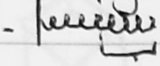
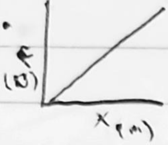
5.3. Stress and Strain

Elasticity

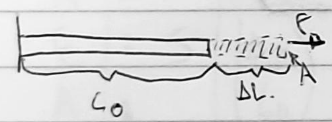
- Ideal Spring (Spring Force) - $F_x = Kx$ (Hookes Law)
  - 
- For small forces, the force and displacements relationship is linear
- 

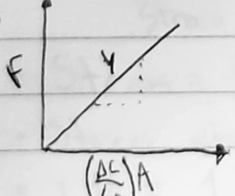
- Example 1 - Spring Constant = 320 N/m, x = .02 m

$$F = Kx$$
$$= (320)(.02)$$
$$F = 6.4\,N$$

- For this level of physics, we can say that atoms are connected by "springs"

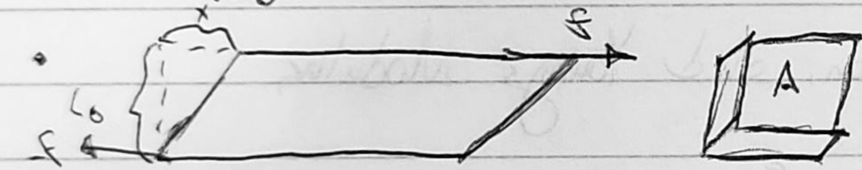
Stretching, Compression, and Young's Modulus

- 

- $F = Y\left(\frac{\Delta L}{L_0}\right)A$, where Y is the young's modulus (N/m^2), ΔL is the length stretched, L is the original length, and A is the surface area
- The surface area is the area in which the force is distributed on.
- 

- $F = Y\left(\frac{\Delta L}{L_0}\right)A \rightarrow (N) = \left(\frac{N}{m^2}\right)\left(\frac{m}{m}\right)(m^2)$

Shear Deformation and the Shear Modulus

- $F = S\left(\frac{\Delta x}{L_0}\right)A$.
- 

- S, the shear modulus;

Example

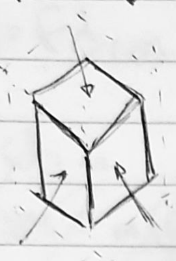
- $F = 0.45N$, $\Delta x = 0.006m$, $L = 0.07$, $W = 0.07$, $H = 0.03$.

$$S = \frac{FL_0}{A\Delta x}$$

$$S = \frac{(0.45)(0.03)}{(0.0049)(.006)}$$

$$S = 459.1836735 \frac{N}{m^2}.$$

Volume Deformation and the Bulk Modulus

- ~~[scribble]~~ $F = B\left(\frac{\Delta V}{V_0}\right)A$, B is the bulk modulus,
- 
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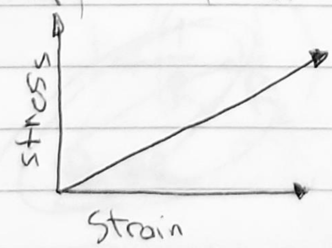
General Summary / Key Ideas.

- In general, $\frac{F}{A}$ is called the stress of ~~on~~ an object. Whether in length, shear, or volume change.
- In general, $\frac{\Delta V}{V}$, $\frac{\Delta L}{L_0}$, $\frac{\Delta x}{L_0}$, are the strains.

Stress		Strain
$\frac{F}{A}$	$= Y$	$\left(\frac{\Delta L}{L_0}\right)$
$\frac{F}{A}$	$= S$	$\left(\frac{\Delta x}{L_0}\right)$
$\frac{F}{A}$	$= B$	$\left(\frac{\Delta V}{V_0}\right)$

- 

Stress = m(strain), where m is some constant that works the units out (moduli)

- Stress = $\frac{N}{m^2}$, Strain = Unitless, Moduli = $\frac{N}{m^2}$
- Stress shares the same units as pressure.
- $1\ \frac{N}{m^2} = 1\ Pa$, or Pascals.

Chapter 7 Work and Energy

Work.

- $W = Fd\cos$, in Joules (J or N·m)

$\cancel{F_{net} = ma}$

$\cancel{.0056 = m(v_2 - v_1)}$

$\cancel{\frac{.0056}{474} = v_2 - v_1}$

$\cancel{\frac{.0056}{474} + 275 = v_2}$

$\cancel{275.000018 \text{ m/s} = v_2}$

$\cancel{a = \frac{v_2 - v_1}{t}}$

$$\frac{v_2^2 - v_1^2}{2d} = a$$

$$\frac{2d(.0056)}{474} = v_2 - v_1$$

$$\frac{2(2.42\times10^4)(.0056)}{474} + 275^2 = v_2^2$$

$$\sqrt{\frac{2(2.42\times10^4)(.056)}{474} + 275^2} = v_2$$

$804 \text{ m/s} = v_2$.

$$\frac{22^2}{2}m = 242m \qquad \frac{44^2}{2}m = 968m$$

$$\frac{1}{\frac{1}{R_1}+\frac{1}{R_2}}$$

46.15 m/s

- $W_{nc} = \Delta KE + \Delta PE$
- $E_2 = E_1$ → When the work done by non-conservative forces = 0, energy is conserved.

Elastic Potential

$U_{Elastic} = \frac{1}{2} kx^2$.

