a *transverse wave*.

Waves on a stringed instrument are transverse; waves in the electromagnetic spectrum, including light, are transverse waves.

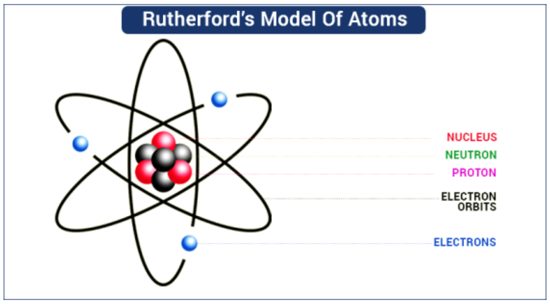
All waves in the electromagnetic spectrum move 300 million m/s in air.

The higher the tension in a string, the faster the wave moves in that string.

Atomic Physics

Introduces the quantization of energy in blackbody radiation and the photoelectric effect and solve problems involving energy quanta, threshold frequency and the work function.

Explore Rutherford's model of the atom, introducing emission and absorption spectra in terms of Bohr's model of the atom and its strengths and weaknesses of the Bohr's model.



Calculate de Broglie wavelengths, introduces the uncertainty principle, and describes the quantum mechanical picture of the atom.

The de Broglie Wavelength

Since $p = \frac{E}{c}$ for a photon $\qquad c = f\lambda$

$$E = hf = \frac{hc}{\lambda} \qquad f = \frac{c}{\lambda}$$

$$p = \frac{hf}{c} = \frac{hc}{\lambda c} = \frac{h}{\lambda}$$

$$\lambda = \frac{h}{p} = \frac{h}{mv} \Rightarrow \frac{[J\cdot s]}{[kg]\left[\frac{m}{s}\right]} = \left[\frac{J\cdot s^2}{kg\cdot m}\right] = \left[\frac{N\cdot m\cdot s^2}{kg\cdot m}\right]$$

$$= \left[\frac{kg\cdot m\cdot s^2}{s^2\cdot kg}\right] = [m]$$