Physics

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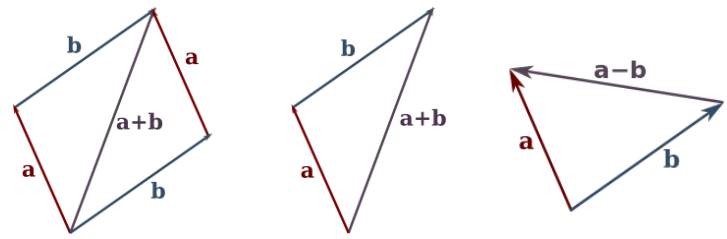
http://denisemeeks.com/science/notebooks/notebook_physics.pdf

Physics: Vector Addition

Vector	x-component	y component	angle
$\vec{A}$	$A_x = A\cos\theta$	$A_x = A\sin\theta$	$\theta = \frac{A_y}{A_x}$
$\vec{B}$	$B_x = B\cos\phi$	$B_x = B\sin\phi$	$\phi = \frac{B_y}{B_x}$
$\vec{R} = \vec{A} + \vec{B}$	$R_x = A_x + B_x$	$R_y = A_y + B_y$	$\vartheta = \frac{R_y}{R_x}$

Physics: Vector Representation



(Image sources: https://en.wikipedia.org/wiki/Euclidean_vector#/media/File:Vector_addition.svg, https://en.wikipedia.org/wiki/Euclidean_vector#/media/File:Vector_subtraction.svg, Benjamin D. Esham, public domain)

Physics: Newton's Laws of Motion

1. The law of inertia: every object will remain at rest or in uniform motion in a straight line unless compelled to change its state by the action of an external force.
2. Acceleration: the acceleration of an object is directly proportional to the net force acting on it and inversely proportional to its mass $\vec{F} = m\vec{a}$
3. Action-reaction: for every action there is an equal and opposite reaction; if object *A* exerts a force $\vec{F}_A$ on a second object *B*, then *B* exerts a force $\vec{F}_B$ on *A*, and the two forces are equal in magnitude and opposite in direction: $\vec{F}_A = -\vec{F}_B$

Physics: Newton's Universal Law of Gravitation

every point mass attracts every single other point mass by a force pointing along the line intersecting both points; the force is proportional to the product of the two masses and inversely proportional to the square of the distance between them

$$F = \frac{Gm_1m_2}{r^2} \quad \text{and} \quad F = mg = W \qquad W = \text{weight}$$

F = force between the masses

G = gravitational constant 6.674×10^{-11} N m/kg^2

m_1 = first mass in kilograms

m_2 = second mass in kilograms

r = distance between the centers of the masses in meters

Physics: Horizontal Kinematics Equations

$$x_f = x_i + v_i t + \frac{1}{2}at^2$$

$$v_f = v_i + at$$

$$v_f^2 = v_i^2 + 2a(x_f - x_i)$$

$$x_f = x_i + \frac{(v_i + v_f)t}{2}$$

x_i = initial displacement

x_f = final displacement

v_i = initial velocity

v_f = final velocity

a = acceleration

t = time

Physics: Vertical Kinematics Equations

$$y_f = y_i + v_i t + \frac{1}{2}gt^2$$

$$v_f = v_i + gt$$

$$v_f^2 = v_i^2 + 2g(y_f - y_i)$$

$$y_f = y_i + \frac{(v_i + v_f)t}{2}$$

y_i = initial displacement

y_f = final displacement

v_i = initial velocity

v_f = final velocity

g = -9.81 m/s

t = time

Physics: Linear Motion and Rotational Motion

Quantity	Linear	Rotational
mass and inertia	m	I
Newton's second law	$F = ma$	torque: $\tau = I\alpha$
momentum	$p = mv$	$L = I\omega = mvr\sin\theta$
work	$W = Fd$	$W = \tau\theta$
kinetic energy	$K = \frac{1}{2}mv^2$	$K = \frac{1}{2}I\omega^2$
power	$P = Fv$	$P = \tau\omega$

Physics: Friction and Work

static friction: $f_{s,\max} = \mu_s F_N \qquad 0 \le f_s \le f_{s,\max}$

kinetic friction: $f_k = \mu_k F_N$

work: $\Delta U =$ change in potential energy

conservative work: $W_c = -(\Delta U)$

ΔE_{mech} = change in mechanical energy

nonconservative work: $W_{nc} = \Delta E_{mech}$

total work: $W_{total} = \Delta K$

Physics: Projectile Motion (1)

	level target	target above	target below	horizontal projectile
parameter	equation			
x(t)	$v_0 t\cos\theta$			$v_0 t$
y(t)	$v_0 t\sin\theta - \frac{1}{2}gt^2$			$H - \frac{1}{2}gt^2$
$v_x(t)$	$v_0\cos\theta$			v_0
$v_y(t)$	$v_0\sin\theta - gt$			$-gt$
v(t)	$\sqrt{v_0^2 - 2gtv_0\sin\theta + g^2t^2}$			$\sqrt{v_0^2 + g^2t^2}$
v(y)	$\sqrt{v_0 - 2gy}$			$\sqrt{v_0 - 2g(H-y)}$

