ISOCHORIC: constant volume
- temp increase, U increase
- rigid volume unusual in living; vacuum/high pressure

$W = 0$ because no volume change

$Q = n * C_V(T_{final} – T_{initial})$; C_V = molar heat capacity

$\Delta U = Q$

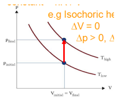
- **IDEAL:** $U = 32*n*R(T_{final} – T_{initial})$

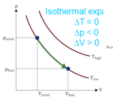
ISOTHERMAL: constant temp
- heat transfers through system and released as work to piston

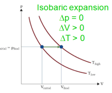
$W = – n R T \ln(V_{final}/V_{initial})$ $Q = -W$ $\Delta U = 0$

ISOBARIC: constant pressure
- heat transfers through system and released as work to piston

$W = – p (V_{final} - V_{initial})$ $Q = n C_p(T_{final} – T_{initial})$ $\Delta H = Q$







ADIABATIC PROCESSES (processes with no heat exchange with environment)

$Q = 0$ $\Delta U = W$ $\Delta U = n C_v \Delta T$
- all heat reservoirs disconnected from system
- all energy comes from internal energy
- **IDEAL GAS:**

$\Delta U = 32 n R \Delta T$; $W = -p \Delta V$

$32 n R \Delta T = n R TV \Delta V$

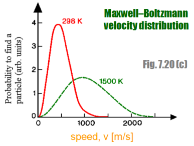
$V_i * T_i^{3/2} = V_f * T_f^{3/2}$

$V_i * T_i^{Cv/R} = V_f * T_f^{Cv/R}$; **Poisson's equation**

$T = pV/nR$; $C_V = C_P - R$

$p_i V_i^k = p_f V_f^k$; k = **adiabatic coefficient** = C_p/C_v = 5/3 gas

- **Maxwell-Boltzmann velocity distribution**: probability, shows us a function of speed vs the fraction of molecules in a gas that lie in an interval of width δ. Vertical axis = probability density because it provides fraction of particles for each bin around respective velocity



-**tells us**: temp of gas, rms, most common speed
- temperature and internal energy cannot be defined without thermal eq'm
- at higher temps more gas particles moving at higher speeds
- **"thermal eq'm only defined when enough particles in system to determine velocity distribution that can be compared to Maxwell-Boltzmann distribution"; temperature is collective property .: temperature is a parameter which characterizes system only when system in thermal eq'm**
- **ideal heat reservoir**: allows heat to flow into or out of system when eq'm thermal contact with gas, ideal because no temp change with heat exchange

ENERGY OF GAS – (J)

$\Delta U = U_{final} – U_{initial} = Q + W$
- Kinetic Energy: $p V = 23 (12 \cdot N \cdot m \cdot v^2) = 32 \cdot E_{kinetic} = nRT$
- Internal Energy (U) = KE = 32*nRT (.: independent of pressure/volume)
- .: when T = 0, V = 0 since no motion? No KE? But finite V .: fail

First Law of Themodynamics. Thermodynamics, thermal physics = study of heat & thermal energy

○ - Temperature: $T=T0+ 1\alpha Hg \cdot h- h0h0$; T_0 = arbitrary reference temp ; h- h0h0 = fraction of height change of mercury column ; αHg = coefficient of linear expansion

● - Latent heat = phase transition temperature when heat supplied to system is used to complete phase transition

● - Thermal eq'm, zeroth law of thermodynamics: in thermal eq'm, every part of system has same temperature. More specifically, if objects A & B are separately in thermal eq'm with a 3rd object (e.g., a thermometer), then objects A & B are in thermal eq'm with each other (zeroth law of thermodynamics)

- Definition of heat: $Q = c*m*\Delta T$; c = specific heat capacity in J/(kg*°C) ; **$Q = C * n/MM * \Delta T$**; C = molar heat capacity; heat = **Joules, J = $(kg*m^2) / s^2$ = N*m**

● - Any amount of heat flowing into system or any work done on system are positive as they increase total energy of system. opposite processes are negative as they lead to a reduction of total energy of system.