$mgh = \frac{1}{2} kh^2$

$\frac{2mg}{k} = h$

$.14m = h$

#1

$mgh = \frac{1}{2} mv^2$

$\sqrt{2gh} = v$

#2

$\sqrt{mgh} = v$

stop being so petard

* Power $= \frac{W}{t}$

Power $= \frac{\text{Change in Energy}}{t}$

$\boxed{\bar{P} = F\bar{v}}$

Average Power = The force · the average velocity

$\frac{1}{2} mv^2 = mgh + \frac{1}{2} mv^2$

$\frac{1}{2} v^2 - gh = \frac{1}{2} v^2$

$v^2 - 2gh = v^2$

$\sqrt{v^2 - 2gh} = v$

$5.4 m/s = v$

Static Fluids.

Density of Mass.

$\rho = \frac{m}{V}$, kg/m^3 m = mass ρ = density
V = volume

SPECIFIC GRAVITY

- Ratio of the object to water.
- $\frac{\rho}{\rho_w}$

Ex 1: $V_A = \frac{m_A}{\rho_A} = \frac{0.075}{850} = 8.82 \times 10^{-5}\ m^3$

$V_B = \frac{m_B}{\rho_B} = \frac{0.075}{1060} = 7.08 \times 10^{-5}\ m^3$

$\rho_m = \frac{(.075 + .075)}{(15.89 \times 10^{-5})}$

$\rho_m = 943.98\ \frac{kg}{m^3}$

$\frac{\rho_m}{\rho_w} \rightarrow \frac{943}{1000} \rightarrow .943$. Specific Gravity

PRESSURE

$P = \frac{F}{A}$ ← Force, ← Area, ↑ Pressure.   measured in $\frac{N}{m^2}$ or pascals. or $\frac{kg}{ms^2}$

- $P_2 = P_1 + \rho h g$

GAUGE PRESSURE

Pascal's Principle

- Any change in pressure applied to a completely enclosed fluid is distributed as an equal change in pressure.

- $\frac{F_2}{A_2} = \frac{F_1}{A_1} \rightarrow 205000\left(\frac{\pi r^2}{\pi r^2}\right) \rightarrow 171N.$

- ~~$\frac{F_2}{A_2} = \frac{F_1}{A_1}$~~

~~$5\times10^5\ Pa = \frac{F_1}{A_1}$~~

$\left\{\frac{F_1}{A_1} = \frac{F_2}{A_2}\right. \leftarrow \pi .15^2$

$5\times10^5 + 1.013\times10^5\ Pa$

Gauge Pressure, Atmospheric Pressure

$F_2 = (6.013\times10^5)(\pi .15^2)$

$F_2 = 42503.39241$

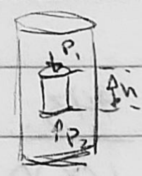
Archimedes Principle

- Buoyant Force
  - $F_B = P_2A - P_1A$

$= (P_2 - P_1)A$

$= \rho g h A \leftarrow V = hA$

$F_B = \rho V g = mg \leftarrow$ mass of the displaced fluid.



$P_2 = P_1 + \rho g h$

$P_2 - P_1 = \rho g h$

- Mass of Displaced fluid.

Density of the liquid

~~of object submerged~~ Volume of liquid displaced by object

Archimedes Principle

- $F_B = W_{fluid}$

G

Fluids in Motion.

- Steady flow - the velocity of fluid particles at any point is constant ~~on~~ as time passes
- Unsteady flow = whenever the velocity changes at any point as time passes
- Fluids can be compressible or incompressible (most incompressible)
- Fluids can be viscous or non viscous.
- Incompressible and non viscous fluids are ideal.
- When the flow is steady streamlines are used to represent trajectories.

The Equation of Continuity

- The mass of liquid per second that flows through a tube
- $= \frac{m}{t}$
- ~~equation~~ $\rho_1 A_1 v_1 = \rho A_2 v_2$
- Flow rate = $Q = Av_1$

Volume/t

Example

a) $Q = \frac{8 \times 10^{-3} \text{ m}^3}{30 \text{ s}}$

$\frac{Q}{A} = v$

$\frac{\left(\frac{8 \times 10^{-3}}{30}\right)}{2.85 \times 10^{-4}} = v$

$.936 \text{ m/s} = v$

b). $A_1 v_1 = A_2 v_2$

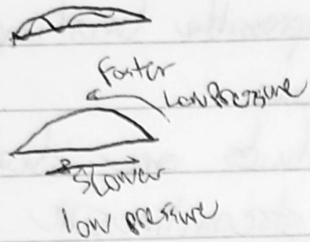
$\frac{A_1 v_1}{A_2} = v_2$

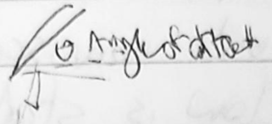
$(2)(.936) = v_2$

$1.87 \text{ m/s} = v_2$.

