# Formula Sheet for LSU Physics 2112, FINAL EXAM, Fall 2019

**Units:**

$1\,\text{m} = 39.4\,\text{in} = 3.28\,\text{ft}$ $\quad 1\,\text{mi} = 5280\,\text{ft}$ $\quad 1\,\text{min} = 60\,\text{s}$, $\quad 1\,\text{day} = 24\,\text{h}$ $\quad 1\,\text{rev} = 360° = 2\pi\,\text{rad}$

$1\,\text{atm} = 1.013\times10^5\,\text{Pa} = 760\ \text{torr} = 14.7\ \text{psi}$ $\quad T = \left(\frac{1\,K}{1°\text{C}}\right) T_\text{C} + 273.15\,\text{K}$ $\quad T_\text{F} = \left(\frac{9\,°\text{F}}{5°\text{C}}\right) T_\text{C} + 32°\text{F}$

$1\ \text{V} = \text{J/C}$ $\quad 1\ \text{eV}{=}1.602\times10^{-19}\ \text{J}$

**Constants:**

| | | |
|---|---|---|
| $\text{g} = 9.8\,\text{m/s}^2$ | $m_e = 9.109\times10^{-31}\,\text{kg}$ | $m_p = 1.673\times10^{-27}\,\text{kg}$ |
| $\text{c} = 3.0\times10^8\,\text{m/s}$ | $m_ec^2 = 511\,\text{keV}$ | $m_pc^2 = 938\,\text{MeV}$ |
| $\text{e} = 1.602\times10^{-19}\,\text{C}$ | $\epsilon_0 = 8.854\times10^{-12}\,\text{C}^2/(\text{N m}^2)$ | $hc = 1239.8\ \text{eV}\cdot\text{nm}$ |
| $k = 1.38\times10^{-23}\,\text{J/K}$ | $R = 8.31\,\text{J/(mol}\cdot\text{K)}$ | Avogadro's # $= 6.02\times10^{23}$ particles/mol |
| $h = 6.626\times10^{-34}\ \text{J}\cdot\text{s} = 4.136\times10^{-15}\ \text{eV}\cdot\text{s}$ | | $\hbar = 1.054\times10^{-34}\ \text{J}\cdot\text{s} = 6.582\times10^{-16}\ \text{eV}\cdot\text{s}$ |

**Properties of $H_2O$:**

| | | |
|---|---|---|
| Density: | $\rho_\text{water} = 1000\ \text{kg/m}^3$ | |
| Specific heat: | $c_\text{water} = 4187\ \text{J/(kg K)}$ | $c_\text{ice} = 2220\ \text{J/(kg K)}$ |
| Heats of transformation: | $L_\text{vaporization} = 2.256\times10^6\ \text{J/kg}$ | $L_\text{fusion} = 3.33\times10^5\ \text{J/kg}$ |

**Static Fluids:**

Density: $\rho = \frac{\Delta m}{\Delta V}$ Pressure: $p = \frac{\Delta F}{\Delta A}$ Absolute Pressure: $p = p_o + \rho g h$

$\rho_\text{Hg} = 13600\ \text{kg/m}^3$ $\quad \rho_\text{Air} = 1.21\ \text{kg/m}^3$

Pressure Variation with Height or Depth: $p_2 = p_1 + \rho\, g\, (y_1 - y_2)$ Gauge pressure: $p - p_o$

Archimedes' Principle: $F_b = \rho_f V_\text{displaced} g = m_f g$ $\quad$ weight$_\text{apparent}$ $= mg - F_b$

**Ideal flow:** Bernoulli's Equation: $p + \rho g y + \frac{1}{2}\rho v^2 = \text{const}$ Continuity: $R_m = \rho R_V = \rho A v = \text{const}$

**Simple Harmonic Motion (SHM):** $T = \frac{1}{f} = \frac{2\pi}{\omega}$

**Linear:**
$$x(t) = x_m\cos(\omega t + \phi)$$
$$v(t) = -x_m\omega\sin(\omega t + \phi)$$
$$a(t) = -x_m\omega^2\cos(\omega t + \phi) = -\omega^2 x(t)$$