● 1 Cal (energy) = 1000 cal (heat) ; 1 Cal = 4.1868 J ; 1 g/cm^3 = 1000 kg/m^3 = 1 kg/L ;1 L = 0.001 m^3 ; C_{water} = 4.186 kJ / (°C*kg)

○ - 1st law of thermodynamics for an isolated system: conservation of energy: sum of all energy forms in an isolated system is constant (matter cannot be created nor destroyed). Internal energy of system: $U_{isolated\ system} = 0$

○ - 1st law of thermodynamics for a closed system: sum of all energy forms in a closed system changes by amounts of heat & work that flow between system & environment. Internal energy of system: $U_{closed\ system} = Q + W$

● - U = state function (like temp, pressure, volume – all independent of history)

Mechanical Work: *system = **eq'm** when all essential physical parameters don't change wit time.* ….eq'm: Mechanical; Thermal ; Chemical; Electric; Electrochemical

- Energy can flow from 1 place to other &/or E can convert from 1 form 2 other. E = capability of system to do work. Heat & work when energy flows in / out of system. **Work done on or done by (describes flow direction; not transfer). Heat received or released.** Energy with descriptive (e.g. kinetic, thermal) when converts

- **Isolated superstructure**: artificial boundary around system/environment so both 2gether r isolated from world
- **Isolated systems**: NO exchange E/matter wit their environment (double dashed lines round system). Hard to establish exp, imp cuz math equations work perfect e.g. calorimeter. Law of Conservation of E: total E of system = sum of all individual contributions (all forms). Total E = internal E of system, conserved. In eq'm, time-independent, each type of E separately constant. Non-eq'm, 2 ways:
- **Closed systems**: exchanging E but NOT transferring matter with environment (single dashed line). Require isolated superstructure envelope so E balance in environment

E.g. glassware reaction with external heating (closed if no gas exchange with external environment). First law of thermodynamics: change of internal E of system between initial & final state is due to 2 contributions

  Work released to or received from environment
  Heat exchanged with environment
  eq'm arrows, heat/work can both enter&leave
- **Open systems**: exchanging matter & E with environment (double-arrows). All matter has E .: can't exchange matter w/o E

- **physical membrane**: barrier separating 2 uniform systems. Each system is in eq'm. At least 1 parameter varies b/w 2 systems, establishing a non-eq'm across membrane. Width and chemical composition
- parameter = **physical** (pressure, temp) or **chemical** (concentration of molecules)
- degree of interaction allowed between 2 systems membrane is separating = permeability (impermeable, fully permeable, **semipermeable**, selectively permeable)
- **width** membrane (thickness) important too thick = impermeable sometimes .: zero-width membrane and finite-width membrane ; - **zero-width**: neglect mechanisms of transport, focus on systems; **finite-width** to focus on transport mechanisms
- time-dependent transport of physical or chemical properties (transport phenomena) heat conduction, diffusion, viscosity, electric current
- heat conduction: flow of energy to eliminate temp differences
- diffusion: process by which molecules move from higher concentration to lower concentration region

FOURIER'S LAW: flow of heat, measured heat transfer through rod/s
- **experiment**: quantified heat conduction in (well-insulated) rod connecting 2 heat reservoirs (const temps, 0°c ice bath and 100°C boiling water) at diff temps; $T_{high} – T_{low}$

$$\frac{Q}{t}\left[\frac{J}{s}\right] = \lambda\, A\, \frac{T_1 - T_2}{L}[K]$$

- with λ thermal conductivity in J/(m · s · K) ; L = length ; A = cross-sectional area of rod ; proportionality constant depends on rod composition; 1 = high, 2 = low (temperatures)
- $\lambda > 0$ for all; metallic good thermal conductors, non-metallic poor, gases/liquids usually poor
- sheet thickness l/λ = **R, thermal resistance**

$-\Delta T/\Delta x$ = gradient

$$T_x = \frac{R_1 \cdot T_{high} + R_2 \cdot T_{low}}{R_1 + R_2}$$

: Tx = temperature in between interfaces of 2 blocks
- **convection**: air flow across skin heat loss, enhanced in air (more for under darker colours)
- **perspiration**: heat loss from water phase change liquid to vapour (thermal energy provides latent heat of evaporation), 2428 kJ / L water, only effective in dry air
- **radiation**: heat loss without medium, heat transport when cooler surface lies in line of site of hotter one

Work: $W = F * d*\cos(\theta)$. scalar (no direction); but + or – ; **joules: J = N * m = $(kg*m^2) / s^2$.** Only if F constant. can have components. **only force** component **in direction of displacement** contributes to achieved work. **THETA b/w F and D**.