• Fluids speed up as area shrinks

$$P_1 + \frac{1}{2}\rho_1 v^2 + \rho_1 g y_1 = P_2 + \frac{1}{2}\rho_2 v^2 + \rho_2 g h_2$$





air change direction momentum

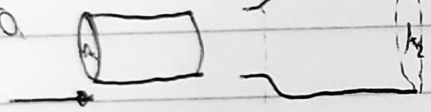
Bernoulli

Newton

Example

• Aneurysm - Enlarged blood vessel.
• Aorta

$A_2 = 1.7A_1$



$v_1 = 0.40\frac{m}{s}$ $\rho = 1060\frac{kg}{m^3}$

• What is the pressure increase at the aneurysm?

$$P_1 + \frac{1}{2}\rho v_1^2 + \cancel{\rho g y_1} = P_2 + \frac{1}{2}\rho v_2^2 + \cancel{\rho g y_2}$$

$$P_1 + \frac{1}{2}\rho v_1^2 = P_2 + \frac{1}{2}\rho v_2^2$$

$$\frac{1}{2}\rho v_1^2 - \frac{1}{2}\rho v_2^2 = P_2 - P_1$$

$$\frac{1}{2}(1060)(.4^2) - \frac{1}{2}(1060)(.235^2) = P_2 - P_1$$

$$55.53075\frac{N}{m^2} = P_2 - P_1$$

Since no v_2 use quation of Continuity,

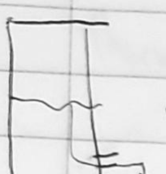
$$A_1 v_1 = A_2 v_2$$

$$A_1 v_1 = 1.7A_1 v_2$$

$$\frac{.4}{1.7} = v_2$$

$$0.2353\ m/s = v_2$$

- The tank is open to the atmosphere the top. Find an expression for the speed of the liquid leaving the pipe at the bottom



- $P_1 + \frac{1}{2}\rho v_1^2 \; \rho g y_1 = P_2 + \frac{1}{2}\rho v_2^2 + \rho g y_2$ $\quad P_1 = P_2 = P_{atm}$, because the air both exposed to air and P_1 is exposed at the end of the pipe

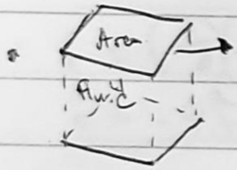
$$\frac{1}{2}\rho v_1^2 = \rho g h$$

$$v_1 = \sqrt{2gh}$$

Viscous flow

- Ideal fluid - constant velocity throughout.
- Viscous fluid = v is maximum at the centre.

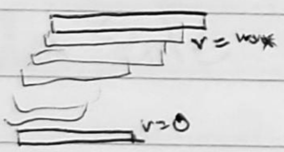
Force needed to move a layer of viscous fluid with a constant velocity



$$F = \frac{\eta A v}{y}$$

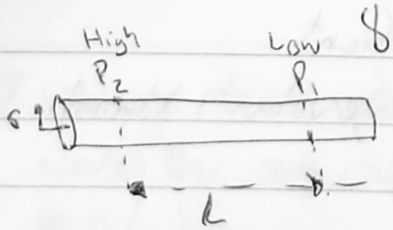
η coefficient of viscous fluid.
units = $Pa \cdot s$
Common unit = 1 Poise (P) = 0.1 $Pa \cdot s$.

y Distance between the top and bottom plate.



Poiseuille's Law

- Volume flow rate $Q = \frac{\pi R^4 (P_2 - P_1)}{8 \eta L}$



Injection.

- Solution = $\eta = 1.5\times10^{-3}$ Pa·s

Radius = 4×10^{-4} m

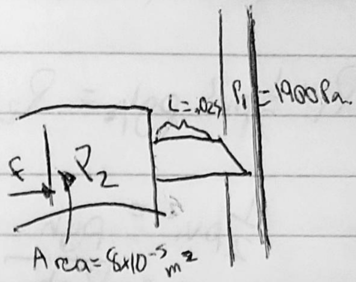
Gauge Pressure in the Vein = 1900 Pa

$V = 1\times10^{-6}\ m^3$

$t = 3s$

$f = ?$

$Q = \frac{1\times10^{-6}}{3}$



$$Q = \frac{\pi r^4 (P_2 - P_1)}{8\eta L}$$

$$\frac{Q 8\eta L}{\pi r^4} + P_1 = P_2$$

$$\frac{\left(\frac{1\times10^{-6}}{3}\right)(8)(1.5\times10^{-3})(.025)}{\pi(4\times10^{-4})^4} + 1900 = P_2$$

$$3100 Pa = P_2$$

$$\frac{f}{A} = P_2$$

$f = P_2 A$

$f = (3100)(8\times10^{-5})$

$f = 0.25 N$.

Reynolds Number

- How to find the flow patterns (turbulence).

- $Re = \frac{2\bar{v}\rho R}{\eta}$

R = radius

ρ = density

η = coefficient

$\bar{v}$ = Average velocity through lamina.

- Re is UNITLESS
- Lamina flow → $Re < 2000$
- turbulent flow → $Re > 4000$
- Between is called transition flow.

Temperature and the Gas Law.

Thermodynamics.

Temperature

- Take temp of 98.6°F

① $98.6°F - 32°F = 66.6F°$ → ② $66.6F° \left(\frac{1C°}{\frac{9}{5}F°}\right)$

ICE POINT

$37.0C°$

③ $37.0C° + 0C° = 37.0C°$

- $°F = \left(\frac{9}{5}\right) \times °C + 32°F$

- $°F = \left(\frac{9}{5}\right)(-20) + 32$
  $F = -4°F$

Kelvin Scale

- $T = T_c + 273.15$

Kelvin   Celsius

~~Linear Thermal~~ Expansion.

