Physics 10154 Formula Sheet

Unit Conversions

Length 1 meter = 39.37 in = 3.281 ft
1 km = 0.621 miles
1 mile = 5280 ft = 1609 meters

Time 1 hour = 3600 sec
1 year = 3.16×10^{7} sec

Volume 1 Liter = 1000 cm^3 = 10^{-3} m^3
1 gallon = 3.786 L = 231 in^3

Force 1 Newton = 0.2248 pounds

Energy 1 Joule = 0.239 calories = 0.738 ft-lb
1 eV = 1.6×10^{-9} J
1 kW·hr = 3.6×10^{6} J

Pressure 1 atm = 1,013 N/m² (Pascals)

Angle $180^{\circ} = \pi$ rad = 0.5 revolutions

Physical Constants

Boltzmann's Constant $k_B = 1.38 \times 10^{-23}$ J/K

Electron mass : $m_e = 9.11 \times 10^{-31}$ kg

Gravitational Constant : $G = 6.67 \times 10^{-11}$ N·m²/kg²

Mass of Earth $M_E = 5.98 \times 10^{24}$ kg

Neutron mass $m_n = 1.67 \times 10^{-27}$ kg

Proton mass $m_p = 1.67 \times 10^{-27}$ kg

Radius of Earth $R_E = 6.38 \times 10^{6}$ m

Speed of light $c = 3.0 \times 10^{8}$ m/s

Ideal Gas Constant $R = 8.31$ J/mol-K = .0821 L·atm/mol-K

Boltzmann's Constant $k_B = 1.38 \times 10^{-23}$ J/K

Stefan-Boltzmann Constant $\sigma = 5.67 \times 10^{-8}$ W/m²K⁴

Avogadro's Number $N_A = 6.023 \times 10^{23}$ molecules/mole

Motion with Constant Acceleration

Average velocity: $\vec{v}_{avg} = \frac{\Delta \vec{x}}{\Delta t}$ or $\bar{v} = \frac{\Delta \vec{x}}{\Delta t}$

Multi-part motion: $\Delta x_1 = \bar{v}_1 t_1, \Delta x_2 = \bar{v}_2 t_2, \ldots, \Delta x_{TOT} = \bar{v}_{TOT} t_{TOT}$

Acceleration $\vec{a} = \frac{\Delta \vec{v}}{\Delta t}$

$= \frac{\vec{v} - \vec{v}_0}{t}$ where $\vec{v}$ = final velocity

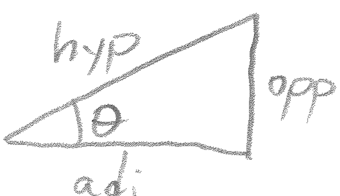
$\vec{v}_0$ = initial velocity

If $\vec{a}$ = constant, then $\vec{v}_{avg} = \frac{\vec{v} + \vec{v}_0}{2}$

5 equations

5 equations	Missing	Units
$\Delta x = \frac{1}{2}(v + v_0)t$	a	Δx = meters
$v = v_0 + at$	Δx	v = meters/sec
$\Delta x = v_0 t + \frac{1}{2}at^2$	v	a = m/s^2
$\Delta x = vt - \frac{1}{2}at^2$	v_0	
$v^2 = v_0^2 + 2a\Delta x$	t	

Basic Trig

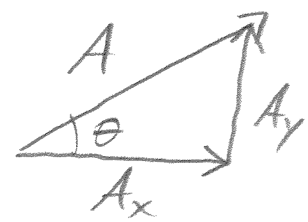


$opp^2 + adj^2 = hyp^2$

$\cos\theta = adj/hyp$

$\sin\theta = opp/hyp$

$\tan\theta = opp/adj$



$A_x = |A| \cos\theta$

$A_y = |A| \sin\theta$

$\theta = \tan^{-1}(|A_y/A_x|)$

Free fall (Ballistic motion)

$\vec{a} = 9.8$ m/s^2, downward $\quad a_x = 0 \quad a_y = 9.8$ m/s^2, down

Forces

Units: 1 Newton (N) = 1 kg·m/s^2

Newton's 2nd Law: $\Sigma \vec{F} = m\vec{a}$

$\Rightarrow \Sigma F_x = ma_x$ or $\Sigma F_{\parallel} = ma_{\parallel}$

$\Sigma F_y = ma_y \qquad \Sigma F_{\perp} = ma_{\perp}$

1st Law: If $\Sigma \vec{F} = 0$, then $\vec{a} = 0$

3rd Law: Action-Reaction (Normal + Static Friction).

Force Definitions
– magnitude, direction

<u>Gravity</u>: $F_g = |mg|$, downward where $g = 9.8\ m/s^2$

<u>Applied</u>: F_{App} = (varies), (varies)

<u>Tension</u>: F_T = (varies), inward from each end of a rope/string, equal + opposite.

