Equation list for Final Exam, PHYS 172

$\vec{v}_{avg} = \frac{\Delta \vec{r}}{\Delta t} \equiv \frac{\vec{r}_f - \vec{r}_i}{t_f - t_i}$ $\quad r_f = r_i + \frac{v_i + v_f}{2}(t_f - t_i)$ $\quad \vec{p} = \gamma m \vec{v}$ $\quad \gamma = 1 \Big/ \sqrt{1 - (v/c)^2}$

$d\vec{p}/dt = \vec{F}_{net}$ $\quad \Delta \vec{p} \equiv \vec{p}_f - \vec{p}_i = \vec{F}_{net} \Delta t$ $\quad \Delta \vec{p}_{system} + \Delta \vec{p}_{surrounding} = \vec{0}$

$\frac{d\vec{p}}{dt} = \frac{d|\vec{p}|}{dt}\hat{p} + |\vec{p}|\frac{d\hat{p}}{dt}$ $\quad \left(\frac{d\vec{p}}{dt}\right)_{\perp} = p\frac{v}{R} = F_{\perp}$ $\quad \left(\frac{d\vec{p}}{dt}\right)_{\parallel} = \frac{dp}{dt} = F_{\parallel}$

$\vec{F}_{grav\ \text{on 2 by 1}} = -G\frac{m_2 m_1}{|\vec{r}_{2-1}|^2}\hat{r}_{2-1}$ $\quad |\vec{F}_{\text{grav}}| \approx mg$ $\quad \vec{F}_{\text{elec on 2 by 1}} = \frac{1}{4\pi\varepsilon_0}\frac{q_2 q_1}{|\vec{r}_{2-1}|^2}\hat{r}_{2-1}$ $\quad \vec{f}_{\max} \approx -\mu F_N \hat{v}$

$|\vec{F}_{spring}| = k_S |s|$ $\quad k_s = Y A/L$ $\quad F_T/A = Y\,\Delta L/L$ $\quad k_{interatomic} = Yd$

$F_{buoy} =$ weight of displaced fluid $\quad \vec{F}_{air} \approx -\frac{1}{2}C\rho A v^2 \hat{v}$ $\quad v_{\text{terminal}} = \sqrt{2mg/(C\rho A)}$ $\quad v_{esc} = \sqrt{2GM/R}$

$U_{\text{grav}} = -G\frac{m_2 m_1}{|\vec{r}|}$ $\quad \Delta U_{\text{grav}} \approx \Delta(mgy)$ $\quad U_{\text{electric}} = \frac{1}{4\pi\varepsilon_0}\frac{Qq}{|\vec{r}|}$ $\quad U_{\text{spring}} = \frac{1}{2}k_s s^2 + U_0$

$\Delta E_{sys} = W_{surr} + Q$ $\quad dW = \vec{F}\cdot d\vec{r}$ $\quad W \equiv F_{\parallel}\Delta r$ $\quad P = dW/dt = \vec{F}\cdot\vec{v}$

$E = \gamma mc^2$ $\quad K \equiv E - mc^2 \approx mv^2/2 = p^2/(2m)$ $\quad E^2 - (pc)^2 = (mc^2)^2$

$E_{system} = Mc^2$ $\quad E_{rest} = mc^2$ $\quad \Delta E_{\text{thermal}} = mC\Delta T$

Spring-mass, $v<<c$: $x = A\cos(\omega t)$ $\quad \omega = \sqrt{k_s/m}$ $\quad T = 2\pi/\omega$ $\quad f = 1/T$

$E_{\text{photon}} = h\nu_{light} = hc/\lambda_{light}$ $\quad E_{N,H} = -13.6/N^2$ eV $\quad r_{N,H} = N^2(0.53\times10^{-10}\text{ m})$

Oscillator: $\omega_0 = \sqrt{k_s/m}$, $E_N = N\hbar\omega_0 + \frac{1}{2}\hbar\omega_0$ $\quad$ Population ~ $\exp(-E/kT)$

$d\vec{P}_{tot}/dt = \vec{F}_{net,ext}$ $\quad \vec{P}_{tot} = M\vec{v}_{cm}\ (v<<c)$ $\quad \vec{r}_{cm} = \sum_{i=1}^{N} m_i \vec{r}_i \Big/ M$ $\quad M = \sum_{i=1}^{N} m_i$