- Solids undergo stress and strain as temperature changes.
- Heat increases the average spacing between atoms.
- $\Delta L = \alpha L_0 \Delta T$

change in temperature.

Change in Length

Coefficient of linear expansion

Original Length

Volume Thermal Expansion

- $\Delta V = \beta V_0 \Delta T$

  β: Coefficient of volume expansion $\left(\frac{1}{C°}\right)$

- Examples.
  - $\Delta V = \beta V_0 \Delta T$

    $\Delta V = (4\times10^{-4})(15)(92-6)$

    $\Delta V = .516$ quarts

    ~~$V_0 + \Delta V = V_f$~~

    ~~$15 + 0.516 = V_f$~~

    ~~$15.516 = V_f$~~

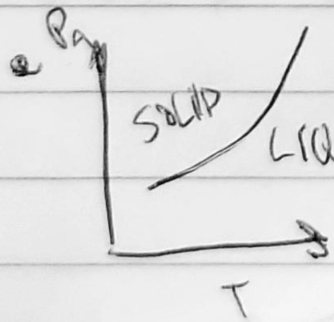
    $\Delta V = (51\times10^{-6})(15)(92-6)$

    $\Delta V = 0.06579$ quarts

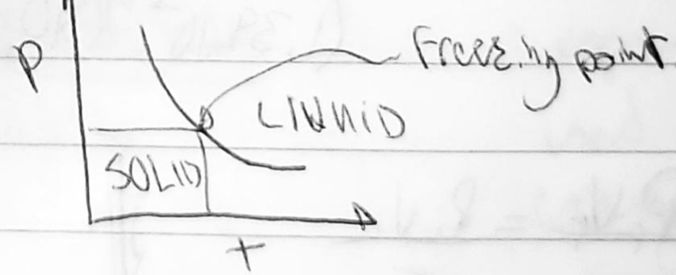
    $V_{spill} = \Delta V_{coolant} - \Delta V_{Radiator}$

    $= .516 - .06579$

    ≈ 0.45 quarts

- 

WATER.



$$P = \frac{nRT}{V} \rightarrow n = \frac{N}{N_A}$$

$$P = \frac{NRT}{N_A V} \rightarrow \frac{R}{N_A} = k$$

$$P = \frac{NkT}{V}$$

$$V = \frac{NkT}{P}$$

$$\frac{m}{\rho} = \frac{NkT}{P}$$

$$\frac{mP}{NkT} = \rho$$

Example.

• $P = 1\times10^5$ Pa $T = 310K$.

$r = .125$ mm

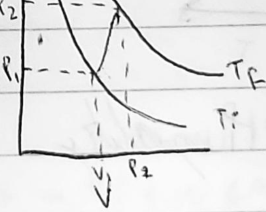
14% oxygen

$$P = \frac{NkT}{V}$$

$$\frac{PV}{kT} = N$$

$$\frac{(1\times10^5)(\frac{4}{3}\pi(.000125^2\,m))}{(1.38\times10^{-23})(310)} = N.$$

$$\frac{P_f V_f}{T_f} = \frac{P_i V_i}{T_i}$$



• Most Probable Velocity } are not equal.
~~Most~~ Average Velocity

$\sqrt{v^2}$ $\sqrt{\frac{1}{N}\sum_i v_i^2} = \bar{V}$ $\overline{KE} = \frac{1}{2}mv_{rms}^2 = \frac{3}{2}kT$

Temperature and Heat.

- Heat - energy that flows from high temp to low temp. because of a temperature difference (in J or joules).
- Hot to Cold flow originates in internal energy.
- $Q = mc\Delta T$

Flow of Heat (J) ↑ Q; Specific Heat Capacity $\left(\frac{J}{kgC^\circ}\right)$ ↑ c

PE → Higher energy shell
CS → interacts with free orbitals.

- 1 Kcal = 4186 J
  1 cal = 4.186 J.

A

$Q = mc\Delta T$

$\frac{Q}{m\Delta T} = c$

$\frac{Q}{.04\Delta T}$

.01

B/C

$\frac{Q=C}{.01\Delta T}$

$\frac{0}{.01(3)}$

.03

$\frac{Q=C}{.02\Delta T}$

.02(3)

.06

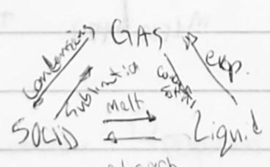
Calorimetry

- If there is not heat less to the surroundings, the heat lost by the hotter object equals the heat gained by the colder ones

Ex: $(mc\Delta T)_{Al} + (mc\Delta T)_{water} = (mc\Delta T)_{unknown}$ ← specific heat capacity can be used in conservation of energy.

$$c_u = \frac{(mc\Delta T)_{Al} + (mc\Delta T)_{H_2O}}{(m\Delta T)_{un}}$$

Phases of matter



Ex

$$\Delta T = \frac{Q}{mc} = \frac{2\times10^9}{(1000)(9.12\times1683)(4186)}$$

$$= \frac{Q}{\rho V c} = 2.4\,C^\circ$$

$15 + 2.4 = 17^\circ C.$

• Heat required to change phase
- $Q = mL$
latent heat ~~of fusion~~ $\left(\frac{J}{kg}\right)$

- latent heat of - Fusion
- Vaporization.