**Angular:**
$$\theta(t) = \theta_m\cos(\omega t + \phi)$$
$$\Omega(t) = -\theta_m\omega\sin(\omega t + \phi)$$
$$\alpha(t) = -\theta_m\omega^2\cos(\omega t + \phi) = -\omega^2\theta(t)$$

**Linear Oscillator:** Spring-Block: $\omega = \sqrt{\frac{k}{m}}$ Horizontal Spring-Block: $E_\text{mec} = \frac{1}{2}kx_m^2$

Hooke's Law: $F = -kx$

**Pendulums:** Torsion: $\omega = \sqrt{\frac{\kappa}{I}}$ Simple: $\omega = \sqrt{\frac{g}{L}}$ Physical: $\omega = \sqrt{\frac{mgh}{I}}$

Torsion torque: $\tau = -\kappa\theta$

**Waves:**

$y(x,t) = y_m\sin(kx \mp \omega t + \phi)$ Angular Frequency: $\omega = \frac{2\pi}{T}$ Wave Number: $k = \frac{2\pi}{\lambda}$

Speed: $v = \frac{\omega}{k} = \lambda f$ **Stretched String Speed:** $v = \sqrt{\frac{\tau}{\mu}}$ Linear Density: $\mu = \frac{m}{L}$

**Power:** $P_{avg} = \frac{1}{2}\mu v\omega^2 y_m^2$

Interference of Waves: $y'(x,t) = \left[2y_m\cos\frac{\phi}{2}\right]\sin\left(kx - \omega t + \frac{\phi}{2}\right)$

Standing Waves: $y'(x,t) = [2y_m\sin(kx)]\ \cos(\omega t)$ Resonance: $f_n = \frac{v}{\lambda_n} = n\frac{v}{2L}$

**Sound Waves:**

$s(x,t) = s_m \cos(kx \mp \omega t)$ $\Delta p(x,t) = \Delta p_m \sin(kx \mp \omega t)$ $\Delta p_m = (v\rho\omega)s_m$

Sound Speed: $v = \sqrt{\frac{B}{\rho}}$ Angular Frequency: $\omega = \frac{2\pi}{T}$ Wave Number: $k = \frac{2\pi}{\lambda}$

Speed: $v = \frac{\omega}{k} = \lambda f$ **Power:** $P_{avg} = \frac{1}{2}\rho A v \omega^2 s_m^2$ Intensity: $I = \frac{P}{A} = \frac{P_s}{4\pi r^2}$

Interference of Waves: $s'(x,t) = \left[2s_m \cos\frac{\phi}{2}\right] \cos\left(kx - \omega t + \frac{\phi}{2}\right)$ $\phi = 2\pi\frac{\Delta L}{\lambda}$ + "other shifts"

Resonant Frequencies in Pipes,

Both Ends Open: $f = \frac{v}{\lambda} = \frac{nv}{2L}$ $n = 1, 2, 3, \ldots$

One End Open, One Closed: $f = \frac{v}{\lambda} = \frac{nv}{4L}$ $n = 1, 3, 5, \ldots$

Sound Level: $\beta = (10\text{dB}) \log \frac{I}{I_0}$ $I_0 = 10^{-12}\text{W/m}^2$

Beats:

$s(t) = s_m \cos\omega_1 t + s_m \cos\omega_2 t$ $= 2s_m[\cos\omega' t]\cos\omega t$ $\omega' = \frac{1}{2}(\omega_1 - \omega_2)$

Doppler Effect:

Source Moving: $f' = f\frac{v}{v \mp v_S}$ Detector Moving: $f' = f\frac{v \pm v_D}{v}$ Combined: $f' = f\frac{v \pm v_D}{v \mp v_S}$

**Thermodynamics:**

Linear Expansion: $\Delta L = L\alpha\Delta T$ Volume Expansion: $\Delta V = V\beta\Delta T = 3\alpha V\Delta T$

