### Wave velocity

$v$ – string tension is $F$

$$v = \sqrt{\frac{F}{\mu}} \quad (\mu \text{ is mass/length})$$

### Wave length

$\lambda$, wave-vector $k$

$$k = \frac{2\pi}{\lambda}$$

### Frequency, angular frequency, period

$\omega = 2\pi f = \frac{2\pi}{T}$ and $v = \lambda f$

### Standing wave – separate factors for $x$ and $t$

$$y(x, t) = A \sin(kx) \sin(\omega t)$$

### Traveling wave – sign determines direction

$$y(x, t) = A \sin(kx \pm \omega t)$$ - for left, + for right

### Normal modes – string fixed at both ends $(0, L)$

$$\lambda_n = \frac{2L}{n} \quad n^{th} \text{ harmonic has } n-1 \text{ nodes}$$

### Fluids – buoyant force – density $\rho$

$$F_B = W = W \text{ (weight of displaced fluid)} = \rho V$$

### Pressure vs depth – if $y$ increases

Upward, then $p = \rho g y$

### Bernoulli equation – fluid in laminar flow

$$p + \rho g y + \frac{1}{2} \rho v^2 \text{ constant}$$

### Work

$$W = \int pdV$$

### Heat, work, energy

$W$ = work done by system

$$\Delta U = Q - W \quad 1^{st} \text{ Law} \quad Q = \text{ heat added to system}$$

### Specific heat capacity $Q = mc\Delta T$

$c$ in joules/kg degree K or C

### Molar heat capacity $Q = nC_A T$

$C$ in Joules/mole degree K or C

### Heat at constant $p$

$p = \text{ heat at constant } V + W$

### Ideal gas law $pV = nRT = Nk_BT$

$T$ in Kelvin = $T$ in Celsius + 273.15

### Water:

$$\rho = 10^3 \text{ kg/m}^3 \quad T_{\text{freeze}} = 0^\circ\text{C} = 273.15\text{K}$$

$$T_{\text{boil}} = 100^\circ\text{C} = 373.15\text{K}$$

### Rate of radiative heat transfer

$H = dQ/dt = e\sigma A(T_1^4 - T_2^4)$ (in W/m$^2$K$^4$)

### Thermal expansion

$$\Delta L = \alpha L_0 \Delta T \quad \Delta V = \beta V_0 \Delta T$$

### Molecular model of gas

$$\overline{KE}_{\text{trans}} = \frac{3}{2} Nk_b T$$

Diatomic molecules also have rotational KE

$$\overline{KE}_{\text{trans}} + \overline{KE}_{\text{rot}} = \frac{5}{2} Nk_b T$$ (neglect vibrational)

### Molar specific heat

$$C_V = \frac{5}{2} Nk_b = \frac{5}{2} nR$$ (diatomic as in O$_2$, N$_2$) $\gamma = C_p/C_v = 7/5$

### Adiabatic process means no heat.

### Ideal gas $pV^\gamma$ is constant

### Second ideal gas law: $\Delta U = nC_V \Delta T$

### Cyclic process $W$ = area in $p-V$ plane $= Q_{in} - Q_{out}$

Efficiency of heat engine $e = W/Q_{in} = 1 - Q_{out}/Q_{in}$

### Carnot cycle – heat in at $T_h$, heat out at $T_c$

No heat (adiabats) in between

### 2nd Law

All heat engines reject heat $Q_c$

Or heat never flows from $T_c$ to $T_h$

### Or no heat engine is more efficient than Carnot

Carnot efficiency $= 1 - Q_c/Q_h = 1 - T_c/T_h$

### Or entropy $S$ depends on state, not path

$$dS = dQ/T \quad S = \int dQ/T$$ (reversible process)