0°C is the only place solid and liquid water can be in equilibrium

Example

• $\underbrace{m_{ICE\ MELTED} L_{H2O}}_{\text{Heat gained to melt ice}} = \underbrace{c_{H2O}\, m_{LEMONADE}\, \Delta T_{LEMONADE}}_{\text{Heat lost by lemonade.}}$

$m = \frac{c\, m\, \Delta T}{L}$

$m = \frac{(4186)(.32)(27°C)}{3.35 \times 10^5}$

$m = .11\ kg$

$0 = Q_2 - Q_1$

$Q_1 = Q_2$

$mL = mc\Delta T$

• Extension #1 - Ultra cold ice freezes lemonade

Heat gained by ice	Heat lost by water	Heat lost to freeze	Heat lost by frozen lem to lower temp
$m_{ICE} c_{ICE} \Delta T_{-80 \to -10}$ =	$m_{LEMON} c_{H2O} \Delta T_{27 \to 0}$ +	$m_{LEM} L_{H2O}$ +	$m_{LEM} c_{ICE} \Delta T$ $0 \to -10$ °C

• Extension #2 - All ice melted

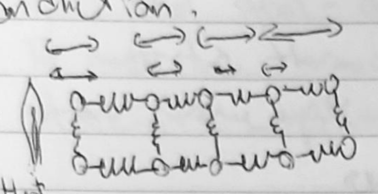
Heat Gained by ice to melt	Heat gained to melt it	Heat lost to lem. to lower T
$m_{ICE} c_{ICE} \Delta T$ +	$m_{ICE} L$ =	$m_{LEM}\, c_{Lem} \Delta T$

Keep Temp change & phase change in mind

① Convection

- Process in which heat is carried from one place ~~to~~ to another by bulk movement of fluid.
- You can force Convection.

② Conduction.



Heat.

High Vibrations

Transfer of ~~from~~ heat over time.

- The strength of the connections of the molecules take part in the transfer of heat over time.

-

- Q Depends on
  ① Time of conduction
  ② Temperature difference
  ③ Cross Sectional Area.
  ④ Length of the ~~Bar~~.

☆ • $Q = \frac{(kA\Delta T)t}{L}$

k is the thermal conductivity constant. $\left(\frac{J}{s\,m\cdot C^\circ}\right)$ ☆ NOT THE BOLTSMAN CONSTANT ☆

Example.

- $Q_{INSULATION} = Q_{PLYWOOD}$ the temperature in between must be isolated for.

$$\frac{kA\Delta Tt}{L} = \frac{kA\Delta Tt}{L}$$

$$\frac{kA(T_1 - T)t}{L} = \frac{kA(T - T_2)t}{L} \qquad Q = \frac{kA(T_1 - T)t}{L}$$

$$\vdots \qquad Q = 9.5 \times 10^5\ J$$

$$T = 5.8°C$$

$$Q = \frac{KA\Delta T\, t}{L}$$

$$K_A = \frac{Q_A L_A}{t A_A \Delta T_A}$$

$$K_B = \frac{Q_B L_B}{t A_B \Delta T_B}$$

$$K = \frac{QL}{tA\Delta T}$$

⋮

③ RADIATION.

- Energy transfer by electromagnetic waves.
- A material that completely absorbs EM is a perfect blackbody.
- $Q = e\sigma T^4 A t$

$\sigma = 5.67 \times 10^{-8} \left(\frac{J}{s\,m^2 K^4}\right)$

Q = radiated energy

t = emitted time.

T = Kelvin temp.

A = Surface area

e = emissivity.

Thermodynamics [redacted]

- Thermodynamics and their surroundings.
- Heat and Work = Thermodynamics.
- Focus on a system and the environment around it, is the surroundings.
- Walls that permit heat flow = diathermal walls
- Walls that dont = adiabatic
- To understand thermodynamics its necessary to understand the ~~state of the system.~~

[redacted]

Zeroth Law

- Equilibrium → Zero heat transfer. ★ $Q = 0$ ★

- Internal Energy = Internal Kinetic + Potential ← For Ideal gases you dont use potential

  Internal Energy = Internal KE ← Ideal Gas.

- $\Delta U = U_f - U_i = Q$

  $\Delta U = U_f - U_i = -W$. work is positive when the work is done by the system

  $\Delta U = U_f - U_i = Q - W$ work is negative when the work is done to the system.

$$\int \frac{1}{x} dx$$

- Isobaric → const. pressure
  Isochoric → Const. Volume
  Isothermal → Const temp.
  Adiabatic → No heat transfer.

$$\int_{V_i}^{V_f} P\, dV.$$

$$\int_{V_i}^{V_f} \frac{nRT}{V} dV.$$

$$W = \int_{V_i}^{V_f} P dV.$$

$$= \int \frac{nRT dV}{V}$$

$$= nRT \int_{V_1}^{V_2} \frac{dV}{V}$$

$$= nRT (\ln V_f - \ln V_i)$$

$$= nRT \ln\left(\frac{V_f}{V_i}\right).$$

$\ln x_2 - \ln x_1$

$\ln \frac{x_2}{x_1}$

- Isobaric → $W = P\Delta V = P(V_f - V_i)$

$W=0$ ← isochoric → $\Delta U = Q - \underset{W=0}{W}$ → $\Delta U = Q$

Isothermal → $P = \frac{nRT}{V}$ → $W = nRT \ln\left(\frac{V_f}{V_i}\right)$

- Adiabatic - $W = \frac{3}{2}nR(T_i - T_f)$
  - $P_i V_i^{\gamma} = P_f V_f^{\gamma}$
  - $\gamma = \frac{C_p}{C_v}$