W > 0	W < 0
- if F & d = parallel	- if F & d ANTIparallel
- system **receives** work /	- system **releases** work /

work done **on** system **(op)** work **done by** system **(KE / velocity up)**

- identify yourself with system, whatever you get (work) is positive since you have more after; whatever you release is negative since you have less after
- Power: P = rate @ work done, watt (1 W = 1 J/s). **P = W / t. P = F * v** (F = const). Horsepower: 1 hp = 746 W

Energy: When a system interacts wit environment, its exchange of work represents a change in E in system
- Kinetic energy: work stored in speed of object | e.g. blood carries high kinetic energy into aorta, reduces past arch
- Potential energy: work stored in position of object relative to other objects
- Gravitational potential energy: energy of an object due to position relative to surface of Earth |e.g. blood at head vs feet
- Electric potential energy: energy of electrically charged object due to its position relative to other electric charges (E.g. electric energy governs transport of nerve impulses)
- Elastic potential energy: energy due to relative position of 2 objects that are connected through elastic medium, typically spring (e.g. elastic energy allows us to characterize molecular vibrations in diff parts of ATP)
- Thermal energy: stored in irregular motion of particles; temperature of system is measure of this energy (e.g. thermal energy generated & released when endotherms maintain constant core body temperature)
- Chemical energy: work stored in chemical bonds of molecules (e.g. chemical energy is transferred during ATP hydrolysis)
- Latent heat: work stored in phase of matter, such as liquid, gaseous, or solid state (e.g. is dissipated during perspiration because perspiration is associated with evaporation of water from skin surface)
- **Mechanical energies = kinetic, gravitational potential, elastic potential**

- **Spirometer**: instrument, measure gas volume in lungs
- tidal V: 0.5 L, usual inhale/exhale, 7.5 L air/min ;
- inspiratory reserve V: 2.5 L (short term) ; - expiratory reserve V: 1.5 L ; - residual V = 1.5 L
- pressure in lungs after exhalation = atmospheric pressure
- BTPS = Body Temp Pres Saturated: 37ºC, 1 atm, p_{water} = 6.3 kPa
- ATPS = Ambient Temp Pres Saturated: spiro temp, 1 atm, p_{water} = 2.3 kPa
- STPD = Standard Temp Pres Dry: 0ºC, 1 atm, p_{water} = 0

1 L = 0.001 m³

FICK'S LAW DIFFUSION

$$\frac{m_i}{t} = D\,A\,\frac{\rho_{i,\,high} - \rho_{i,\,low}}{l}$$

; A = contact area, l = width

D = diffusion coefficient [m²/s]; n = mol component, c [mol/m³] = p / MM;

j_i = **material flux** = $\frac{n_i}{t} = D\,A\,\frac{c_{i,\,high} - c_{i,\,low}}{l}$ = amount of matter that continuously passes given location in unit (mol/s)

-Δc/Δx = concentration gradient
- occurs in steady state, no essential parameter of system varies with time

TEMPERATURE DEPENDENCE OF DIFFUSION
- phenomenological law: not derived theoretically but describes phenomenon
- crystalline silicon matrix chosen
- fast diffusers = **interstitial diffusion**
- slow diffusers = **substitution diffusers**: move from lattice site to lattice site, displacing silicon atoms

$D = D_0\, e^{\left(-\frac{\Delta E}{kT}\right)}$; D = diffusion coefficient [m²/s], temp dependent ; D_0 = pre-exponential factor [m²/s]; DE = E_A [J]/molecule ; k = k_B = Boltzmann's constant = 1.38×10^{-23} J/K ; T = temp [K]

- $\ln(D) = \ln(D_0) - \frac{\Delta E}{kT}$ = **Arrhenius plot**, y = mx + b; b = ln(D_0) ; m = –E/k
- .: D becomes larger at higher temp
- E_A = energy barrier for single hop of diffusing particle from one possible site to adjacent one .: temp only GIVES energy but doesn't change E_A, E depends on arrangement of matrix atoms
- 1 J = 6.24×10^{18} eV

