Physics

The following does not cover every facet of this introductory college level course. It does contain key information to solve complex problems. The student should refer to the previous review sheets for details on Newtonian Mechanics, Thermal Physics, Electricity & Magnetism, Waves & Optics, and Modern Physics.

The pages that follow focus heavily on major principles that allow a student to recognize the nature of a complex problem and move smoothly between all five strands taught in this course. It pays particular attention to Energy, and also addresses Force, Kinematics, Collisions, Circular Motion, Graphing, Rates, and Electricity and Magnetism. Many items are mentioned repetitively. The information may seem redundant, however you will be asked in exams to use the information in a variety of ways. So some of the same information is presented in a variety of ways.

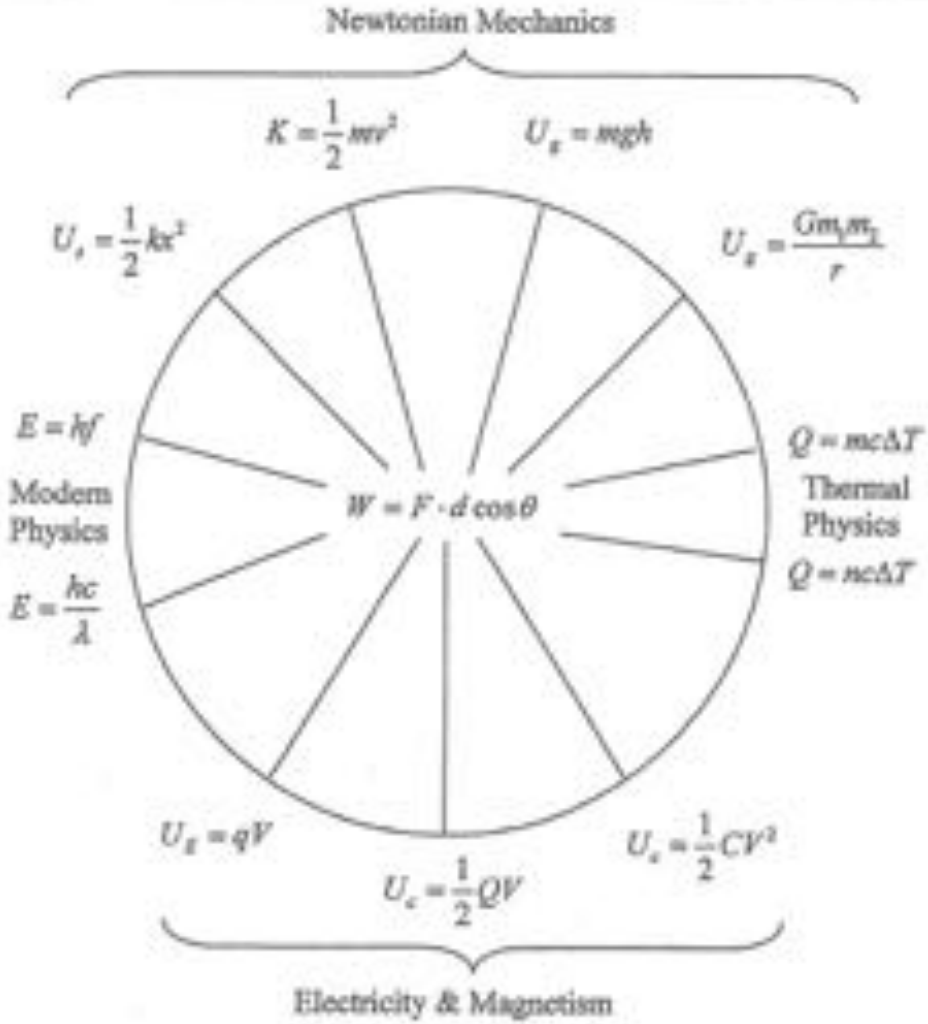
This document is a review, designed for students familiar with the variables and equations. The important equations to begin a problem are given, but the subsequent substitutions, of minor equations given with the test, is up to the student.

The following equations and facts are not given on the exam, but are essential for your success.

