Formulas:

Ideal gas:
- Mean free path: $\lambda = \frac{1}{2} \frac{V}{\rho}$
- Velocity distribution: $f(v) = \frac{1}{\sqrt{2\pi m k T}} e^{-mv^2/(2kT)}$
- Distribution of molecular speeds: $P(v) = 4\pi \frac{m}{2\pi k T} \frac{3}{2} v^2 e^{-mv^2/(2kT)}$

Conduction: $P_{cond} = \frac{Q}{t} = kA \frac{T_H - T_L}{L}$; $R = \frac{L}{k}$; k,R=thermal conductivity, resistance

Radiation: $P_{rad} = \sigma \varepsilon A T^4$; $\sigma = 5.67 \times 10^{-8} \text{W/m}^2 \text{K}^4$; $\varepsilon = 1$ for black body

Ideal gas: $PV = nRT = nN_A k T$; $R=8.31 \text{J/molK}$; $k=1.38 \times 10^{-23} \text{J/K}$

Pressure: $P = \frac{Nm}{3V} (v^2)_{avg}$

Kinetic energy: $K_{avg} = \frac{1}{2} m \left( \frac{V}{C^2} \right)_{avg} = \frac{3}{2} kT$

Internal energy: $E_{int} = NK_{avg}$; $C_v = \frac{3}{2} R$ for monoatomic gas; $C_p = C_v + R$

$C_v, C_p = \text{molar heat capacity at constant volume, pressure}$

$C_v = \frac{f}{2} R$ for polyatomic gases with $f$ degrees of freedom per molecule

Adiabatic expansion of ideal gas: $PV^\gamma = \text{const}$; $TV^{\gamma-1} = \text{const}$; $\gamma = C_p / C_v$

Distribution of molecular speeds: $P(v) = 4\pi \left( \frac{m}{2\pi k T} \right)^{3/2} v^2 e^{-mv^2/(2kT)}$

Velocity distribution: $F(v_x, v_y, v_z) = f(v_x) f(v_y) f(v_z)$; $f(v_x) = \left( \frac{m}{2\pi k T} \right)^{1/2} e^{-mv_x^2/(2kT)}$

Mean free path: $\lambda = 1/(\sqrt{2\pi d^2 N/V})$, d=diameter; $v_{rms} = \sqrt{(v^2)_{avg}}$

Entropy: $dS = dQ/T$ in a reversible process. S is a function of state. $\Delta S = \int dQ/T$

$\Delta S \geq 0$ for a closed system. $= 0$ if reversible process, $> 0$ if irreversible process

Ideal gas: $S(T,V) = nR \ln V + nC_v \ln T + \text{const}$

Heat engine: $\varepsilon = \frac{|W|}{|Q_H|}$; Carnot engine: $\varepsilon = 1 - \frac{|Q_L|}{|Q_H|} = 1 - \frac{T_L}{T_H}$

Refrigerator coefficient of performance $K = \frac{|Q_L|}{|W|}$; Carnot refrigerator $K_C = \frac{T_L}{T_H - T_L}$

Statistical view of entropy: $S = k \ln W$; $W = N!/(n_1! n_2! \ldots)$; $N! \approx N(\ln N) - N$
**Fluids:** $\rho = m/V$, $p = F/A$, $1\text{ atm} = 1.01 \times 10^5 Pa = 760\text{torr}$

Fluid at rest: $p_2 + \rho g y_2 = p_1 + \rho g y_1$; gauge pressure = $p-p_{\text{atmospheric}}$

Pascal's principle: $\Delta p = F_1/A_1 = F_2/A_2$

Archimedes principle: buoyant force $F_b = m_{\text{fluid}}g$

Continuity equation: volume flow rate $= R_V = Av = \text{a constant}$

Bernoulli equation: $p + \frac{1}{2}\rho v^2 + \rho gy = \text{a constant}$

**Oscillations:**

Simple harmonic motion: $x(t) = x_m \cos(\omega t + \phi)$; $\omega = 2\pi f = 2\pi/T$

Spring: $F = -kx$, $\omega = \sqrt{k/m}$, energy: $E = U + K = \frac{1}{2}kx_m^2$; $U = \frac{1}{2}kx^2$, $K = \frac{1}{2}mv^2$

Torsion pendulum: $\tau = -\kappa \theta$, $\omega = \sqrt{k/I}$; Simple pendulum: $\omega = \sqrt{g/L}$

Physical pendulum: $\omega = \sqrt{\text{mg}h/I}$; $I = I_{CM} + mh^2 = \int r^2 dm$