Physics: Projectile Motion (2)

	level target	target above	target below	horizontal projectile
parameter	equation			
H (height)	$\frac{v_0^2\sin^2\theta}{2g}$		$z + \frac{v_0^2\sin^2\theta}{2g}$	$\frac{1}{2}gt^2$
R (range)	$v_0 T\cos\theta$			$v_0 t$
	$\frac{v_0^2\sin 2\theta}{g}$	*	**	

* = $\frac{v_0\cos\theta}{g}\left[v_0\sin\theta + \sqrt{v_0^2\sin^2\theta - 2gz}\right]$

** = $\frac{v_0\cos\theta}{g}\left[v_0\sin\theta + \sqrt{2gz + v_0^2\sin^2\theta}\right]$

Physics: Projectile Motion (3)

	level target	target above	target below	horizontal projectile
parameter	equation			
T (total time)	$\frac{R}{v_0\cos\theta}$			
	$2v_0\sin\theta$	***	****	$\sqrt{\frac{2H}{g}}$
t_H (time at max height)	$\frac{v_0\sin\theta}{g} = \frac{T}{2}$			$T = 0$

z = height difference between launch and landing sites

*** = $\frac{v_0\sin\theta}{g} + \sqrt{\frac{2(H-z)}{g}}$ **** = $\frac{v_0\sin\theta}{g} + \sqrt{\frac{2H}{g}}$

Physics: Elastic Deformation

changing the length of a solid: $F = Y\left(\frac{\Delta L}{L_0}\right)A$

F = applied force Y = Young's modulus L_0 = initial length

A = cross-sectional area perpendicular to the applied force

shear deformation: $F = S\left(\frac{\Delta x}{L_0}\right)A$

S = shear modulus Δx = shear deformation

changing the volume of a solid: $\Delta P = -B\left(\frac{\Delta V}{V_0}\right)$

ΔP = change in pressure B = bulk modulus

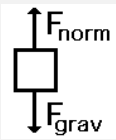
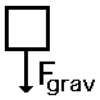
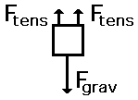
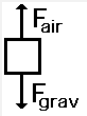
Physics: Mechanical Forces (1)

Contact forces	Notation
air resistance: related to object size and shape, usually ignored unless large surface area or high speeds	F_{air}
applied: usually pushing or pulling exerted by a person or by one object on another object	F_{app}
centripetal	$F_{cp} = mv^2/r$
gravitational: mass x acceleration of gravity	$F_{grav} = mg$
kinetic friction: kinetic friction coefficient x normal force	$f_K = \mu_K F_N$
normal: perpendicular to the surface of object motion	F_N
spring: product of the spring constant and change in length of the stretched object, Hooke's law $F_{spring} = -kx$	$F_{spring} = kx$
static friction: less than or equal to the product of the coefficient of static friction and the normal force	$f_S \le \mu_S F_N$
tension force: usually calculated by resolving other forces first	F_T or T

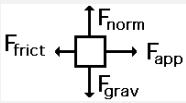
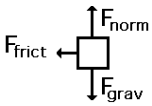
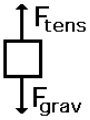
Physics: Mechanical Forces (2)

Conservative force: if the work done by a force in going from an arbitrary point A to an arbitrary point B is independent of the path
gravity
spring force
Nonconservative force: if the work done by a force in going from an arbitrary point A to an arbitrary point B is dependent of the path
friction
tension in a rope, cable, etc.
forces exerted by a motor
forces exerted by muscles

Physics: Free Body Diagrams (1)

an object at rest		a falling object, ignoring air resistance	
an object on a pulley or bar		an object gliding in the air	

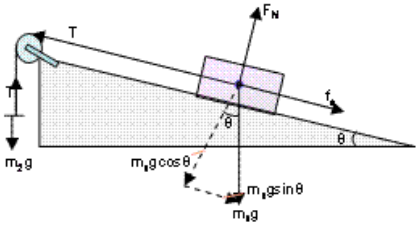
Physics: Free Body Diagrams (2)

an object pushed toward the right, along a surface, constant velocity or constant acceleration		an object coasting to the right and slowing down	
an object suspended from a rope		(Image sources: http://www.physicsclassroom.com/class/newtlaws/Lesson-2/Drawing-Free-Body-Diagrams)	

Physics: Steps for Drawing a Force Diagram

1. Identify the object(s). Each will require a separate diagram.
2. Select a coordinate system.
3. Identify all forces acting directly on the object.
4. Draw a dot or box to represent the object.
5. Draw a vector to represent each force, in the direction the force is being exerted, and clearly label each force.
6. Label as many angles as possible.
7. Set up a table and record all of the forces in the x and y directions, with the correct signs.
8. If the object is stationary or is moving at a constant velocity, the vectors should graphically add up to zero. If the object is accelerating, the sum of the vectors should produce a vector in the same direction as the acceleration.