<u>Normal</u>: F_N = sum of all other perpendicular forces ($|\Sigma F_\perp|$), dir: $\perp$ to + out of surface

<u>Static Friction</u> = sum of all other parallel forces ($|\Sigma F_\parallel|$), dir: opposite the sum $\Sigma F_\parallel$

Max value: $F_{SF,MAX} = |\mu_s F_N|$ where μ_s = coefficient of static friction

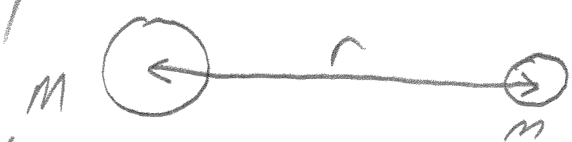
<u>Kinetic Friction</u> $= |\mu_k F_N|$, opposes motion

<u>Spring</u> $= |k \Delta x|$, restoring where k = spring constant (N/m), and Δx = displacement from equilibrium

<u>"Proper" Gravity</u> $F_G = \left|\dfrac{GMm}{r^2}\right|$ where $G = 6.67 \times 10^{-11}\ \frac{N \cdot m^2}{kg^2}$

dir: attractive

r connects centers of $M + m$.



<u>"Centrifugal"</u> $F_C = \left|\dfrac{mv^2}{r}\right|$, radially outward

or $|mr\omega^2|$

<u>Buoyancy</u> $F_B = |\rho_f V_f g|$, upward ρ_f = fluid density

V_f = displaced fluid volume

Energy and Work
Units: 1 Joule = 1 $\frac{kg\,m^2}{s^2}$

1 Joule/sec = 1 Watt

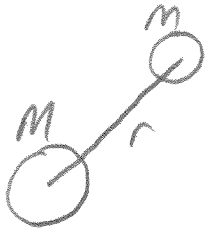
<u>Work done by a force</u> (W_F)

Method 1: $W_F = |\vec{F}| \cdot |\vec{\Delta s}| \cdot \cos\theta$

Method 2: $W_F = -\Delta U_F$ or $U_i - U_f$

Method 3: $\underbrace{W_{F1}}_{\text{known}} + \underbrace{W_{F2}}_{\text{known}} + W_{F3} = \underbrace{W_{TOT}}_{\text{known}}$ + solve for W_{F3}

$\boxed{\text{Potential Energy } (U)}$ – Units: Joules



Gravitational $U_{grav} = mgy$ or mgh

"Proper" Gravitational $U_{grav} = -\frac{GMm}{r}$

where $G = 6.67 \times 10^{-11}\ N \cdot m^2/kg^2$

Spring – $U_{spr} = \frac{1}{2} k (\Delta x)^2$ Δx = displacement from equilibrium

k = spring constant (N/m)

$\boxed{\text{Work}}$ Units: Joules

Work-Energy Theorem $W_{TOT} = \Sigma W_F = \Delta K$

where $K = \frac{1}{2} m v^2$, Kinetic Energy

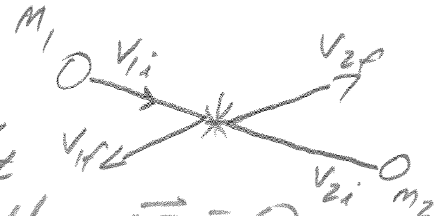
Mechanical Energy $E = K + U$

$\boxed{\text{Power}}$ Units: $\frac{\text{Joules}}{\text{sec}}$ = Watts

Power = Work/time

$= |\vec{F}| \cdot |\vec{v}| \cdot \cos\theta$

$\boxed{\text{Momentum}}$ $\vec{p} = m\vec{v}$ Units: $kg \cdot m/sec$



Impulse $\Delta\vec{p} = \vec{F}_{avg} \Delta t$, or $\vec{F}_{avg} = \Delta\vec{p}/\Delta t$

Momentum Conservation If $\Sigma \vec{F}_{ext} = 0$, then $\Delta\vec{p} = 0$

If $\Delta\vec{p} = 0$, then $m_1 v_{1i,x} + m_2 v_{2i,x} = m_1 v_{1f,x} + m_2 v_{2f,x}$

and $m_1 v_{1i,y} + m_2 v_{2i,y} = m_1 v_{1f,y} + m_2 v_{2f,y}$

If masses stick after collision, then $\vec{v}_{1f} = \vec{v}_{2f} = \vec{v}_f$

Elastic Collisions

If $\Delta\vec{p} = 0$ + $\Delta K = 0$, then

$$v_{1f} = \frac{m_1 - m_2}{m_1 + m_2} v_{1i} + \frac{2m_2}{m_1 + m_2} v_{2i}$$

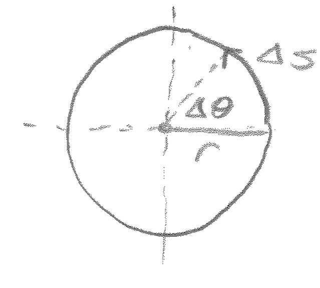
$$v_{2f} = \frac{2m_1}{m_1 + m_2} v_{1i} + \frac{m_2 - m_1}{m_1 + m_2} v_{2i}$$