- **Einstein's diffusion formula**: (**diffusion length =** , average distance diffusing particle moves during time *t*) $\Lambda\ [m] = \sqrt{2 \cdot D\ [m^2/s] \cdot t\ [s]}$
- particles select jump sites randomly from neighbouring eq'm sites

OTHER
- Q. **WHALE** Area of sphere = 4 π R² .: for whale, **$(Q/t)_{loss}$ = (110 J/m*s) * R²/l.** Food consumption (unit kg/day) = e * $m^{3/4}$; e = 0.01 ecotherm; e = 0.11 endotherm. **Metabolic rate** (M) [Kj/day] = 450 (m [kg])$^{3/4}$ = 5.2 $m^{3/4}$ (J/s) = **(heat source), $(Q/t)_{gain}$.** relate mass to volume V = (4/3) π R³, d = m/V. d = 1020 (avg density sea water) = **2750 * $R^{9/4}$** equate loss and gain .: **l = 0.04 / $R^{1/4}$** **BULK EFFECT**, large R needs thinner fat layer

- U = 32*nRT = ½ * MM * v²
- **ε** (U per particle) = 32 * R*TNA = 32 **k * T** ; k =**Boltzmann constant** = RNA = 1.38×10^{-23} J/K
- **root-mean-square speed, v_{rms}** = v2=3*R*TMM=3*k*Tm .: p, V independent

Kinetic Energy: **E_{kin} = ½ * m * v²** ; system = isolated object
- Work-kinetic energy theorem: W = $E_{kin,final} - E_{kin,intial}$ when work is done on object causing exclusively a change in its speed, that work is equal to change in kinetic energy of object

- Potential Energy: **E_{pot} = mgh** : W = $E_{pot,final} - E_{pot,intial}$
- Definition of potential energy is based on external force that is required to establish at least 2 different eq'm states for system (rest @ position 1 @ time 1; rest @ position 2 @ time 2). Simplest transfer = lower system very slowly from initial to final height, constant speed, so system always in mechanical eq'm
- Potential energy depends linearly on distance of system from surface of Earth. This statement is correct as long as we remain close to surface of Earth, in particular up to heights reached by birds in flight (upper end of biosphere)
- Cannot be defined for all forces, leading to distinction between conservative forces (with potential E) & dissipative forces (without potential E)

EMPIRICAL GAS LAWS
- **Boy's Law** (Robert 1664): **p * V = const;** isothermal (no temp change)
    - U-shaped tube with Hg @ eq'm, seal U, add Hg, increase p,
- **Charles' Law** (Jaques Alexandre 1787): **V/T = const** ; isobaric (no pressure change)
    - U-shape, seal, increase T, remove Hg to even p
- **Kelvin** extrapolated lines to **-273.15ºC** (V vs T)
- 1 mol of ideal gas: 6.02×10^{23} particles (**Avogadro**) - 1 mol gas always V = 22.414 L (0ºC)
- **universal gas constant** = R = 8.314 J/(K*mol), other units atm*m3K*mol ; calK*mol
- **ideal gas law** = pv = nRT ; **(Pa)(m³) = (mol)(R)(K),** classical thermodynamics, macroscopic approach
- **1 atm = 101 325 Pa = 760 torr = 760 mmHg**
- plethysmograph: airtight box, measure volume change of body in box using pressure in box (Boyle): V_{lungs} = p.final* ΔVp.atm-p.final - **Pressure**: p= F.xl2= m*vx2l3= m*vx2V

4 postulates that define a gas as a mechanical system
- **kinetic gas theory** (statistical thermodynamics, microscopic approach) based on mechanical model of gas, gas by made by particles, exclude molecular properties (vibrations, rotations)

(1) individual volumes of particles are negligible (2) gas consists of very large number of identical particles (3) particles are in continuous random motion (4) only form of interaction between the particles or between particles and container walls are elastic collisions

- average x-component of velocity (v_x) = 1/N * sum of V_x **- p*V = 12 * N * m * v²**

Gas Model Work, Gas Pressure. Gas model: container wall ideal (isolated system), ideal piston, etc

● - **pressure: *p* = F / A** ; F = perpendicular to piston surface, F parallel to surface does not affect piston