$K_{tot} = K_{trans} + K_{rel}$ $\quad K_{rel} = K_{rot} + K_{vib} = \sum_{i=1}^{N}\left(\frac{p_{\tan,i}^2}{2m_i}\right) + \sum_{i=1}^{N}\left(\frac{p_{rad,i}^2}{2m_i}\right)$

$U_g = Mgy_{cm}$ $\quad K_{trans} = Mv_{CM}^2/2\ \ (v << c)$ $\quad \Delta K_{trans} = \int_i^f \vec{F}_{net,ext}\cdot d\vec{r}_{cm}$

Head-on collision, $v<<c$: $p_{3x} = \left[\frac{m \pm M}{m + M}\right] p_{1x}$

$\vec{L}_A = \vec{r}_A \times \vec{p} = \langle (yp_z - zp_y), (zp_x - xp_z), (xp_y - yp_x) \rangle$ $\quad L_A = r_\perp p = r_A p \sin\theta$

$\vec{L}_A = \vec{L}_{trans,A} + \vec{L}_{rot}$ $\quad \vec{L}_{trans} = \vec{r}_{cm} \times \vec{P}_{tot}$ $\quad \vec{L}_{rot} = \vec{r}_1 \times \vec{p}_1 + \vec{r}_2 \times \vec{p}_2 + \ldots$

$I = m_1 r_{\perp 1}^2 + m_2 r_{\perp 2}^2 + \ldots$ $\quad \vec{L}_{rot} = I\vec{\omega}$ $\quad$ solid disk: $I = \frac{1}{2}MR^2$ $\quad$ sphere: $I = \frac{2}{5}MR^2$

$K_{rot} = \frac{1}{2}I\omega^2 = \frac{L_{rot}^2}{2I}$ $(v << c)$

$\frac{d\vec{L}_A}{dt} = \vec{\tau}_A$ $\quad \vec{\tau}_A \equiv \vec{r}_A \times \vec{F}_{net}$ $\quad \Delta\vec{L}_{A,system} + \Delta\vec{L}_{A,surroundings} = 0$

$\frac{d\vec{L}_{rot}}{dt} = \vec{\tau}_{net,cm}$

For circular motion: $\left|\frac{d\vec{r}}{dt}\right| = v = \omega r$, $\quad |\vec{\omega}| = 2\pi / T$

$\Omega = \frac{RMg}{I\omega}$; $\quad$ Angular momentum quantum= $\hbar$

$\Omega = \frac{(q+N-1)!}{q!(N-1)!}$ $\quad S \equiv k\ln\Omega$ $\quad \Delta S_{sys} + \Delta S_{surroundings} \geq 0$ $\quad \frac{1}{T} \equiv \frac{dS}{dE_{\text{int}}}$

Boltzmann distribution: $\Omega(E)e^{-\frac{E}{kT}}$;

$P(h) = e^{-\frac{Mgh}{kT}}P(0)$ $\quad P(v) = 4\pi\left(\frac{M}{2\pi kT}\right)^{\frac{3}{2}} v^2 e^{-\frac{\frac{1}{2}Mv^2}{kT}}$

$\overline{K}_{trans} = \frac{3}{2}kT$ (for $kT >> \hbar\omega$) $\quad v_{rms} = \sqrt{3kT/M}$ $\quad \overline{v} = 0.92v_{rms}$

$P(E_{vib}) \propto e^{-\frac{E_{vib}}{kT}}$ $\quad$ diatomic: $\overline{E}_{vib} = \overline{E}_{rot} = kT$ $\quad$ each degree of freedom: *kT/2*

Constants:

$G = 6.7\times10^{-11}$ N×m^{2}kg^{-2} $\quad 1/(4\pi\varepsilon_0) = 9\times10^9$ Nm^{2}C^{-2} $\quad h = 6.6\times10^{-34}$ kg·m^2/s

$c = 3\times10^8$ m/s $\quad g = 9.8$ N/kg $\quad \hbar \equiv h/2\pi = 1.05\times10^{-34}$ J·s

$N_A = 6\times10^{23}$ mol^{-1} $\quad e = 1.6\times10^{-19}$ C $\quad k = 1.4\times10^{-23}$ J/K

1 eV = 1.6×10^{-19} J $\quad 1u = 1.66\times10^{-27}$ *kg*

Geometry:

$\pi \approx 3.14$

Circle: *circumference* = $2\pi r$, *area* = πr^2

Sphere: *area* = $4\pi r^2$, *volume* = $(4/3)\pi r^3$