Heat of Warming/Cooling: $Q = mc\Delta T$ Heat of Transformation: $Q = mL$

Work Done **by** the System: $W = \int_i^f p\, dV$

First Law: $\Delta E_{int} = Q - W$ $\Delta E_{int} = E_{int,f} - E_{int,i}$ $dE_{int} = dQ - dW$

**Ideal Gas Law:** $pV = nRT = NkT$ $\frac{pV}{T} = \text{const}$ for n=const

Kinetic Theory: $p = \frac{nMv_{\text{rms}}^2}{3V} = \frac{\rho v_{\text{rms}}^2}{3}$ $v_{\text{rms}} = \sqrt{\frac{3RT}{M}} = \sqrt{\frac{3kT}{m}}$

**Change in Entropy**: $\Delta S = \int_i^f \frac{dQ}{T}$ ...(reversible path) $\Delta S = S_f - S_i$

**Second Law:** $\Delta S \geq 0$ ...(closed system)

**Solids/Liquids:** $\Delta S = \frac{mL}{T}$ (transformation) $\Delta S = mc\ln\frac{T_f}{T_i}$ (warming/cooling)

**Ideal Gases:** $\Delta S = nR\ln\frac{V_f}{V_i} + nC_V\ln\frac{T_f}{T_i}$

| Molecule | Monoatomic | Diatomic | Polyatomic |
|---|---|---|---|
| $C_V$ | $(3/2)R$ | $(5/2)R$ | $3R$ |
| $C_p$ | $(5/2)R$ | $(7/2)R$ | $4R$ |

$\gamma = C_p/C_V$, $E_{\text{int}} = nC_V T$

| **Process Type** | **Const. Quant.** | **Useful Relations (reversible processes)** |
|---|---|---|
| **Any** path | | $W = \int p\, dV$, $\Delta E_{\text{int}} = Q - W = nC_V\Delta T$, $\Delta S = \int dQ/T$ |
| Isochoric | $V$ | $W = 0$, $Q = nC_V\Delta T$ |
| Isobaric | $p$ | $W = p\Delta V$, $Q = nC_P\Delta T$ |
| Isothermal | $T$ | $W = nRT\ln(V_f/V_i)$, $\Delta E_{\text{int}} = 0, \Delta S = Q/T$ |
| Cyclic | | $Q = W$, $\Delta E_{\text{int}} = 0$, $\Delta S = 0$ |
| Adiabatic | $pV^\gamma$, $TV^{\gamma-1}$ | $Q = 0$, $W = -\Delta E_{\text{int}}$, $\Delta S = 0$ |

**Engines:**

$1^{\text{st}}$ Law for Eng. and Refrig.: $0 = |Q_H| - |Q_L| - |W|$

Efficiency: $\epsilon = \frac{|W|}{|Q_H|}$ Carnot (ideal) efficiency: $\epsilon_C = 1 - \frac{|Q_L|}{|Q_H|} = 1 - \frac{T_L}{T_H}$

**Refrigerator:**

Coeff. of performance: $K = \frac{|Q_L|}{|W|}$ Carnot coeff. of performance: $K_C = \frac{|Q_L|}{|Q_H| - |Q_L|} = \frac{T_L}{T_H - T_L}$

**Electromagnetic Waves:**

Plane waves propagating in the $x$-direction:

$$E = E_\mathrm{m}\cos(kx \pm \omega t) \qquad B = B_\mathrm{m}\cos(kx \pm \omega t) \qquad k = \frac{2\pi}{\lambda} \qquad \lambda = \frac{c}{f} = \frac{2\pi c}{\omega}$$

Poynting Vector, Energy Density:

$$\mathbf{S} = \frac{1}{\mu_0}\mathbf{E}\times\mathbf{B} \qquad S = \frac{1}{c\mu_0}E^2 \qquad u_E = u_B = \epsilon_0 E^2/2 = B^2/(2\mu_0)$$