Specific Heat Capacity

- $Q = mc\Delta T$
- $Q = C n \Delta T$

molar specific heat capacity

Const P
- $Q_{\text{constant pressure}} = \Delta U + W = \overbrace{\frac{3}{2}nR(T_f - T_i)}^{\Delta U} + \overbrace{nR(T_f - T_i)}^{W = P\Delta V}$
  $= \frac{5}{2}nR\Delta T$
- Constant Pressure for ideal monoatomic gas $= C_p = \frac{5}{2}nR$

$C n \Delta T = \frac{5}{2}nR\Delta T$

$C_p = \frac{5}{2}R$.

- $Q_{\text{constant volume}} = \Delta U + W = \frac{3}{2}nR(T_f - T_i) + 0$
- ~~Constant Pressure~~ $= C_v = \frac{3}{2}R$
- Ideal gas $\gamma = \frac{5}{3}$
- Any Ideal gas $C_p - C_v = R$

2nd Law of Thermodynamics.

- Spontaneous flow of heat.

~~Heat~~ Engine.

Hot → Engine → Work; Engine → Cold

$|Q_H|$ = magnitude of input heat

$|W|$ = magnitude of work done

$|Q_c|$ = magnitude of ~~[illegible]~~ rejected heat

- efficiency $= \frac{|W|}{|Q_H|}$

$$= \frac{|Q_H - Q_c|}{Q_H}$$

$$= 1 - \frac{|Q_c|}{|Q_H|}$$

$$\Delta S = C_v \ln\left(\frac{T_f}{T_i}\right) + nR \ln\left(\frac{V_f}{V_i}\right)$$

$$COP_{Cooling} = \frac{|Q_c|}{W}$$

$$COP_{Heating} = \frac{|Q_H|}{W}$$

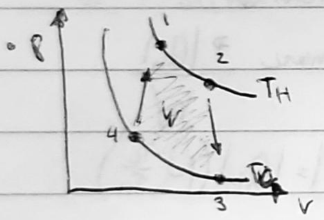
2nd Week

- 0th Law ⇒ $T_A = T_B$ & $T_B = T_C \Rightarrow T_A = T_C$.
- 1st Law ⇒ $\Delta U = Q - W$
- 2nd Law ⇒ V1 → Spontaneous flow of heat from $T_H \to T_C$.
  V2 → Cannot be more efficient than a reversible process.

Heat Engines

- $|Q_H|$ - Input heat, $|W|$ - Useful work, $|Q_C|$ - Heat not used.
- efficiency $= \frac{|W|}{|Q_H|}$ ① $\Rightarrow 1 - \frac{|Q_C|}{|Q_H|}$ ② $\Rightarrow 1 - \frac{T_C}{T_H}$ ③

Carnot's Principle (2nd Law V2)

- 

$$\frac{|Q_C|}{|Q_H|} = \frac{T_C}{T_H}$$

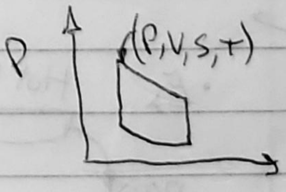
Refrigeration

- $|Q_C|$ ↓ Engine ← work ↓ $|Q_H|$

$|Q_C| + |W| = |Q_H|$

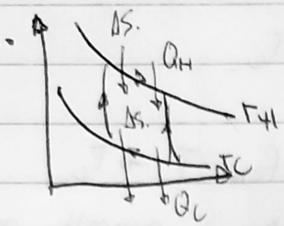
- Coefficient of Performance $= \frac{|Q_C|}{W}$

Entropy Change: $\Delta S = ($



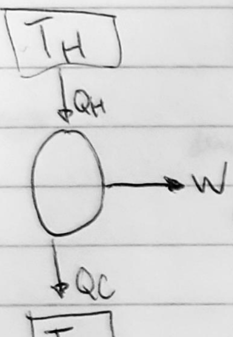
Heat Pump COP $= \frac{|Q_H|}{W}$

Carnot



$$\frac{Q_H}{Q_C} = \frac{T_H}{T_C} \qquad |Q_H| = W + |Q_C|$$

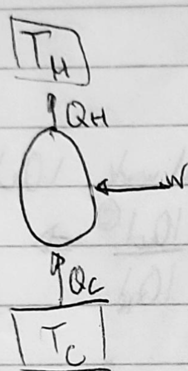
ENGINE



$e = \frac{|W|}{|Q_H|}$

$e = 1 - \frac{T_C}{T_H}$

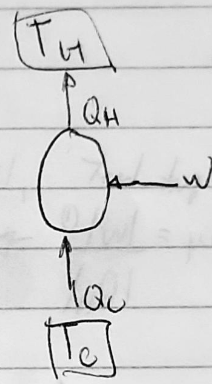
Refrigeration



Coefficient of Performance $\rightarrow \frac{|Q_C|}{W}$

$|W| = |Q_C|\left(1 - \frac{T_C}{T_H}\right)$

Heat Pump



Coefficient of performance $\rightarrow \frac{|Q_H|}{W}$

$|W| = |Q_H|\left(1 - \frac{T_C}{T_H}\right)$

- IDEAL $\rightarrow \frac{Q_H}{T_H} = \frac{Q_C}{T_C}$

  $\rightarrow \Delta S_H = \frac{Q_H}{T_H} = \frac{Q_C}{T_C} = \Delta S_C$

$\Delta S_{\text{lost by system}} = -\Delta S_{\text{universe}}$

- $\Delta S_{TOT} = \Delta S_H - \Delta S_C = 0$

- Ex

$\Delta S_{\text{univers}} = \frac{Q_C}{T_C} - \frac{Q_H}{T_H}$ $\qquad \Delta S_{\text{universe}} > 0$