Physics: Incline Free Body Diagram



(Image source: http://demos.smu.ca/index.php/demos/mechanics/141-free-body-diagram, Classroom Physics Demos , St. Mary's University)

Physics: Circular Motion (1)

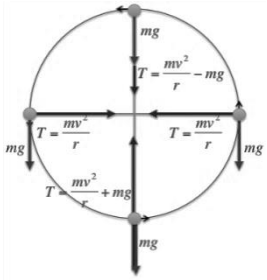
bottom of circle: $F_{c1} = F_{N1} - mg = \frac{mv_1^2}{r}$ $\quad F_{N1} = mg + \frac{mv_1^2}{r}$

$F_1 = \frac{mv_1^2}{r}$ $\quad K_1 = \frac{1}{2}mv_1^2$ $\quad U_1 = 0$

right side of circle:

$F_{c2} = F_{N2} = \frac{mv_2^2}{r}$ $\quad F_2 = m\sqrt{\frac{v_2^4}{r^2} + g^2}$

$K_2 = \frac{1}{2}mv_2^2$ $\quad U_2 = mgr$



(Image source: https://sites.google.com/a/morgan.k12.ga.us/mr-johnson/2nd-period/topic-6/6-1-circular-motion)

Physics: Circular Motion (2)

top of circle: $F_{c3} = F_{N3} + mg = \frac{mv_3^2}{r}$ $\quad F_{N3} = \frac{mv_3^2}{r} - mg$

$F_3 = \frac{mv_3^2}{r}$ $\quad K_3 = \frac{1}{2}mv_3^2$ $\quad U_3 = 2mgr$

left side of circle:

$F_{c4} = F_{N4} = \frac{mv_4^2}{r}$ $\quad F_4 = m\sqrt{\frac{v_4^4}{r^2} + g^2}$

$K_4 = \frac{1}{2}mv_4^2$ $\quad U_4 = mgr$

Physics: Simple Machines

lever: beam or rigid rod pivoted at a fixed hinge, or fulcrum., which can rotate on a point on itself

wheel and axle: wheel attached to a smaller axle that rotate together in which a force is transferred from one to the other

pulley: wheel on an axle or shaft designed to support movement and change of direction of a cable, rope or belt

inclined plane: flat supporting surface tilted at an angle, with one end higher than the other

wedge: triangular shaped tool, portable inclined plane, used to separate two objects or portions of an object, lift up an object, or hold an object in place

screw: converts rotational motion to linear motion, and a torque (rotational force) to a linear force

Physics: Energy

kinetic energy $E_k = \frac{1}{2}mv^2$ $\quad m$ = mass $\quad v$ = velocity

g = 9.81 m/s^2

potential energy $E_p = mgh$ $\quad h$ = height

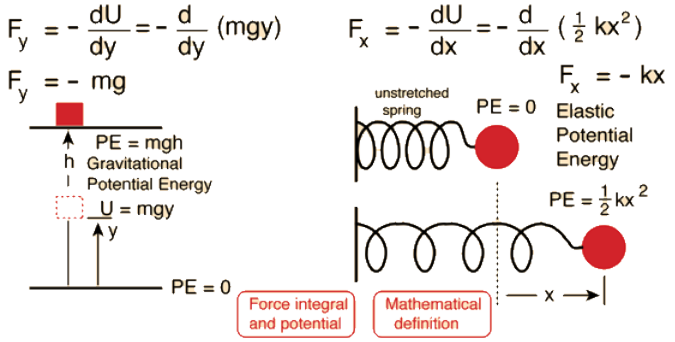
elastic energy $E_e = \frac{1}{2}kx^2$ $\quad k$ = spring constant

x = displacement

rotational energy $E_r = \frac{1}{2}I\omega^2$ $\quad I$ = rotational inertia

ω = angular velocity

Physics: Springs

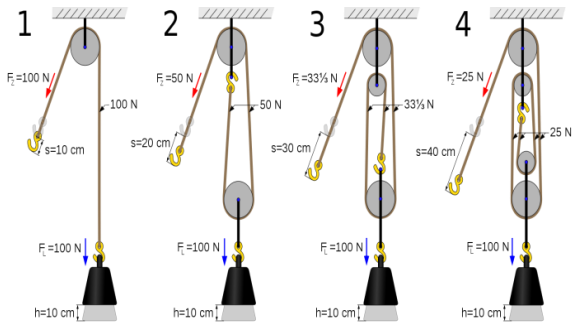


(Image source: http://hyperphysics.phy-astr.gsu.edu/hbase/pegrav.html, R. Nave, Georgia State University, used with permission)