Intensity, Energy Flux: $$I = S_\mathrm{avg} = \frac{1}{2c\mu_0}E_m^2 = \frac{1}{c\mu_0}E_\mathrm{rms}^2 \qquad I = \frac{P}{4\pi r^2}$$

**Geometrical Optics and Images:**

$$\mathrm{Reflection:}\quad \theta_\mathrm{r} = \theta_\mathrm{i} \qquad \mathrm{Snell's\ Law:}\quad n_1\sin\theta_1 = n_2\sin\theta_2$$

$$\frac{1}{p} + \frac{1}{i} = \frac{1}{f} \qquad f = r/2(\mathrm{spherical\,mirror}) \qquad m = -\frac{i}{p} \qquad m_\theta = -\frac{f_\mathrm{ob}}{f_\mathrm{ey}} \qquad M = m_1 m_2$$

**Physical Optics:**

$$n = \frac{c}{v} \qquad \lambda_n = \frac{\lambda}{n} \qquad f_n = \frac{c/n}{\lambda/n} = f \qquad \frac{\Delta\phi}{2\pi} = \Delta\left(\frac{L}{\lambda_n}\right) + \text{“other”} \qquad \frac{\Delta\phi}{2\pi} = \Delta N = \frac{L}{\lambda}(n_1 - n_2)$$

$$\Delta L + \text{“other”} = \begin{cases} m\lambda & \text{(bright)} \\ (m+\frac{1}{2})\lambda & \text{(dark)} \end{cases}$$

$$\mathrm{Two-Slit\ Interference:}\quad \Delta L = d\sin\theta = m\lambda \qquad \Delta L = d\sin\theta = (m + \frac{1}{2})\lambda$$

$$I(\theta) = 4I_0\cos^2\beta = 4I_0\cos^2(\phi/2) = 4I_0\cos^2\left(\frac{\pi d}{\lambda}\sin\theta\right) \quad I_\mathrm{max} = 4I_0$$

Thin Films: $\Delta\phi = \pi$, reflecting off a higher $n$; $\Delta\phi = 0$, reflecting off a lower $n$

Diffraction through a rectangular slit and a circular aperture:

$$\mathrm{One-Slit\ Minima:}\quad a\sin\theta = m\lambda \qquad \mathrm{Rayleigh's\ Criterion:}\quad \theta_\mathrm{R} = 1.22\frac{\lambda}{d}$$

$$I(\theta) = I_m\left(\frac{\sin\alpha}{\alpha}\right)^2 \qquad \alpha = \frac{\pi a}{\lambda}\sin\theta$$

Two-Slit Interference and Diffraction:

$$I(\theta) = I_m\cos^2\beta\left(\frac{\sin\alpha}{\alpha}\right)^2 \qquad \beta = \phi/2 = \frac{\pi d}{\lambda}\sin\theta \quad \alpha = \frac{\pi a}{\lambda}\sin\theta$$

Diffraction Gratings:

$$\mathrm{Maxima:}\quad d\sin\theta = m\lambda \qquad \mathrm{Dispersion:}\quad D = \frac{\Delta\theta}{\Delta\lambda} = \frac{m}{d\cos\theta} \qquad \mathrm{Resolving\ Power:}\quad R = \frac{\lambda_\mathrm{avg}}{\Delta\lambda} = Nm$$

**Modern Physics:**

Photons: $E = hf = \dfrac{hc}{\lambda} \quad p = E/c = \dfrac{h}{\lambda}$ $\qquad$ Photoelectric Effect : $hf = K_\mathrm{max} + \phi_s$

de Broglie Wavelength: $\lambda_\mathrm{dB} = \dfrac{h}{p} = \dfrac{h}{mv}$ $\qquad$ Compton : $\Delta\lambda = \dfrac{h}{mc}(1 - \cos\phi)$

$$\mathrm{Heisenberg\ Uncertainty\ Principle:}\quad \Delta x\Delta p_x \geq \hbar,\ \Delta y\Delta p_y \geq \hbar,\ \text{and}\ \Delta z\Delta p_z \geq \hbar.$$