$= \frac{1200}{350} - \frac{1200}{650}$

$= 1.6 \frac{J}{K}$

2nd Law - Heat flows spontaneously from higher T to lower T never in reverse.

- Irreversible engines (Operating between T_H and T_C) cannot be more efficient than a reversible engine.
- $\Delta S \geq 0$, $\Delta S = nC\ln\left(\frac{T_f}{T_i}\right)$, $\Delta S = nR\ln\left(\frac{V_f}{V_i}\right)$.

- $Q = nC\Delta t$

  $\Delta S = nC\ln\left(\frac{T_f}{T_i}\right)$

- $W = P\Delta V = nRT\frac{\Delta V}{V}$ $\quad \Delta U = 0,\ Q = W$

  $\Delta S = nR\ln\left(\frac{V_f}{V_i}\right)$

$\Delta S = nC\ln\left(\frac{T_f}{T_i}\right) + nR\ln\left(\frac{V_f}{V_i}\right)$ ← Reversible.

$S = K\ln(W)$ $\quad W = \frac{N!}{n_1!\,n_2!}$

$\Delta S = \Delta S_H + \Delta S_C$ $\quad \Delta S = nC_v\ln\left(\frac{T_f}{T_i}\right) + nR\ln\left(\frac{V_f}{V_i}\right)$.

$\Delta S = \frac{Q_H}{T_H} + \frac{Q_C}{T_C}$

$W_{\text{unavailable}} = \Delta S \cdot T_C$.

$W_{\text{done by engine}} = Q_H \cdot \text{Eff}$.

Simple Harmonic Motion and Waves.

- $F = -Kx$ ← distance from equilibrium
  K: Spring Constant → N/m.
  $= -K(x - x_0)$

$f = kx \quad f = \frac{YA}{L}\Delta L.$

$\frac{FL}{YA} = \Delta L.$

$\frac{F 2L}{YA}$

$f = kx \quad f = ky. \quad F_{net} = 0.$

$mg = W$

$f(x)$	$f'(x)$
$\sin x$	$\cos x$
$\cos x$	$-\sin x$
$\tan x$	$\sec^2 x$
$\csc x$	$-\csc x \tan x$
$\sec x$	$-\sec x \tan x$
e^x	e^x
$\ln x$	$\frac{1}{x}$
a^x	$a^x \ln x$
$\log_a x$	$\frac{1}{\log a x}$
$\sin^{-1} x$	$\frac{1}{\sqrt{1-x^2}}$

$x = A\cos\theta = A\cos\omega t.$

A: amplitude; ω: angular frequency

$f = \frac{1}{T} \quad \omega = 2\pi f = 2\pi \frac{f}{T}$

$V_x = -V_T \sin\theta = -\underbrace{A\omega}_{v\ max} \sin\omega t$ } directional changes.

$v_{max} = A\omega.$

Ex $v_{max} = A 2\pi f$
$= (.2\times10^{-3})(2)(\pi)(1\times10^{3})$
$= 1.3 \text{ m/s}.$

Max velo occurs midpoint.

Acceleration.

$a_x = -a_c \cos\theta$
$= \underbrace{-A\omega^2}_{a_{max}} \cos(\omega t)$

Frequency of vibration

$$\left.\begin{aligned} F_{net} &= ma \\ \cancel{k}x &= ma. \\ -kx &= -mA\omega^2 \\ -kA &= -mA\omega^2 \leftarrow x = A. \\ \sqrt{\frac{k}{m}} &= \omega. \end{aligned}\right\}$$ for springs and masses.

$A \Rightarrow v_{max} = A\omega$
$= A\frac{2\pi}{T}$

$B \Rightarrow v_{max} = 2A\omega$
$= 2A\frac{2\pi}{2T}$
$= A\frac{2\pi}{T}.$

$\cancel{x} = A\cos\omega t.$
$x = \frac{3\cancel{x}}{4}\cos\omega t.$
$\cos^{-1}\left(\frac{4}{3}\right)\cancel{A} = \omega t.$

$v = \frac{d}{t}$

$t = \frac{d}{v} \Rightarrow t = \frac{43 A\cos\omega t}{43}$

$\omega =$

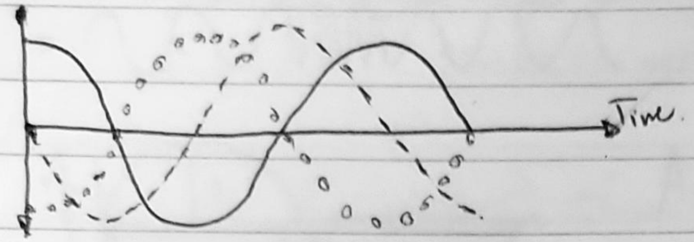
$f = \frac{\sqrt{\frac{k}{m}}}{2\pi}$

$f_N = \frac{\sqrt{\frac{k}{3m}}}{2\pi}.$

$x(t) = A\cos(\omega t)$ ————

$v(t) = -A\omega \sin(\omega t)$ - - - -

$a(t) = -A\omega^2 \cos(\omega t)$ • • • • •



Energy

- $PE = \frac{1}{2}kx^2$ (—)
- $= \frac{1}{2}k A^2 \cos^2(\omega t)$

$KE = \frac{1}{2}mv^2$ (- - -)