Unit = **pascal (Pa) = N/m² = kg / (m*s²)** ;

1 atm = 101 325 Pa. Scalar = vector / scalar. **.: p = ^{1A} F * n**

● - **Work is done when F_{ext} pushes piston resulting in displacement; piston & force = parallel**

○ **W** = F_{ext} * Δd

= FextA (A * Δd)

= -*p* * ΔV

● - absolute value of work is **area under curve** of force as a function of position, F(x), between initial & final position of displacement W=limn→ ∞i=1nFi*xfinal- xinitialn

● - Work = area under curve of *p* vs V for gas

○ =-limn→ ∞i=1npi*Vfinal- Vinitialn ; work on a gas (vs mechanical work)

- Gas expansion (volume increases):

$V_{initial} < V_{final}$ **W < 0** = GAS work ON piston

- Gas compression (volume decrease):

$V_{initial} > V_{final}$ **W > 0** = PISTON work ON gas

○ .: compression of gas = positive work, work done ON gas

○ .: expansion of gas = negative work, force & displacement opposite directions

$$\sum_{i=1}^{4} W_i = -RT_{high} \ln\left(\frac{V_2}{V_1}\right) - RT_{low} \ln\left(\frac{V_4}{V_3}\right)$$

$$Step\ II: T_{high}^{\frac{C_v}{R}} V_2 = T_{low}^{\frac{C_v}{R}} V_3$$

$$Step\ IV: T_{high}^{\frac{C_v}{R}} V_1 = T_{low}^{\frac{C_v}{R}} V_4$$

$$\rightarrow \frac{V_2}{V_1} = \frac{V_3}{V_4}$$

SUMMARY: Carnot process per cycle with 1 mol ideal gas: $W = -R\,(T_{high} - T_{low})\ln(V_2/V_1)$ $Q = -W$ $\Delta U = 0$

Efficiency coefficient: $\eta \equiv \frac{|net\ work|}{heat\ input} = \frac{|W_1 + W_3|}{Q_{high}} = \frac{T_{high} - T_{low}}{T_{high}}$

- Q. spirometer V = 5 L; $fraction_{initial}$ = 10% He instead of air. In/Out, in spiro = 6.25% He. V_{lungs}? $f_{initial} * V_{spiro} = f_{final}(V_{spiro} + V_{lungs})$

- **Bohr's formula for dead space in respiration**: V.deadspaceV.total= f.exhaled-f.alveolif.inhaled-f.aveoli

- density = m/V = n*MM/V C = n/v = d/M; inverse = **volume per mole particles**

- changes in pressure occurring at higher temperatures = MORE heat loss

THE CARNOT PROCESS

- system = ideal gas, sealed in container with frictionless piston - piston and 2 heat reservoirs (T_{high} and T_{low}) = environment

- superstructure (system and environment) NOT in eq'm since reservoirs = diff Ts - START: gas at temp T_{high}, $p = p_1$, $v = v_1$

1) isothermal expansion: contact with HIGH to keep at T_{high}

- system thermal contact with HIGH; LOW isolated; $Q_1 = Q_{high}$ so T constant v_2, p_2; gas does work on piston

(work) $W = -R\,T_{high} \ln(V_2/V_1)$; (heat) $Q = -W_1$; (Internal energy change) $\Delta U = 0$

2) adiabatic expansion: isolated; gas expanding; temp drops to T_{low}

- HIGH disconnected, gas expands but adiabatically, T_{high} drops to T_{low}; v_3 (max), p_3 (min); gas more work ON piston

(work) $W = \Delta U_2$; (heat) $Q = 0$; (Internal energy change) $\Delta U = C_V(T_{low} - T_{high})$

3) isothermal compression: contact with LOW to keep at T_{low}

- LOW contact, gas compressed to p_4, V_4; heat $Q_3 = Q_{low}$ released to reservoir to maintain temp of system; piston work ON gas

(work) $W = -R\,T_{low} \ln(V_4/V_3)$; (heat) $Q = -W_3$; (Internal energy change) $\Delta U = 0$

4) adiabatic compression: isolated; temp rises to T_{high}

- p_4, V_4, then LOW removed, gas compressed adiabatically, raises gas temp, system back to T_{high}, p_1, V_1; piston again work ON gas