If $m_1 = m_2$,

$v_{1f} = v_{2i}$

$v_{2f} = v_{1i}$

Angular Motion



Angular displacement (rad): $\Delta\theta = \frac{\Delta s}{r}$

Angular velocity (rad/s): $\omega = \frac{v}{r}$

Angular acceleration (rad/s²): $\alpha = \frac{a_{tan}}{r}$

Centripetal acceleration (m/s²): $a_c = \frac{v^2}{r}$ or $r\omega^2$, radially inwar

Motion with constant α

$\Delta\theta = \frac{1}{2}(\omega + \omega_0)t$

$\omega = \omega_0 + \alpha t$

$\Delta\theta = \omega_0 t + \frac{1}{2}\alpha t^2$

$\Delta\theta = \omega t - \frac{1}{2}\alpha t^2$

$\omega^2 = \omega_0^2 + 2\alpha\Delta\theta$

Orbits

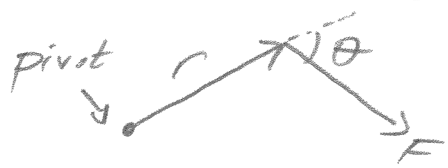
$2\pi r_{orbit} = V_{orbit} T$ ← period (se

$V_{orbit} = \sqrt{\frac{GM}{r_{orbit}}}$ M = central ma
$G = 6.67 \times 10^{-11}$

Kepler's 3rd Law: $T^2 = \left(\frac{4\pi^2}{GM}\right) r_{orbit}^3$

Torque

Units: N·m



$|\vec{\tau}| = |\vec{r}| \cdot |\vec{F}| \cdot \sin\theta$

+ if ccw, − if cw

Static Equilibrium: $\Sigma F_x = \Sigma F_y = \Sigma \tau = 0$

Moment of Inertia r = distance to axis, R = radius of object

point mass: $I = Mr^2$ solid cylinder: $I = \frac{1}{2}MR^2$ Units:

ring: $I = MR^2$ sphere: $I = \frac{2}{5}MR^2$ kg·m²

Newton's 2nd Law (Angular): $\Sigma\vec{\tau} = I\vec{\alpha}$

Rotational Motion

$V_{tan} = r\omega$ or $\omega = V_{tan}/r$

Kinetic Energy $K = \underbrace{\frac{1}{2}mv^2}_{\text{translation}} + \underbrace{\frac{1}{2}I\omega^2}_{\text{rotation}}$ Units: Joules

Angular Momentum Units: kg·m/sec

$\vec{L} = I\vec{\omega}$

Just as $\vec{F} = \frac{\Delta\vec{p}}{\Delta t}$, so is $\vec{\tau} = \frac{\Delta\vec{L}}{\Delta t}$

and if $\Sigma\vec{F}_{ext} = 0$, $\Delta\vec{p} = 0$. Also, if $\Sigma\vec{\tau}_{ext} = 0$, $\Delta\vec{L} = 0$

Conservation If $\Delta\vec{L} = 0$, $I_1\omega_{1i} + I_2\omega_{2i} = I_1\omega_{1f} + I_2\omega_{2f}$

Fluids

<u>Density</u> $\rho = {}^{Mass}/_{Volume}$ (Units: kg/m^3)

Since $m = \rho V$, $F_{grav} = mg = \rho V g$

<u>Pressure</u> $P = {}^{Force}/_{Area}$ (Units: N/m^2 or Pascals)

<u>Pascal's Principle</u> $P_{bot} = P_{top} + \rho g h$ ($P_{bot} - P_{top}$ = gauge pressure)

<u>Continuity</u>: $A_1 v_1 = A_2 v_2$ A = cross-sectional area (m^2)

where $Q = Av$ = flow rate (m^3/s) v = fluid velocity (m/s)

<u>Bernoulli's Equation</u>: $P_{bot} + \rho g y_{bot} + \frac{1}{2}\rho v_{bot}^2 = P_{top} + \rho g y_{top} + \frac{1}{2}\rho v_{top}^2$

or $(P_{bot} - P_{top}) + \rho g (y_{bot} - y_{top}) + \frac{1}{2}\rho(v_{bot}^2 - v_{top}^2) = 0$