$= \frac{1}{2}m A^2\omega^2 \sin^2(\omega t)$

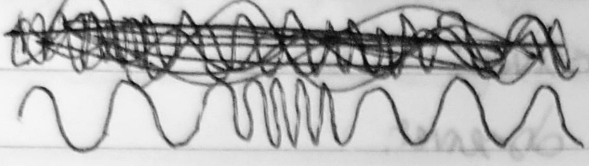
Pendulums

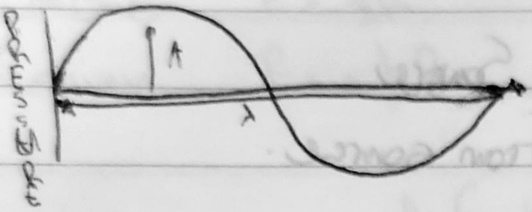
- $\omega = \sqrt{\frac{g}{L}}$ - Simple pendulum
- $\omega = \sqrt{\frac{mgL}{I}}$ - Physical pendulum

$$v = \sqrt{\frac{\overbrace{F}^{\to \text{Tension}}}{\underbrace{\frac{m}{L}}_{\Rightarrow \text{Linear Density}}}}$$

Sound, Linear Super Position, and Interference Phenomena.

Longitudinal Waves

- 

-  $A\sin\left(\frac{2\pi x}{\lambda} - 2\pi f t\right)$

- $v = \sqrt{\frac{\gamma k T}{m}}$ $\quad k = 1.38 \times 10^{-23}$.

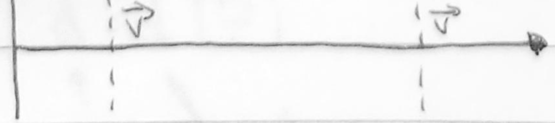
- Liquids → $v = \sqrt{\frac{B}{\rho}}$

  Solids → $v = \sqrt{\frac{Y}{\rho}}$

$I =$

Sound Intensity

- $I = \frac{P}{A} = \frac{\text{Power}}{\text{Area}}$.

- 

Doppler Effect.

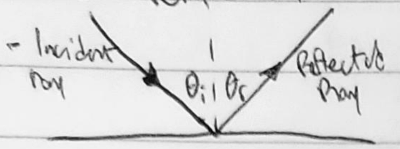
- $\lambda' = \lambda - v_s T$
- $f_o = f_s\left(\frac{1}{1 - \frac{v_s}{v}}\right) \leftarrow$ Towards observer
- $f_o = f_s\left(\frac{1}{1 + \frac{v_s}{v}}\right) \leftarrow$ Away from observer.
- Moving Observer
  - $f_o = f_s\left(1 + \frac{v_o}{v}\right) \leftarrow$ Towards Source
  - $f_o = f_s\left(1 - \frac{v_o}{v}\right) \leftarrow$ Away from source.

- General Case $f_o = f_s\left(\frac{1 \pm \frac{v_o}{v}}{1 \pm \frac{v_s}{v}}\right)$

- $A\sin\left(\frac{2\pi x}{\lambda} - 2\pi f t + \text{constant}\right)$

The Reflection of Light: Mirrors.

- Law of Reflection



$\theta_i = \theta_r$.

- Concave $f = \frac{1}{2}R$.
  Convex $f = -\frac{1}{2}R$.

f> focal length.

- $\dfrac{1}{d_o} + \dfrac{1}{d_i} = \dfrac{1}{f}$

$m = \dfrac{h_i}{h_o} = -\dfrac{d_i}{d_o}$

$n = \dfrac{c}{v}$

$nv = c$. $c = c$.

$nv = nv$.

$n_A 1.4v = n_B v$.

$\dfrac{n_A}{n_B} = \dfrac{1}{1.4}$.

Snells

- $n_1 \sin\theta_1 = n_2 \sin\theta_2$.

Apparent Depth. $d' = d\left(\dfrac{n_2}{n_1}\right)$

Apparent Actual.

$d_o > 2f$: real ; inverted ; $h_i < h_o$

$2f > d_o > f$: real ; inverted ; $h_i > h_o$

$d_o < f$: virtual ; upright ; $h_i > h_o$

$$\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f} \qquad m = \frac{h_i}{h_o} = -\frac{d_i}{d_o}$$

$$d_i = \frac{1}{f} - \frac{1}{2f}$$

$$\frac{1}{d_i} = \frac{1}{2f}$$

$$d_i = 2f$$

$\sin\theta = \frac{m\lambda}{w}$ $m =$ ~~integer~~ integer. * Dark fringes single slit.

$\sin\theta = \frac{m\lambda}{d}$ * Bright 2 slit

$\sin\theta = \frac{(m+\frac{1}{2})\lambda}{d}$ * Dark. 2 slit.