(work) $W = \Delta U_4$; (heat) $Q = 0$; (Internal energy change) $\Delta U = C_V(T_{high} - T_{low})$

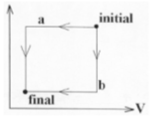
- KE after M falls? PE: M falls X, but m gains X*sin0
- **Q.** Biological System: OPEN = everything (e.g. human, we lose heat and cycle matter); CLOSED = dormant virus with rigid membrane; ISOLATED = none
- **Q.** m = 0.2 kg, initial velocity = 30 m/s UP. (a) KE @ high point? UP speed @ top = 0 m/s .: KE = 0 (b) PE @ high point? total ME conserved .: use KE @ start where PE = 0, .: 90 J (c) how far high point above initial position? PE =mgh
- **Q.** bhvr of crows indicates optimum height exists for dropping molluscs such that lifting E required per mollusc is min. is obs consistent wit assumption that probability P for mollusc shell to crack is proportional to its linear momentum @ impact?

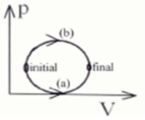
Probability to crack open shell = y * $m_{mollusk}$ * v_{ground}. y = proportionality factor.
Total lifting work for crow per mollusc: W_{total} = N * ($m_{mollusk}$ + m_{crow}) *g*h. N = # drops needed to crack from height h. N inversely proportional to P . N = 1/P. e.g. P = 50%; N = 2 attempts. .: W_{total} = 1/P * ($m_{mollusk}$ + m_{crow}) *g*h . .: conservation of energy…
$m_{mollusk}$ *g*h = ½ * $m_{mollusk}$ * v^2_{ground} . .: v_{ground} = sqrt(2*g*h).
..: W_{total} = ($m_{mollusk}$ + m_{crow}) / (sqrt(2) * y * $m_{mollusk}$) * sqrt(g*h). work proportional to sqrt(h) .: no minimum @ finite h .: P NOT proportional to momentum of mollusk
- **Q.** Air, 100 kPa, sealed wit piston (A = 10.0 cm^2). Push piston with additional F = 100 N to compress. Final p? change to standard units. Pressure by F: p = F/A = 100 kPa + 100 from before
- **Q.** Formula describe reading of temp T when measured by expanding Hg column? H = Hg height; H = height @ reference temp; A and B = const, A = reference temp @ h=H. .: T = A – B(h – H / H)
- **Q.** winter, store food underground with large open barrel of water . heat stored in liquid water helps keep temp of storage above freezing
- **Q.** amount air for which temp can rise 1 degree if 1 m^3 water cools by 1 degree. Heat goes from water to air, .: Q = $c_w p_w V_w \Delta T$ = $c_{air} p_{air} V_{air} \Delta T$; solve for V_{air}
- **Q.** what is wrong with stating that of any 2 objects, one with higher temp has more thermal E? heat capacities and masses of objects have been neglected.
- **Q.** 2 masses over 2 pulleys. Speed after moved down 0.4 m? PE = mgh + mgh of BOTH HANGING MASSES e.g. PE = g(m_1*h + m_3*-h) ; .: PE_{final} = ½ * (m_1 + m_2 + m_3) *v^2_{final}
- **Q.** Water at top of Niagara = 10oC, falls 50 m, assume all PE TE, temp water @ bottom? ∆T = PEcH20*mH20= mH20*g*hcH20*mH20 , independent of mass
- **Q.** You want to push an object up a ramp onto a platform. Do you need to do less work if you lengthen the ramp, as this lowers the angle of the ramp with the horizontal?

