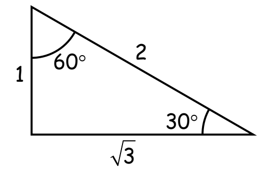
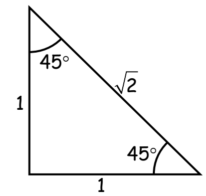
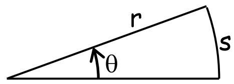
Essential Physics Knowledge *... a work in progress!*

STUFF EVERY PHYSICIST SHOULD KNOW.





Basics

$s = r\theta$ 

$v = \frac{ds}{dt}$ $a = \frac{dv}{dt}$

- derivatives give v, ω, a, α and their relationships.

Trigonometry: $\sin^2\theta + \cos^2\theta = 1$, $\sin(90 - \theta) = \cos\theta$ (Unit Circle)

Notation: $\dot{y} = \frac{dy}{dt}$ and $y'(x) = \frac{dy}{dx}$

Wavelength and Wave Number: $k = \frac{2\pi}{\lambda}$

Magnitude of a complex number: $|z| = z^*z$ where z^* is the complex conjugate of z

$\left|e^{i\phi}\right| = 1$

Vector dot product multiplies parallel components $\vec{a} \cdot \vec{b} = ab\cos\theta$ (scaler product)

Vector cross product multiplies perpendicular components $\left|\vec{a} \times \vec{b}\right| = ab\sin\theta$, dir. by RHR (vector product)

Momentum

Momentum: $\vec{p} = m\vec{v}$

De Broglie: $p = \frac{h}{\lambda} = \hbar k$

Angular Momentum: $\vec{L} = \vec{r} \times \vec{p} = rp\sin(\theta)$

- For r perpendicular to p (circular motion) $L = rp = r(mv) = mr(r\omega) = mr^2\omega \rightarrow I\omega$

Energy

Work: W = (force)(distance in direction of force), $W_{s_1 \text{ to } s_2} = \int_{s_1}^{s_2} \vec{F} \cdot d\vec{s}$

Kinetic Energy: $T = \frac{1}{2}mv^2 = \frac{p^2}{2m}$

Potential Energy: $U_{s1 \text{ to } s2} = -W_{s1 \text{ to } s2}$ for conservative forces (W independent of path)

$$U_{s_1 \text{ to } s_2} = -\int_{s_1}^{s_2} \vec{F}_{\text{conservative}} \cdot d\vec{s} \quad \Rightarrow \quad \vec{F} = -\nabla U$$

$$U_G = \frac{GMm}{r} = mgh, \quad U_{Spring} = \frac{1}{2}kx^2, \quad U_E = \frac{kQq}{r} = \frac{Qq}{4\pi\epsilon_0 r}$$

Mechanical Energy: E = T + U

Work-Energy Theorem:

First form: $W_{total} = \Delta T$

Second form: $W_{non\text{-}conservative} = \Delta T + \Delta U$ or $T_{init} + U_{init} - W_{NC} = T_{final} + U_{final}$

Mechanics

Newton's Laws

1. Stuff coasts (it takes a force to change velocity magnitude or direction)
2. $\sum \vec{F}_{External} = m\vec{a}$ or $\Sigma\vec{\tau}_{External} = I\vec{\alpha}$
   - $\Rightarrow$ apply to each body in each coordinate direction using FBDs
   - In static equilibrium the sums of the forces and torques are zero
3. Stuff pushes back (forces act on two bodies equally in opposite directions)
   - a normal force acts on *both bodies* in opposite directions
   - a frictional force acts on *both surfaces* in opposite directions

Forces

$F_{Gravity} = \dfrac{GMm}{r^2}$, Weight = $F_{Earth's\ Surface} = m\left(\dfrac{GM_{Earth}}{R^2_{Earth}}\right) = mg$

For two charges: $F_E = \dfrac{kQq}{r^2} = \dfrac{Qq}{4\pi\epsilon_0 r^2}$, Force on a charge in a uniform field: $F_{E\ Field} = qE$

$F_{Spring} = -kx$ (opposes displacement from equilibrium)

Friction

Static (surfaces not moving) $f_s \le \mu_s N$

Kinetic (surfaces in relative motion) $f_k = \mu_k N$

Normal Force: A reactive force between surfaces that resists deformation

Tension: A reactive force of a string that redirects force (no stretching or compression)

Kinematics (only when $\vec{a}_0 = \text{constant}$)

$v(t) = v_0 + a_0 t$ no x

$x(t) = x_0 + v_0 t + \frac{1}{2}a_0 t^2$ no v

} Derived from $\vec{a}_0 = \dfrac{d\vec{v}}{dt}$ and $\vec{v} = \dfrac{d\vec{x}}{dt}$

$v^2 = v_0^2 + 2a_0(x - x_0)$ no t

$x = x_0 + \left(\dfrac{v + v_0}{2}\right)t$ no a

} Derived from first two equations by eliminating t or a

For circular motion, $s = r\theta$, $v = r\omega$, $a = r\alpha$

$\omega(t) = \omega_0 + \alpha_0 t$ no θ

$\theta(t) = \theta_0 + \omega_0 t + \frac{1}{2}\alpha_0 t^2$ no ω

$\omega^2 = \omega_0^2 + 2\alpha_0(\theta - \theta_0)$ no t

$\theta = \theta_0 + \left(\dfrac{\omega + \omega_0}{2}\right)t$ no α

$$a_{centripetal} = \frac{v^2_{tangential}}{r} = r\omega^2$$

Drag: Velocity-Dependent Forces $F_{Drag} = -bv^n$

NSL has two useful forms: $\Sigma\vec{F}_{Ext} = \frac{d\vec{p}}{dt} = m\frac{d\vec{v}}{dt} = mv\frac{d\vec{v}}{dx}$

Equilibrium and Stability:

Equilibrium points are extrema in the potential energy function with stability determined by the concavity (value of the 2nd derivative)

$$\left.\frac{dU(x)}{dx}\right|_{x=x_0} = 0 \quad \text{and} \quad \left.\frac{d^2U(x)}{dx^2}\right|_{x=x_0} > 0?, \;\; = 0?, \;\; < 0?$$

Stable equilibrium: concave up, $U''(x) > 0$, slope is increasing
Neutral equilibrium: flat, $U''(x) = 0$, slope remains zero for some span of x
Unstable equilibrium: concave down, $U''(x) < 0$, slope is decreasing