Damped shm: $F_d = -bv$, $x(t) = x_m e^{-bt/2m} \cos(\omega t + \phi)$, $\omega' = \sqrt{\omega^2 - (b/2m)^2}$

Forced oscillations: $F_f = f \cos(\omega_d t)$, $x(t) = x_m \cos(\omega_d t + \phi)$; Resonance: $\omega_d = \omega$

$x_m = (f/m) / \sqrt{(\omega_d^2 - \omega^2) + b^2 \omega_d^2 / m^2}$, tan $\phi = (b/m) \omega d / (\omega_d^2 - \omega^2)$

**Waves:**

$y(x,t) = y_m \sin(kx - \omega t)$; $\omega = 2\pi f = 2\pi/T$; $k = 2\pi/\lambda$; $v = \omega/k = \lambda f = \lambda/T$

String: $v = \sqrt{\tau/\mu}$; Power: $P_{\text{avg}} = \frac{1}{2} \mu \omega^2 y_m^2$

Interference: $y'(x,t) = [2y_m \cos \frac{1}{2} \phi \sin(kx - \omega t + \frac{1}{2} \phi)$

Standing waves: $y'(x,t) = [2y_m \sin(kx)] \cos \omega t$; Resonance: $f = \frac{v}{\lambda} = n \frac{v}{2L}$

Speed of sound: $v = \sqrt{\frac{B}{\rho}}$; $B = -V \frac{\partial P}{\partial V}$; Ideal gas: $B = \gamma P$

$s = s_m \cos(kx - \omega t)$; $\Delta p = \Delta p_m \sin(kx - \omega t)$; $\Delta p_m = \nu \rho \omega s_m$

Interference: $\phi = \frac{\Delta L}{\lambda} 2\pi$; Constructive $\phi = 2\pi m$, destructive $\phi = \pi(2m+1)$

Sound intensity $I = \frac{P}{A} = \frac{1}{2} \rho \omega^2 s_m^2 = \frac{P_s}{4\pi r^2}$; Decibels $\beta = (10 \text{dB}) \log \frac{I}{I_0}$, $I_0 = 10^{-12} W/m^2$
pipes: $f = \frac{n v}{2L}$, $n = 1, 2, 3$ or $f = \frac{n v}{4L}$, $n = 1, 3, 5$; beats $f_{beat} = f_1 - f_2$

Doppler: $f' = f \frac{v \pm v_p}{v \pm v_s}$; shock wave $\sin \theta = \frac{v}{v_s}$

For problems 1, 2: A traveling sinusoidal wave propagates along a string of mass density 0.5 kg/m. The amplitude of the string oscillation is 1 cm, the wavelength of the wave is 10 cm and the frequency of the wave is 100 Hz.

**Problem 1:** What is the tension on the string?
A: 30 N; B: 10 N; C: 50 N; D: 70 N; E: 90 N

**Problem 2:** What is approximately the kinetic energy of the string in one wavelength?
A: 1 J; B: 0.5 J; C: 2 J; D: 5 J; E: 10 J

**Problem 3**
The power transmitted by a sinusoidal wave traveling along a string is 200 W. Adding a second wave of the same wavelength and amplitude traveling in the same direction, the power transmitted is 600 W. What is the phase difference between the two waves?
A: 15°; B: 30°; C: 45°; D: 60°; E: 90°

**Problem 4**
A spring that obeys Hooke’s law has length 5 cm with no tension. When it is stretched to 10 cm length its second harmonic frequency is 100 Hz. If it is now stretched to 20 cm length, what will be its second harmonic frequency?
A: 48 Hz; B: 244 Hz; C: 82 Hz; D: 168 Hz; E: 122 Hz

**Problem 5**
What is the amplitude of the air oscillations for a sound wave of frequency 1000 Hz and intensity 20 dB?
Sound velocity = 343 m/s, air density 1.21 kg/m$^3$
A: 100 nm; B: 10 nm; C: 1 nm; D: 0.5 nm; E: 0.1 nm

**Problem 6**
The speed of waves in a violin string is 170 m/s, the length of the string is 12 cm. What is the third largest sound wavelength that will set up a standing wave in this string? Assume sound velocity is 340 m/s.
A: 6 cm; B: 16 cm; C: 12 cm; D: 20 cm; E: 24 cm

**Problem 7** (for extra credit)
There is a police chase going on, one police car races by you and another is approaching you, they go at the same speed of 120 km/h and their siren’s frequency is $f$. Assume $v_{sound}=330$ m/s. You hear beats of frequency
A: 0.05$f$; B: 0.1$f$; C: 0.15$f$; D: 0.2$f$; E: 0.25$f$