Physics: Mechanical Advantage of Pulleys (1)

to calculate mechanical advantage MA: count the number of rope sections that support whatever object is being lifted (not counting the rope that is attached to the effort). For example, in a one pulley system the MA is 1; in a two pulley system the MA is 2. The more compound the pulley is the easier the load is to lift; lifting a 600 kg object with 2 pulleys would require use enough effort to pull 300 kg to lift the 600 kg object, meaning that the mechanical advantage = 2 (600/300)

Physics: Mechanical Advantage of Pulleys (2)



(Image source: https://en.wikipedia.org/wiki/Mechanical_advantage_device#/media/File:Four_pulleys.svg, Prolineserver, Tomia, CC BY 2.5)

Physics: Mechanical Advantage of Screws and Inclined Planes

theoretical mechanical advantage for a screw $MA = \frac{\pi d_m}{\ell}$

d_m = mean diameter of the screw thread

ℓ =lead of the screw thread

actual mechanical advantage of a screw system is greater, as a screwdriver or other screw driving system has a mechanical advantage

inclined plane MA = length of slope ÷ height of the slope

Physics: Mechanical Advantage of Gears

velocity $v = r_A\omega_A = r_B\omega_B$

r_A = radius of input gear *A* r_B = radius of output gear *B*

ω_A = angular velocity of gear *A* ω_B = angular velocity of gear *B*

$$\frac{r_A}{r_B} = \frac{\omega_B}{\omega_A} = \frac{N_B}{N_A}$$

N_A = number of teeth on gear *A* N_B = number of teeth on gear *B*

mechanical advantage $MAv = \frac{T_B}{T_A} = \frac{N_B}{N_A}$

T_A = torque of gear *A* T_B = torque of gear *B*

Physics: Momentum

conservation of linear momentum

$$m_1v_{i1} + m_2v_{i2} = m_1v_{f1} + m_2v_{f2}$$

velocity after elastic collision

$$v_{f1} = \frac{v_{i1}(m_1 - m_2) + 2m_2v_{i2}}{m_1 + m_2}$$

$$v_{f2} = \frac{v_{i2}(m_2 - m_1) + 2m_1v_{i1}}{m_1 + m_2}$$

velocity after inelastic collision $v_{f1} = v_{f2} = \frac{m_1v_{i1} + m_2v_{i2}}{m_1 + m_2}$

Physics: Center of Mass

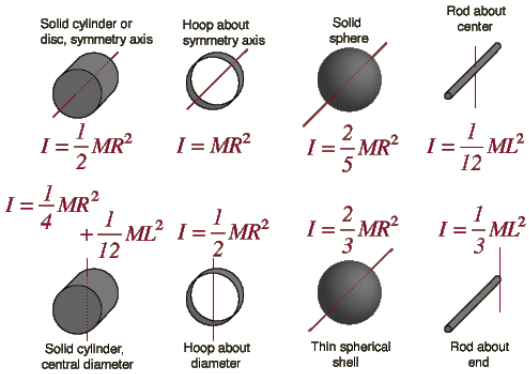
center of mass

$$X_{cm} = \frac{m_1x_1 + m_2x_2 + \ldots}{m_1 + m_2 + \ldots} = \frac{\sum mx}{M}$$

velocity of center of mass

$$V_{cm} = \frac{m_1\vec{v}_1 + m_2\vec{v}_2 + \ldots}{m_1 + m_2 + \ldots} = \frac{\sum m\vec{v}}{M}$$

Physics: Moment of Inertia



(Image source: http://hyperphysics.phy-astr.gsu.edu/hbase/mi.html, R. Nave, Georgia State University, used with permission)

Physics: Pendulums

period of a mass on a spring $T = 2\pi\sqrt{\frac{m}{k}}$

period of a simple pendulum $T = 2\pi\sqrt{\frac{L}{g}}$ L = length

period of a compound pendulum $T = 2\pi\sqrt{\frac{I}{mgR}}$

R = distance between pivot point and center of mass
I = moment of inertia

Foucault pendulum angular speed $\omega = 360^0 \sin\varphi / day$
φ = latitude

Physics: Circular and Harmonic Motion Equations

tangential velocity $v_T = r\omega$

tangential acceleration $a_T = r\alpha$

centripetal acceleration $a_c = \frac{v_T^2}{r} = r\omega^2$

total acceleration $a_{total} = \sqrt{a_T^2 + a_C^2}$

$v = -A\omega\sin(\omega t)$ $v_{\max} = A\omega$

$a = -A\omega^2\cos(\omega t)$ $a_{\max} = A\omega^2$

Physics: Waves

transverse waves: the displacement of individual particles is at right angles to the direction of wave propagation
longitudinal waves: the displacement of individual particles is parallel to the direction of wave propagation

frequency $f = \frac{1}{T}$ period $T = 2\pi/\omega$ velocity $v = f\lambda$

λ = wavelength

speed of a wave on a string $v = \sqrt{\frac{F}{m/L}}$ L = string length

vertical displacement in a wave $y(t) = A\cos\left(\frac{2\pi}{\lambda}x - \frac{2\pi}{T}t\right)$