$v=\frac{x}{t}$	$v=\frac{2\pi r}{T}$	$g=G\frac{m}{r^2}$	
$m_A v_{Ai}+m_B v_{Bi}=m_A v_{Af}+m_B v_{Bf}$	$m_A v_{Ai}+m_B v_{Bi}=(m_A+m_B)v_{ABf}$	$(m_A+m_B)v_{ABi}=m_A v_{Af}+m_B v_{Bf}$	$K_{lost/dissipated}=\Sigma K_i-\Sigma K_f$
$mgh_i+\frac{1}{2}mv^2{}_i=mgh_f+\frac{1}{2}mv^2{}_f$	$mgh_{top}=\frac{1}{2}mv^2{}_{bottom}$	$\frac{1}{2}kx^2=\frac{1}{2}mv^2$	$qV=\frac{1}{2}mv^2$
And any combination of Work Energy Theorem and Conservation of Energy that might be applicable to the problem.			
Adiabatic (fast) $Q=0$ $\Delta U=Q-W$ so $\Delta U=-W$	Isothermal (slow) $\Delta U=0$ $\Delta U=Q-W$ so $Q=W$	$+W$ work done by engine. Gas expands. $-W$ work done on engine. Gas is compressed.	$+Q$ heat is added. $-Q$ heat is subtracted.
Work is the area under Force distance.	Work is the area under pressure volume	e: real or actual efficiency	e_c: Carnot, ideal, or reversible efficiency
Series circuits: current stays the same	Series circuits: voltage adds	Parallel circuits: voltage stays the same	Parallel circuits: current adds
$E=k\frac{q}{r^2}$	$P=I^2R$	$P=\frac{V^2}{R}$	$E=\frac{hc}{\lambda}$
Lenses: Rays thru center keep going straight. Rays arriving parallel go thru far focus on convex lenses, and the back trace goes thru the near focus in concave lens.			
Mirror: Rays thru 2*F* bounce straight back. Rays arriving parallel go thru the focus on concave mirrors, and the back trace goes thru the focus on convex mirrors.			
Right Hand Rule: Used for positive current. Thumb is +particle / +current, fingers are magnetic field lines, and palm is force. Use left hand for -particles / -current.			
$V=\varepsilon-Ir$	A changing flux induces a current in a wire. The direction of the current is the opposite that specified by the right hand rule. The current induced in the wire generates its own magnetic field, which is opposite to the field that caused the emf.		

Energy Overview

Energy is a central concept that connects the various strands of physics. Through the Work Energy Theorem and the Principle of Conservation of Energy a host of equations and possibilities help generate solutions.



Work Energy Theorem

Work is a change in any energy

$W = \Delta Energy$

Work, in the center, is equal to any change in energy around the circle. For example:

$W = \Delta K = \frac{1}{2}m(\Delta v)^2$ so $F \cdot d\cos\theta = \frac{1}{2}m(\Delta v)^2$

$W = \Delta U_g = mg\Delta h$ so $F \cdot d\cos\theta = mg\Delta h$

$W = \Delta Q = mc\Delta T$ so $F \cdot d\cos\theta = mc\Delta T$

$W = \Delta U_E = qV$ so $F \cdot d\cos\theta = qV$

Conservation of Energy

Energy can change forms

$Total\ Energy_i = Total\ Energy_f$

Any energy around the circle can change into another energy around the circle. For example:

$\frac{1}{2}m(\Delta v)^2 = mg\Delta h$ so $mgh_i + \frac{1}{2}mv_i^2 = mgh_f + \frac{1}{2}mv_f^2$

$qV = \frac{1}{2}m(\Delta v)^2$ A charge accelerated by charged plates

$\frac{1}{2}m(\Delta v)^2 = mc\Delta T$ If the kinetic energy of an object turns to heat

Power: If work and energy are important, then any variable that has work / energy in its equation is equally important.

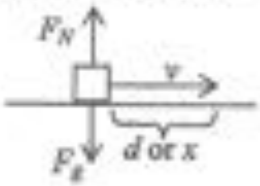
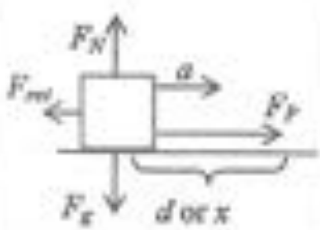
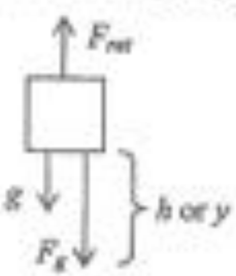
Power is the rate that work is done or that energy is delivered, expended, or used. So from power we can get work and energy, and from work and energy we can get power. **One easy way is to set time to 1.0 s.** Then power and work / energy have the same value, but different units. If you find the time later in the problem just multiply or divide by the time to solve as necessary.