Thermal Physics

- Temperature Conversions $T_F = \frac{9}{5}T_C + 32$

$T_C = \frac{5}{9}(T_F - 32)$

$T_K = T_C + 273$

Thermal Expansion

<u>Length</u>: $\Delta L = L_0 \alpha \Delta T$ α = linear expansion coefficient

<u>Area</u>: $\Delta A = A_0(2\alpha)\Delta T$ or $A_0 \beta \Delta T$ β = area exp. coefficient

<u>Volume</u>: $\Delta V = V_0(3\alpha)\Delta T$ or $V_0 \gamma \Delta T$ γ = volume exp. coefficient

Ideal Gas Law

$PV = NRT$

$PV = nk_B T$

$n = {}^{m}/_{M} = {}^{N}/_{N_A}$

P = Pressure (Pa)

V = Volume (m^3)

T = Temperature (K)

n = # of moles

N = # of molecules

m = mass of entire gas

M = molar mass (kg/mol)

R = ideal gas constant, k_B = Boltzmann's constant

Calorimetry

<u>Heat</u>: Q (Units: Joules)

<u>Specific heat</u>: c (Units: $J/kg \cdot {}^\circ C$)

$\Delta Q = \underset{\text{mass}}{m}\, \underset{\text{specific heat}}{c}\, \underset{\text{in }^\circ C\text{ or K}}{\Delta T}$

<u>Finding thermal equilibrium</u> $\Delta Q_1 + \Delta Q_2 + \Delta Q_3 + \ldots = 0$

<u>Phase changes</u> $\Delta Q = \pm m L_f$ (liquid ↔ solid)

$\Delta Q = \pm m L_v$ (liquid ↔ gas)

Calorimetry Useful Values

Specific heats:

- ice: $c_{ice} = 2090\ J/kg\cdot°C$
- water: $c_{water} = 4186\ J/kg\cdot°C$
- steam: $c_{steam} = 2010\ J/kg\cdot°C$
- Aluminum: $c_{Al} = 900\ J/kg\cdot°C$
- Copper: $c_{Cu} = 387\ J/kg\,°C$
- Iron: $c_{Fe} = 448\ J/kg\,°C$

Latent heats

L_f (fusion) for water $= 333{,}000\ J/kg$

L_v (vaporization) for water $= 2.26 \times 10^6\ J/kg$

Heat Transfer - Units: Joules/sec or Watts

Conductive heat transfer: Power $= \dfrac{\Delta Q}{\Delta t} = \dfrac{A\Delta T}{R\text{-value}}$

R-value $= \dfrac{l_1}{k_1} + \dfrac{l_2}{k_2} + \dfrac{l_3}{k_3} + \ldots$ for multiple layers

where A = surface area

l_1, l_2, l_3, etc = thickness (meters) of each layer

k_1, k_2, k_3, etc = thermal conductivity of each layer (Units: Joules/sec$\cdot$m$\cdot$°C)

Radiative heat transfer: Power $= \sigma A e (T^4 - T_0^4) = \dfrac{\Delta Q}{\Delta t}$

where σ = Stefan-Boltzmann constant

A = surface area

e = emissivity (between 0-1)

T_0 = Temperature of surroundings

T = Temperature of object

Thermodynamics

pressure ↓ change in volume ↙

Work done by a gas: $W_{by\ gas} = P\Delta V$

Work done on a gas: $W_{on\ gas} = -P\Delta V$

Internal energy of a gas: U (Joules)

Laws of Thermodynamics

Let Q = heat added to a gas (or system)

$$\Delta U = Q - W_{by\ gas}$$

or $\Delta U = Q + W_{on\ gas}$

Also, $\Delta U = 0$ for a cyclic process in P, V

Harmonic Motion

Spring period $T = 2\pi\sqrt{\frac{m}{k}}$ m = mass on spring (kg), k = spring constant (N/m)

Pendulum period $T = 2\pi\sqrt{\frac{l}{g}}$ l = pendulum length (m), g = gravitational acceleration (on Earth, $g = 9.8\ m/s^2$)

Frequency $f = \frac{1}{T}$ (Hertz)

Angular frequency $\omega = \frac{2\pi}{T}$ (rad/sec, also angular velocity)

Spring Oscillations

A = Amplitude (maximum possible displacement or x_{max})

Kinetic Energy $K = \frac{1}{2}mv^2$

Potential Energy $U = \frac{1}{2}kx^2$

Total Mechanical Energy $E = K + U = \frac{1}{2}kA^2$

Spring velocity: $v = \pm\sqrt{\frac{k}{m}(A^2 - x^2)}$