Physics: Speed of Sound

speed of sound: is the distance travelled per unit time by a sound wave as it propagates through an elastic medium; in dry air at 20°C (68°F), the speed of sound is 1,130 feet per second / 343.2 meters per second (1,236 km/h; 768 mph; 667 kn), or a kilometer in 2.914 s or a mile in 4.689 s

speed of sound in dry air $v_S = 20.05\sqrt{T + 27.3.15}$ m/s

T = temperature in ^{0}C

speed of sound in an ideal gas $v_S = \sqrt{\frac{\gamma p}{\rho}} = \sqrt{\frac{\gamma RT}{M}} = \sqrt{\frac{\gamma kT}{m}}$

γ = ratio of specific heats c_P / c_V

p = pressure ρ = density R = 8.314 J/ mol K

T = temperature in K M = molar mass

k = Boltzmann constant 5.67 x 10^{-8} W/m^2 K^4 m = molecular mass

(Source: https://en.wikipedia.org/wiki/Speed_of_sound)

Physics: Sound Intensity and Doppler Effect

sound intensity $I = \frac{P}{A}$ P = pressure A = area

intensity level $\beta = (10\ db)\log(I/I_0)$ I_0 = 10^{-12} W/m^2

Doppler effect:

moving observer $f' = (1 \pm u/v)f$, f = frequency

plus observer approaching source, minus observer receding

moving source $f' = \left(\frac{1}{1 \mp u/v}\right)f$, f' = change in frequency

minus source approaching observer, plus source receding

Physics: Archimedes Principle

1. The buoyant force exerted on a submerged or floating body is equal to the weight of the fluid displaced by the body.
2. A floating body displaces a weight of fluid equal to its own weight; i.e., a floating body is in equilibrium. The center of buoyancy is located at the centroid of the displaced fluid volume. In the case of a body lying at the interface of two immiscible fluids, the buoyant force equals the sum of the weights of the fluids displaced by the body.

Physics: Fluids

density $\rho = \frac{m}{V}$ specific volume $V = \frac{1}{\rho}$

specific gravity $SG = \frac{\rho_{liquid}}{\rho_{water}}$, $SG = \frac{\rho_{gas}}{\rho_{air}}$

atmospheric pressure P_{atm} = 1.01 x 10^5 N/m^2 1 bar = 10^5 pascals

pressure $P = \frac{F}{A}$ A = area F = force

fluid pressure $P = P_0 + \rho g h$

buoyant force $F_B = \rho_{fluid} g V$ V = displaced fluid volume

Physics: Equation of Continuity and Bernoulli's Equation

equation of continuity: $\rho_1 A_1 v_1 = \rho_2 A_2 v_2$

ρ_1 and ρ_2 = fluid densities

A_1 and A_2 = cross-sectional areas

v_1 and v_2 = velocities

Bernoulli's equation:

$$P_1 + \frac{1}{2}\rho v_1^2 + \rho g y_1 = P_2 + \frac{1}{2}\rho v_2^2 + p g y_2$$

P_1 and P_2 = pressures

y_1 and y_2 = heights

Physics: Terminal Velocity in a Fluid

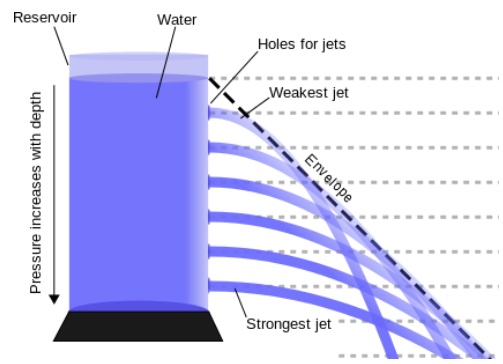
terminal velocity $v = \sqrt{\frac{2Dg(\rho_{sphere} - \rho_{fluid})}{3C_D \rho_{fluid}}}$

D = sphere diameter $C_D = \frac{24}{\mathrm{Re}}$ Re = Reynolds number

if the spherical particle is very small use Stoke's law

$$v = \frac{D^2(\rho_{sphere} - \rho_{fluid})}{18\mu} x \frac{g}{g_c}$$

Physics: Toricelli's Law



the speed of efflux,*v*, of a fluid through a sharp-edged hole at the bottom of a tank filled to a depth *h* is the same as the speed that a body would acquire in falling freely from a height *h*

$v = \sqrt{2gh}$

(Image source: https://en.wikipedia.org/wiki/Torricelli%27s_law#/media/File:TorricelliLawDiagram.svg , Matt Cook, CC BY-SA 4.0)

Physics: Linear and Volumetric Expansion

linear expansion $\Delta L = \alpha L_0 \Delta T$

α = coefficient of linear expansion L_0 = initial length

area expansion $\Delta A = 2\alpha A_0 \Delta T$

volume expansion $\Delta V = \beta V_0 \Delta T$ $\beta = 3\alpha$

β = coefficient of volume expansion V_0 = initial volume

specific heat $c = \frac{Q}{m\Delta T}$ Q = heat m = mass

Physics: Conduction and Convection

conduction: transfer of heat (internal energy) by microscopic collisions of particles and movement of electrons within a body rather than between bodies.