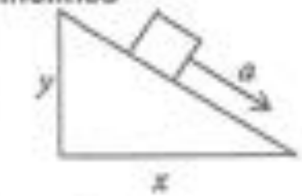
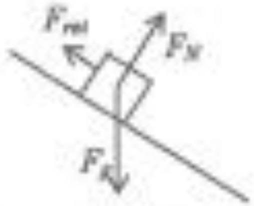
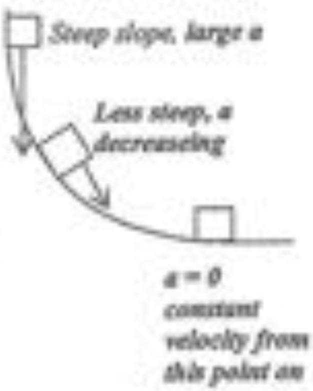
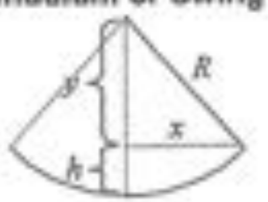
MOTION OF A SINGLE OBJECT: Relevant Kinematics, Force, and Energy

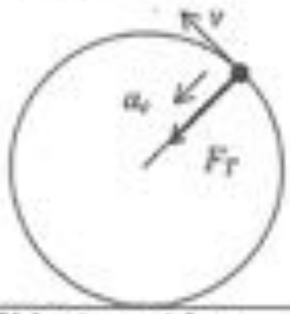
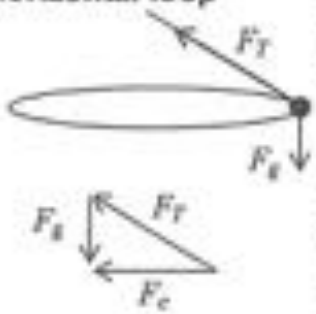
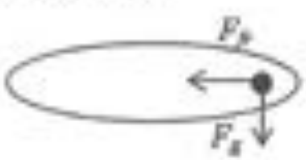
Start a problem by asking "What is the object doing?", then "What is causing it to do that?".

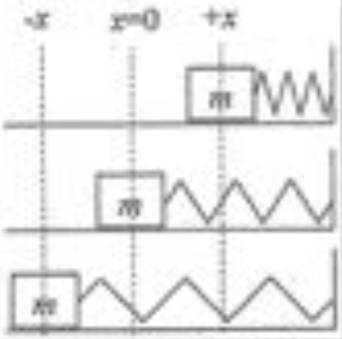
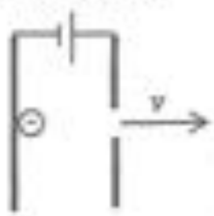
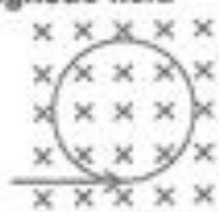
What direction is it moving in (if two find ***x*** and ***y*** components)? Is it moving at constant ***v*** (this includes ***v*** = 0)? Is it accelerating? Force? Energy change?
See if energy solves the problem first. Then think force and kinematics.

Most common usage is boxed. But, the most common usage is often a special case. Knowing the overall equations and logic will allow you to solve any scenario.

Situation	Kinematics	Force	Energy
Constant Velocity  	Need constant velocity $\boxed{v=\frac{x}{t}}$ or $x=vt$	Always think sum of force $\boxed{\sum F=0}$ Forces are vertical, while motion is horizontal $\boxed{F_g=mg}$ $F_N=mg\cos\theta$ 0° slope $\boxed{F_N=mg}$	Inertia only. No force. No energy needed. $W=F\cdot d\cos\theta$ Where θ is the angle between **F** and **d** vectors. $W=F\cdot d\cos 90°$ $\boxed{W=0}$
Accelerating in *x*  	Use Kinematic Equations $\boxed{v_x=v_{ox}+at}$ $\boxed{v_x^2=v_{ox}^2+2a(x-x_o)}$ $\boxed{x=x_o+v_{ox}t+\frac{1}{2}at^2}$ In projectile motion $\boxed{x=v_{ox}t}$	There is a sum of force $\boxed{\sum F=ma}$ $\sum F_x=F_{F_x}-F_{retarding_x}$ example $\sum F_x=F_{F_x}-F_{fr}$	A force through a distance. $W_x=\sum F_x\cdot d\cos\theta$ Where θ is the angle between **F** and **d** vectors. $W=F\cdot d\cos 0°$ No retarding forces present $\boxed{W=F\cdot d}$ This time work is done, so there is a Δ energy. $W=\Delta Energy$ $\boxed{W=\Delta K=\frac{1}{2}m(\Delta v)^2}$ The only thing changing is velocity, so ***K*** is changing.
Accelerating in *y*  	$\boxed{v_y=v_{oy}+gt}$ $\boxed{v_y^2=v_{oy}^2+2g(y-y_o)}$ $\boxed{y=y_o+v_{oy}t+\frac{1}{2}gt^2}$ Horizontal projectile or dropped object $\boxed{y=\frac{1}{2}gt^2}$	$\sum F_y=F_g-F_{retarding_y}$ example $\sum F_y=F_g-F_{air\ resistance}$	$W_y=\sum F_y\cdot h$ Includes retarding forces $W=F_g\cdot h$ No retarding forces $\boxed{W=\Delta U_g=mg\Delta h}$ Height is changing, so ***U*** is changing. $\boxed{W=\Delta K=\frac{1}{2}m(\Delta v)^2}$ Velocity is changing, so ***K*** is changing. $mg\Delta h=\frac{1}{2}m(\Delta v)^2$ $\boxed{mgh_i+\frac{1}{2}mv_i^2=mgh_f+\frac{1}{2}mv_f^2}$ Energy conserved.

Situation	Kinematics	Force	Energy
Inclines  	Kinematic Equations Apply $v_x = v_{ox} + at$ $v_x^2 = v_{ox}^2 + 2a(x - x_o)$ $x = x_o + v_{ox}t + \frac{1}{2}at^2$ $v_y = v_{oy} + gt$ $v_y^2 = v_{oy}^2 + 2g(y - y_o)$ $y = y_o + v_{oy}t + \frac{1}{2}gt^2$	Motion is parallel to slope Acceleration down the slope is caused by the addition of F_g and F_N. The resultant of these two vectors is $F_g\sin\theta$. Since the natural motion is down the slope set that direction as +. In some problems it is useful to reverse this (if the object is going up hill). $\boxed{\Sigma F_{\parallel} = F_g \sin\theta - F_{retarding}}$ $F_N = mg\cos\theta$	Work and energy can work parallel, in the ***x***, and in the ***y*** $W = F_{\parallel} \cdot d_{\parallel}$ Force and distance vectors form similar triangles. $W = F_x \cdot d_x$ Work depends on ***F*** and ***d*** being parallel. $W = F_y \cdot d_y$ So any pair of parallel vector will solve the problem $\boxed{W = \Delta K = \frac{1}{2}m(\Delta v)^2}$ $\boxed{W = \Delta U_g = mg\Delta h}$ $mg\Delta h = \frac{1}{2}m(\Delta v)^2$ $\boxed{mgh_i + \frac{1}{2}mv^2_i = mgh_f + \frac{1}{2}mv^2_f}$
Down a curve 	Kinematics Fail The net force is changing as the vectors F_g and F_N change. In addition the direction is changing. Acceleration is changing. The Kinematic Equations are designed for changing velocity, but only work for uniform (constant) acceleration.	Force Fails The net force is changing as the vectors F_g and F_N change.	Energy is directionless. $\boxed{W = \Delta K = \frac{1}{2}m(\Delta v)^2}$ $\boxed{W = \Delta U_g = mg\Delta h}$ $mg\Delta h = \frac{1}{2}m(\Delta v)^2$ $\boxed{mgh_i + \frac{1}{2}mv^2_i = mgh_f + \frac{1}{2}mv^2_f}$ A very important case. $\boxed{mgh_{top} = \frac{1}{2}mv^2_{bottom}}$ No initial velocity moving to a height of zero.
Pendulum or Swing  $h = R - y$ $y = \sqrt{R^2 - x^2} = R\cos\theta$	Kinematics Fail See accelerating down a curve above. The velocity is zero at either end. The velocity is greatest at the lowest point	Force Fails See accelerating down a curve above. The restoring force is greatest at the ends, as is the acceleration. The restoring force is zero in the middle, and so is the acceleration.	Energy is directionless. $\boxed{W = \Delta K = \frac{1}{2}m(\Delta v)^2}$ $\boxed{W = \Delta U_g = mg\Delta h}$ $\boxed{mgh_{top} = \frac{1}{2}mv^2_{bottom}}$ If it has no initial velocity and goes all the way down. At the ends it is all potential no motion, in the middle it is all motion no potential.