$Q = kA\left(\frac{\Delta T}{L}\right)t$ Q = heat k = thermal conductivity

ΔT = change in temperature L = length

convection: movement of groups of molecules within fluids such as liquids or gases, and within non-molten solid that deforms by viscous flow; takes place through advection, diffusion, or both

Physics: Carnot Cycle and Entropy

efficiency $e = \frac{W}{Q_H} = \frac{Q_H - Q_C}{Q_H} = 1 - \frac{Q_C}{Q_H}$

Q_H = hot reservoir heat Q_C = cold reservoir heat

coefficient of performance $COP = \frac{Q_C}{W}$

change in entropy $\Delta S = \frac{Q}{T}$

Physics: Conservation of Energy

Conservation of Energy: in a system with no heat exchange with the surroundings, the heat that flows out of one object equals the heat that flows into a second object

Physics: Radiation and Newton's Law of Cooling

radiation: electromagnetic radiation generated by the thermal motion of charged particles in matter; all matter with a temperature greater than absolute zero emits thermal radiation.

Stefan-Boltzmann constant σ = 5.67 x 10^{-8} W/m^2 K^4

$P_{net} = e\sigma A(T^4 - T_s^4)$ P_{net} = net radiated power

e = emissivity A = area

T = object temperature T_s = temperature of surroundings

temperatures in K

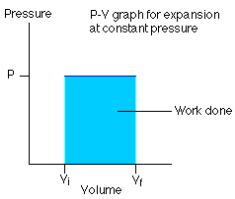
Newton's law of cooling $T(t) = T_s + (T(0) - T_s)e^{-rt}$

Physics: Laws of Thermodynamics

- Zeroth law: If two systems are in thermal equilibrium with a third system, they are in thermal equilibrium with each other.
- First law: When energy passes, as work, as heat, or with matter, into or out from a system, the system's internal energy changes in accordance with the law of conservation of energy.
- Second law: In a natural thermodynamic process, the sum of the entropies of the interacting thermodynamic systems increases.
- Third law: The entropy of a system approaches a constant value as the temperature approaches absolute zero. With the exception of non-crystalline solids (glasses) the entropy of a system at absolute zero is typically close to zero, and is equal to the logarithm of the product of the quantum ground states.

Physics: Isobaric Thermodynamics

isobaric (constant pressure) $W = P\Delta V = nR\Delta T$



$$\Delta U = Q - P\Delta V = \frac{3}{2}nR\Delta T$$

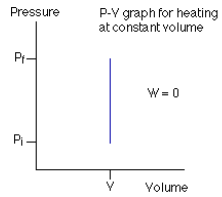
$$Q = \Delta U + P\Delta V = \frac{5}{2}nR\Delta T$$

W = work ΔU = change in internal energy Q = heat

(Image source: http://physics.bu.edu/~duffy/py105/Firstlaw.html, A. Duffy)

Physics: Isochoric Thermodynamics

isochoric (constant volume) $W = 0$



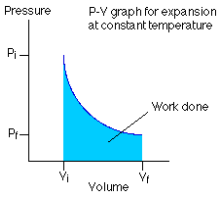
$$\Delta U = Q = \frac{3}{2}nR\Delta T$$

$$Q = \Delta U = \frac{3}{2}nR\Delta T$$

(Image source: http://physics.bu.edu/~duffy/py105/Firstlaw.html, A. Duffy)

Physics: Isothermal Thermodynamics

isothermal (constant temperature) $P_iV_i = P_fV_f = nRT$



$$W = Q = nRT\ln\left(\frac{V_f}{V_i}\right) = P_iV_i\ln\left(\frac{V_f}{V_i}\right)$$

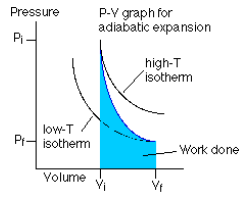
$$\Delta U = 0$$

$$Q = W = nRT\ln\left(\frac{V_f}{V_i}\right) = P_iV_i\ln\left(\frac{V_f}{V_i}\right)$$

(Image source: http://physics.bu.edu/~duffy/py105/Firstlaw.html, A. Duffy)

Physics: Adiabatic Thermodynamics

adiabatic (no heat flow) $P_iV_i^{\gamma} = P_fV_f^{\gamma}$,



$\gamma = \frac{5}{3}$ for monatomic ideal gas

$$W = -\Delta U = \frac{-3}{2}nR\Delta T$$

$$\Delta U = -W = \frac{3}{2}nR\Delta T$$

$$Q = 0$$

(Image source: http://physics.bu.edu/~duffy/py105/Firstlaw.html, A. Duffy)