Situation	Kinematics	Force	Energy
Object on string, Vertical loop  	Tangential Velocity Instantaneous velocity is tangent to the circular motion. $v = \frac{2\pi r}{T}$ Acceleration is toward center, centripetal. $a_c = \frac{v^2}{r}$	Center seeking. Force is centripetal, F_c is the sum of force in circular motion. Toward center is +. Find tension at the top. $F_c = F_T + F_g$ Find tension at the bottom. $F_c = F_T - F_g$	Unlike previous scenarios, the object definitely has velocity at the top. There is a height difference from top to bottom, but the object has speed at the top as well. And the bottom may not necessarily be the lowest point in the problem. $mgh_{top_i} + \frac{1}{2}mv_{top}{}^2{}_i = mgh_{bottom_f} + \frac{1}{2}mv_{bottom}{}^2{}_f$
Object on string, Horizontal loop  	Tangential Velocity Instantaneous velocity is tangent to the circular motion. $v = \frac{2\pi r}{T}$ Acceleration is toward center, centripetal. $a_c = \frac{v^2}{r}$	Center seeking. Force is centripetal, F_c is the sum of force in circular motion. Toward center is +. Find F_c by adding vectors (tip to tail). Then solve for F_T. $F_T = \sqrt{F_c^2 + F_g^2}$	No work is done $W = F \cdot d\cos\theta$ Where θ is the angle between ***F*** and ***d*** vectors. $W = F \cdot d\cos 90^\circ$ $W = 0$ At any instant the direction of motion (tangent to the circle) is perpendicular to the center seeking F_c, the F_T, and the F_g. And for one revolution there is no total displacement from the origin, since a single revolution brings you back to the starting point.
Object turning on flat surface  	Tangential Velocity $v = \frac{2\pi r}{T}$ $a_c = \frac{v^2}{r}$	Why is there circular motion? Object not sliding off disk, or car turning on a road. $F_c = F_\mu$	No work is done See above.
Roller Coaster 	Need uniform slope Kinematics only work on sections that have constant slope. If the track is curved try energy.	Force centripetal in the loop. To find the speed needed to have passengers feel weightless at the top of the loop $F_c = F_g$	Energy works everywhere, with its directionless advantage. You can solve for any point ***A*** using any other point ***B***. Use the complete equation. The car will usually have both speed and height at every point. An exception is the lowest point on the track, or if it starts with zero velocity at the top of a hill (this is unlikely since roller-coasters don't stop at the top of each hill). If it has velocity and height at the top you need to include both. $mgh_A + \frac{1}{2}mv_A{}^2 = mgh_B + \frac{1}{2}mv_B{}^2$

Situation	Kinematics	Force	Energy
Spring  	Kinematics Fail See Down a curve, and Pendulum above. The velocity is zero at maximum +/- x (amplitude) The velocity is greatest at $x = 0$	Force Fails See Down a curve, and Pendulum above. The restoring force is greatest at maximum +/- x (amplitude). The restoring force is zero at $x = 0$, and so is the acceleration.	Energy is directionless. $W=\Delta K=\frac{1}{2}m(\Delta v)^2$ $W=\Delta U_s=\frac{1}{2}k(\Delta x)^2$ If it starts at maximum x (amplitude) and it converts all the springs energy into speed of the object pushed / pulled by the spring $\frac{1}{2}kx^2=\frac{1}{2}mv^2$ $\quad$ $\frac{1}{2}kx_i^2+\frac{1}{2}mv_i^2=\frac{1}{2}kx_f^2+\frac{1}{2}mv_f^2$
Particle accelerated by electric field  	Potential difference. Velocity increases. Positive charges go in the opposite direction. But, + particles are more massive, don't accelerate as quickly, and have lower final velocities.	The force of the electric field $F=qE$	Electromagnetism: New forms of energy, but energy is still conserved. $W=\Delta Energy$ $W=\Delta K=\frac{1}{2}mv^2$ $W=\Delta U_E=qV$ $qV=\frac{1}{2}mv^2$ $\quad$ $qV_i+\frac{1}{2}mv_i^2=qV_f+\frac{1}{2}mv_f^2$
Charged particle parallel to plates 	It acts like a projectile $x=v_{o,x}t$ $y=\frac{1}{2}at^2$ get **a** from ***F***	Electric field is perpendicular Particle is forced toward the plate with opposite sign. $E=\frac{F}{q}$ $\quad$ $F=qE$ $\sum F=ma$ $\quad$ $ma=qE$	Work is done in the direction of the electric field. $W=F\cdot d$ $W=qE\cdot d$
Charged particle in a magnetic field 	Path curved by field. If the field is large enough the particle will follow a circular path. $v=\frac{2\pi r}{T}$ $\quad$ $a_c=\frac{v^2}{r}$	Forced to center by field. $F_c=F_B$ $m\frac{v^2}{r}=qvB$	No work is done $W=F\cdot d\cos 90°$ $W=0$ At any instant the direction of motion (tangent to the circle) is perpendicular to the center seeking F_c, and the F_B.

Collisions

Momentum is always conserved in a collision

Know the following equations

$m_A v_{Ai} + m_B v_{Bi} = m_A v_{Af} + m_B v_{Bf}$ — 2 objects before, 2 objects after

$m_A v_{Ai} + m_B v_{Bi} = (m_A + m_B) v_{ABf}$ — 2 objects before, 1 objects after

$(m_A + m_B) v_{ABi} = m_A v_{Af} + m_B v_{Bf}$ — 1 objects before, 2 objects after

If there are more than two objects add $m_C v_C$, $m_D v_D$, etc.

If the collisions happen in two dimensions, ***x*** and ***y***, turn all mv vectors into ***x*** and ***y*** components. Solve for the result in the ***x*** direction and then solve for the result in the ***y*** direction. Take the final ***x*** and ***y*** and use Pythagorean Theorem to find the overall resultants.

If the object has momentum it also has kinetic energy.

Total energy is also conserved, but energy changes forms.

Perfectly elastic collision (An idealized unrealistic case)

Kinetic energy is conserved in this rare case.

Use these two equations together (System of 2 equations & 2 varibles).

$m_A v_{Ai} + m_B v_{Bi} = m_A v_{Af} + m_B v_{Bf}$

$$\frac{1}{2}m_A v_A{}^2{}_i + \frac{1}{2}m_B v_B{}^2{}_i = \frac{1}{2}m_A v_A 2_f + \frac{1}{2}m_B v_B 2_f$$

Inelastic Collision (The common type)

Kinetic energy is lost or dissipated.

There is less kinetic energy after the collision.

$K_{lost/dissipated} = \Sigma K_i - \Sigma K_f$

(Note this is the opposite of change in kinetic energy. Change in kinetic energy is $K_f - K_i$. The value is the same, but the sign is reversed.)

$$K_{lost/dissipated} = \left(\frac{1}{2}m_A v_A{}^2{}_i + \frac{1}{2}m_B v_B{}^2{}_i\right) - \left(\frac{1}{2}m_A v_A 2_f + \frac{1}{2}m_B v_B 2_f\right)$$

The kinetic energy lost often turns into heat from the impact

$K_{lost/dissipated} = mc\Delta T$

Circular Motion

The key to circular motion is to ask:

"What is causing it to stay in a circle?"

Centripetal means center seeking

The direction of motion is toward the center

Any force pointing to the center is a positive force.
Any force pointing away from the center is a negative force.

Force Centripetal is the sum of forces in these problems

It is not drawn on free body diagrams since it is the net force.
Any force (gravity, tension, friction, normal, magnetic, etc.) can contribute to F_c

Possible equations

$F_c = F_g$	To find minimum speed at the top of a roller coaster loop.
$F_c = F_f$	Object is revolving on a horizontal surface, or a car turning.
$F_c = F_T$	If a (horizontal) string spins the object in a horizontal circle.
$F_c = \sqrt{F_T{}^2 - F_g{}^2}$	If an object at the end of a string is spinning through the air and gravity pulls the string down from the horizontal.
$F_c = F_T + F_g$	An object (at the top) spinning at the end of a string in a vertical circle.
$F_c = F_T - F_g$	An object (at the bottom) spinning at the end of a string in a vertical circle.
$F_c = F_N$	Inside an amusement park ride (Gravitron)
$F_c = F_B$	For a charged particle in a magnetic field.

Substitute and solve.

$$F_c = m\frac{v^2}{r}$$

Velocity is Tangential

The instantaneous velocity is tangent to the circular motion.

$v = \dfrac{2\pi r}{T}$ — T is the period, the time for one revolution.