Physics: Spherical Mirrors

spherical mirrors:

convex $F = -\frac{1}{R}$

concave $F = \frac{1}{R}$

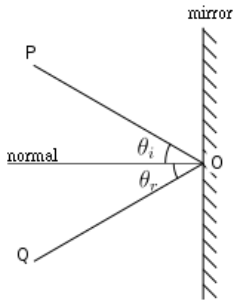
F = focal length R = mirror radius C = center of curvature

Physics: Mirrors

convex mirror object location	image orientation	image size	image type
arbitrary	upright	reduced	virtual
concave mirror object location	**image orientation**	**image size**	**image type**
beyond *C*	inverted	reduced	real
at *C*	inverted	same as object	real
between *F* and *C*	inverted	enlarged	real
just beyond *F*	inverted	approaching infinity	real
just inside *F*	upright	approaching infinity	virtual
between mirror and *F*	upright	enlarged	virtual

Physics: Reflection

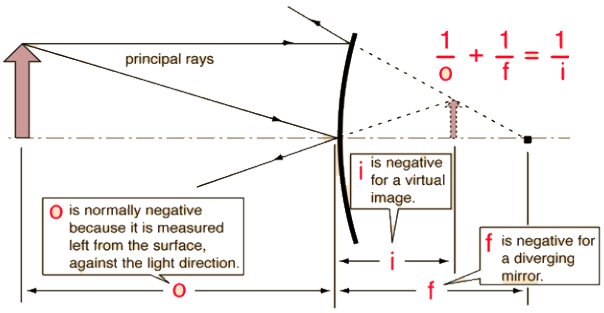
reflection: change in direction of a wavefront at an interface between two different media so that wavefront returns into the medium from which it originated; includes reflection of light, sound and water waves; law of reflection states that for specular reflection angle of incidence equals angle of reflection



(Image source: https://en.wikipedia.org/wiki/Reflection_(physics)#/media/File:Reflection_angles.svg, Arvelius, CC BY-SA 3.0)

Physics: Convex Mirrors

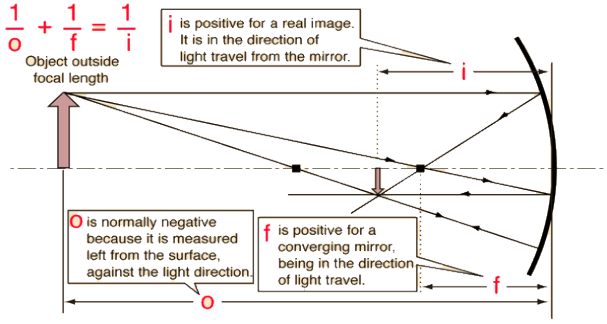
convex mirrors:



(Image source: http://hyperphysics.phyastr.gsu.edu/hbase/geoopt/mirray.html, R. Nave, Georgia State University, used with permission)

Physics: Concave Mirrors

concave mirrors:



(Image source: http://hyperphysics.phyastr.gsu.edu/hbase/geoopt/mirray.html, R. Nave, Georgia State University, used with permission)

Physics: Refraction and Snell's Law

index of refraction $v = \frac{c}{n}$ v = velocity of light through a substance

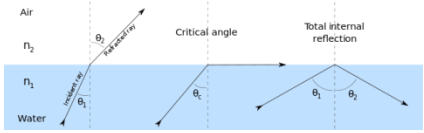
n = substance index of refraction c = 3.00 x 10^8 meters/second

Snell's law $n_1 \sin\theta_1 = n_2 \sin\theta_2$

n_1 and n_2 = indexes of refraction of the two substances

θ_1 = angle of incidence

θ_2 = angle of refraction



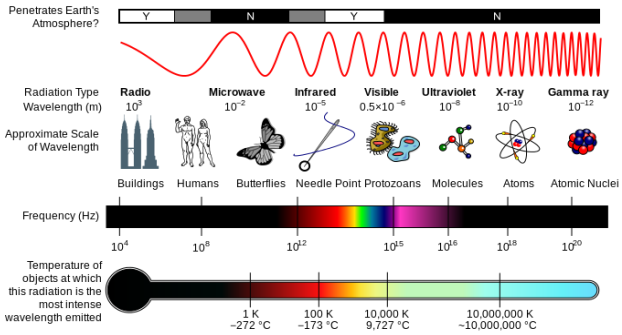
critical angle for total internal reflection $\theta_C = \frac{n_2}{n_1}$

(Image source: https://en.wikipedia.org/wiki/Reflection_(physics)#/media/File:RefractionReflextion.svg, Josell7, CC BY-SA 3.0))

Physics: Lenses

convcave lens object location	image orientation	image size	image type
arbitrary	upright	reduced	virtual
convex lens object location	**image orientation**	**image size**	**image type**
beyond *F*	inverted	reduced or enlarged	real
just beyond *F*	inverted	approaching infinity	real
just inside *F*	upright	approaching infinity	virtual
between lens and *F*	upright	enlarged	virtual