If the object is released (the force stops working) then the object will move at this velocity in a direction tangent to the circle at the time of the release.

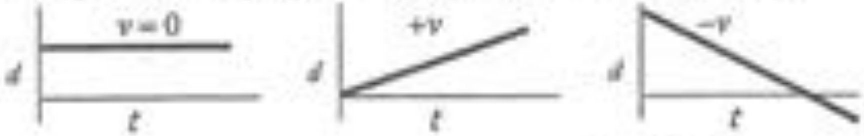
Rates and Graphing

A change in a variable as a function of time (in seconds).

In the graphed examples the *y* intercepts and slopes would depend on where the problem started and on how fast the rate is changing.

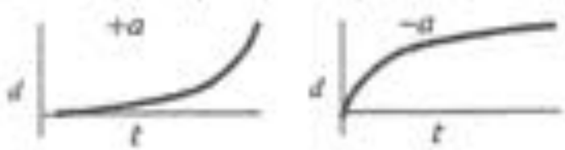
Constant Velocity: change in position $v = \frac{d}{t}$

Velocity is the slope (derivative) of distance time graph

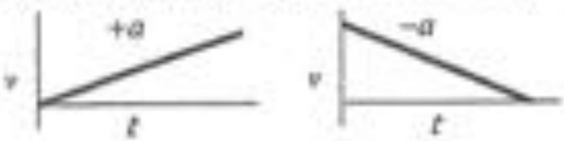


Acceleration: change in velocity $a = \frac{\Delta v}{t}$

Distance increases (or decreases) in an exponential manner.



Acceleration is the slope (derivative) of velocity time graph

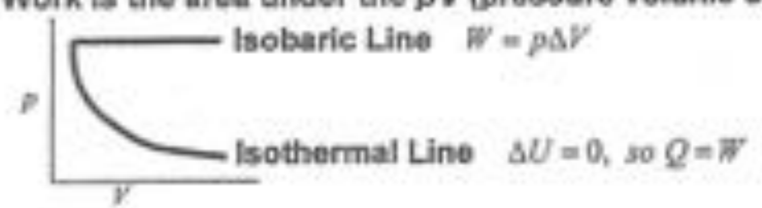


Areas Under Curves

Velocity is the area (integral) under the acceleration graph.
Displacement is the area (integral) under the velocity graph.

***** Work is the area under the force distance curve.**

***** Work is the area under the *pV* (pressure volume curve).**



Rates and Graphing

Power: Work (and any form of energy) done in a time *t* $P = \frac{W}{t}$

Remember you can convert directly to work (or energy) from power if you solve the problem using 1 second for time. (Example: 100 *W*, means 100 *J* in one second). If you get information about time later in the problem, just multiply by the amount of time to find the actual total work (or energy). Example: If the proceeding 100 *W* was delivered for 1 minute, then 100 *J* were delivered each second for 60 *s*. So 6000 *J* of work (energy) was done, used, or delivered.

Current: amount of charge moving through a point in a circuit $I = \frac{\Delta Q}{t}$

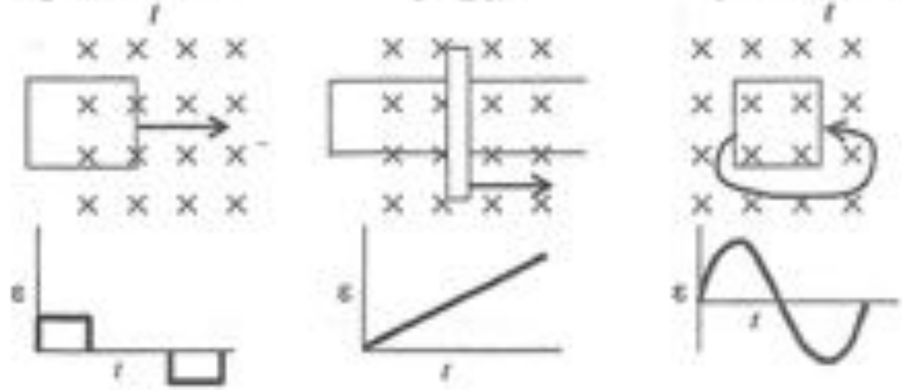
Current stays the same in a series circuit. All the resistors are in line. It's like a traffic jam on one road with no alternate routes. All the cars are going the same speed on the entire road, so the amount of cars passing any point in a certain time interval is the same everywhere.

Current adds in a parallel circuit. The electrons have multiple pathways to choose from. If 100 C arrive at a fork in the circuit they must split up. Due to conservation of charge, the amount of electrons in the parallel paths must add up to the amount of electrons arriving at the fork.

emf: change in flux (magnetic field thru an area) $\varepsilon = \frac{\Delta\phi}{t}$

Remember, current can only be generated by a changing flux. So a closed loop of wire must move through the field, or the loop must be getting larger, or the loop must be rotating.

Loop moved thru	Bar moved, enlarging loop	Loop rotates
$\varepsilon = \frac{B \cdot A\cos\theta}{t}$	$\varepsilon = B\ell v$	$\varepsilon = \frac{B \cdot A\cos\theta}{t}$



Winter Break Review

Significant figures - reflect the precision of the least precise measurement used in solving the problem. Usually not the answer provided by your calculator.

Distance and speed - scalars

Displacement and velocity - vectors

Acceleration - vector, if change of velocity, scalar if change of speed

Relationships of distance, velocity, time, and acceleration (when acceleration is constant)

$$\Delta x = \tfrac{1}{2}(v_i + v_f)\Delta t$$

$$\Delta x = v_i \Delta t + \tfrac{1}{2} a \Delta t^2$$

$$v_f = v_i + a \Delta t$$

$$v_f^2 = v_i^2 + 2a\Delta x$$

Newton's Three Laws:

1. Bodies at rest remain at rest and bodies in motion remain in motion unless acted upon by an external force.
2. The acceleration of an object is proportional to the net external force acting on the object and inversely proportional to the mass of the object. Simply stated: $\Sigma \mathbf{F} = m\mathbf{a}$
3. For every action there is an equal and opposite reaction.

Force is measured in newtons (N) ($kg \cdot m/s^2$)

Free body diagrams - isolate the object of interest and describe all of the forces acting upon it

Friction - force exerted at the interface of two bodies

$$\mathbf{F}_f = \mu \mathbf{N}$$

Normal force - force exerted on one body by another, perpendicular to the interface

Work - product of the magnitude of the component of a force along the direction of displacement and the displacement.

$$W_{net} = F_{net}\, d\,(\cos\theta)$$

Work is measured in joules (J) ($kg \cdot m^2/s^2$)

Kinetic energy - energy associated with an object in motion, dependent upon mass and speed

$$K = \tfrac{1}{2} mv^2$$

Kinetic energy is measured in joules (J)

Gravitational potential energy is the potential energy associated with an object due to its position relative to a gravitational source

$$U_g = mgh$$

Elastic potential energy is the stored energy in a stretched or compressed elastic object

$$U_{elastic} = \tfrac{1}{2} kx^2$$

Potential energy is measured in joules (J).

In the absence of friction, mechanical energy is conserved, although potential energy may change to kinetic energy and vice versa. Thus, we may say:

$$ME_i = ME_f$$

$$PE_1 + KE_1 = PE_2 + KE_2$$

The Work-Kinetic Energy Theorem states:

$$W_{net} = \Delta KE$$

$$ME_i = ME_f + W_{net}$$

Power is the rate at which work is performed.

$$P = \frac{W}{\Delta t}$$

An alternate form is:

$$P = Fv$$

Power is measured in watts (W) ($kg \cdot m^2/s^3$)

Linear momentum

$$\mathbf{p} = m\mathbf{v}$$

Momentum is a vector quantity with its direction matching the direction of the object's velocity.

$$\mathbf{F} = \frac{\Delta \mathbf{p}}{\Delta t}$$

From this, we develop the impulse-momentum theorem

$$\mathbf{F}\Delta t = \Delta \mathbf{p} \quad \text{or} \quad \mathbf{F}\Delta t = \Delta \mathbf{p} = m\mathbf{v}_f - m\mathbf{v}_i$$

In all interactions between isolated objects, momentum is conserved.

$$m_1v_{1,i} + m_2v_{2,i} = m_1v_{1,f} + m_2v_{2,f}$$

Elastic collisions - kinetic energy is conserved

$$\tfrac{1}{2}m_1v_{1,i}^2 + \tfrac{1}{2}m_2v_{2,i}^2 = \tfrac{1}{2}m_1v_{1,f}^2 + \tfrac{1}{2}m_2v_{2,f}^2$$

Inelastic collisions - kinetic energy is not conserved.

Center of mass - the point at which a body's mass may be considered to be concentrated to simplify calculations