Physics: Spectrum



(Image source: https://en.wikipedia.org/wiki/Spectrum#/media/File:EM_Spectrum_Properties_edit.svg, Inductiveload, NASA, CC BY-SA 4.0)

Physics: Energy Quanta and Photoelectric Effect

energy $E = h\upsilon = \frac{hc}{\lambda}$

Planck's constant h = 6.626196 x 10^{-34} J s

υ = frequency of electromagnetic radiation

c = speed of light

λ = wavelength of electromagnetic radiation

photoelectric effect: $h\upsilon = \phi + \frac{1}{2}mv^2$

Physics: Heisenberg Uncertainty Principle, Schrödinger Wave Equation, De Broglie Equation

Heisenberg uncertainty principle: $\Delta x \Delta p \geq \frac{h}{4\pi}$

Δx = change in location Δp = change in momentum

h = Planck's constant

Schrödinger wave equation: $\Psi = A\exp\left[2\pi i\left(\frac{x}{\lambda} - vt\right)\right]$

De Broglie equation: relationship between particle and wave properties $\lambda = \frac{h}{p}$

Physics: Atomic Particles

particle	kg	u	charge
alpha, α	6.6416×10^{-27}	4.00153	+2
beta, β	9.1091×10^{-31}	5.48597×10^{-4}	-1
deuteron, d	3.3421×10^{-27}	2.01355	+1
electron, e	9.1091×10^{-31}	5.48597×10^{-4}	-1
gamma ray, γ	0	0	0
neutrino, ν	0	0	0
neutron, n	1.6748×10^{-27}	1.0086654	0
positron, +e	9.1091×10^{-31}	5.48597×10^{-4}	+1
proton, p	1.6725×10^{-27}	1.00727663	+1

Physics: Maxwell's Equations (1)

Gauss' law for electricity: electric flux out of any closed surface is proportional to the total charge enclosed within the surface

integral form $\oint \vec{E} \cdot d\vec{A} = \frac{q}{\varepsilon_0}$ differential form $\nabla \cdot E = \frac{\rho}{\varepsilon_0} = 4\pi k\rho$

$\vec{E}$ = electric field $\vec{A}$ = area q = charge

ε_0 = permittivity k = constant ρ =charge density

Gauss' law for magnetism: net magnetic flux out of any closed surface is zero

integral form $\oint \vec{B} \cdot d\vec{A} = 0$ differential form $\nabla \cdot B = 0$

$\vec{B}$ = magnetic field

Physics: Maxwell's Equations (2)

Faraday's law of induction: line integral of the electric field around a closed loop is equal to the negative of the rate of change of the magnetic flux through the area enclosed by the loop

integral form $\oint \vec{E} \cdot d\vec{s} = \frac{-d\Phi_B}{dt}$ differential form $\nabla x E = \frac{-\partial B}{\partial t}$

Ampere's law: line integral of the magnetic field around a closed loop is proportional to the electric current flowing through the loop

integral form $\oint \vec{B} \cdot d\vec{s} = \mu_0 i + \frac{1}{c^2}\frac{\partial}{\partial t}\int \vec{E} \cdot d\vec{A}$ μ_0 = permeability

differential form $\nabla x B = \frac{4\pi k}{c^2} J + \frac{1}{c^2}\frac{\partial E}{\partial t}$ i = electric current

$\vec{s}$ = enclosed loop length Φ_B = magnetic flux

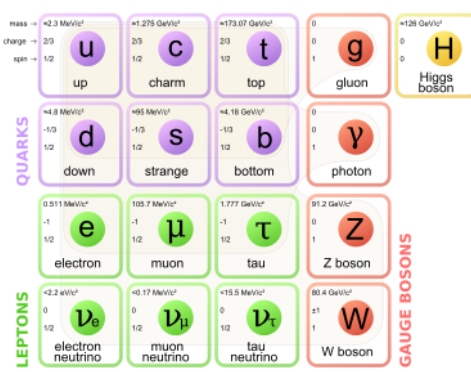
c = speed of light J = current density

Physics: Fundamental Forces

property/ interaction	gravitation	weak (electroweak)	electro-magnetic (electroweak)	strong: fundamental	strong: residual
acts on	mass - energy	flavor	electric charge	color charge	atomic nuclei
particles experiencing	all	quarks, leptons	charged particles	quarks, gluons	hadrons
particles mediating	gravitons (theoretical)	W and Z bosons	photons	gluons	mesons
strength in the scale of quarks	10^{-41}	10^{-4}	1	60	N/A to quarks
strength in the scale of protons/neutrons	10^{-36}	10^{-7}	1	N/A to hadrons	20

(Source: https://en.wikipedia.org/wiki/Standard_Model)

Physics: Standard Model of Particle Physics



(Image source: https://en.wikipedia.org/wiki/Standard_Model#/media/File:Standard_Model_of_Elementary_Particles.svg, MIssMJ, public domain)