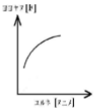
You need less force but for a longer distance. In the end, you end up doing the same amount of work. Note that, if there is also friction acting on the object, you will end up doing extra work by increasing the distance over which that force acts.?
- **Q.** Which of the following reasons did not contribute to Celsius' choice of the melting point of water (at 0^0C) and the boiling point of water (at 100^0C) as the two reference points on his newly developed thermometer? (A) Reproducibility of a reference system at these two temperatures. (B) Easy accessibility of water as the system providing the two reference temperatures. (C) Technical simplicity of obtaining a water system at all three states of matter: solid, liquid and vapour. (D) The temperature independence of the heat capacity of water between 0^0C and 100^0C
- Q. The specific heat for a material A is greater than that for a material B. If equal amounts of heat are added to both materials, the one reaching a higher temperature will be (assume that no phase transitions in either material occur): (A) material A, (B) material B, (C) they reach the same temperature, (D) it could be either material A or B. Answer: (D) because the final temperature depends also on the mass of the object.
- Q. Concrete has a higher specific heat than soil. Can this help us to explain why a city usually has a higher temperature than the surrounding countryside? Answer: During the night, concrete releases significant amounts of thermal energy as heat to the cooler air.
- Q. Ethyl alcohol has about 50% of the specific heat of water. If equal amounts of alcohol and water in separate beakers are supplied with the same amount of heat, which liquid will show the larger increase in temperature? Answer: The ethyl alcohol temperature increase (ΔT) is about twice that of water.

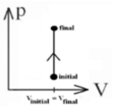
- **Q.** Which needed for Celsius thermometer? Mercury filling, **thermal eq'm** b/w sample & thermometer. 3 calibration points for temp scale (2 needed)
- **Q.** Why distinguish terms heat / thermal E? Same reason we introduced work / PE as diff terms (work / heat = forms of E transfer; TE / PE = forms of E system can have/hold/possess)
- **Q.** which NOT in **Joule's** experiment? Temperature increases || object on string moves down || stirrer moves in direction indicated arrow || pulley rotation accelerates || ambient pressure > air pressure || liquid in beaker moves up || object on string UP || temp DECREASE || stirrer opposite to arrow stirrer spinning faster inevitable in RL
- **Q.** why HEAT and WORK have the same units? b/c both represent E transferred to or from a system
- **Q.** why HEAT and THERMAL E have same units?? b/c both represent E transferred to or from system || both related to irregular motion of gas || NONE
- **Q.** u try to prevent car rolling down road. car does work on you
- **Q.** u prevent car rolling down road, succeed and HOLD IT IN PLACE. No work is done either way (no movement!)
- **Q.** u push crate across level floor, **NO MOVE**. No work done
- **Q.** u push crate down slope. You do work on crate
- **Q.** u push car up into garage. You do work on car .: NEGATIVE WORK ON YOU
- **Q.** which **NOT ASSUMPTION** when derived KE formula? Nonnegative velocities exist || KE increases with increasing speed || kinetic energy depends on mass || KE depends linearly on speed
- **Q.** which **NOT ASSUMPTION** when derived PE formula? Experiment on surface of Earth || specific form of PE = gravitational PE || **PE linearly on height above ground (result, not assumption)** || ground level is y = 0 (challenged) **but NOT REALLY ANSWER**

- **Q.** p-V, gas goes a, returns along b. work is positive ;;;;;; **Q.** initial to final along a? path impossible || work=0 || depends on axes values || path = compression
- **Q.** p-V gas, initial to final ; path b? work is negative, W < 0 ;;;;;; - **Q.**? work for "a" > work for "b"
- **Q.** speed (y-axis) / KE (x-axis) = **NONLINEAR** RELATIONSHIP || heat / temp || height / PE
- **Q.** W? || W = 0 (no V change)









- light has **wave-corpuscle duality**
- ray model: light moves straight lines in homo medium, changes direction when reflected by/passing through interface into another medium

FLAT MIRROR REFLECTION

- **law of reflection**: $\alpha_{in} = \alpha_{out}$
- real image: light rays actually reach image vs virtual image

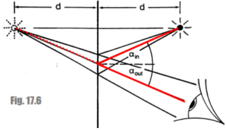
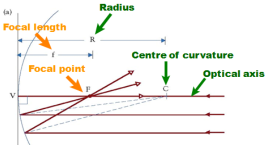


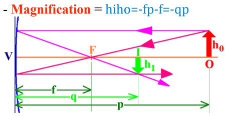
Fig. 17.6

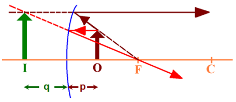
SPHERICAL MIRROR



- light rays must come from infinite distance away .: hit parallel to mirror, [must be close to optical axis]
- C = centre of curvature**;** - R = radius of curvature
- **focal point**, focal length; **f = Radius/2**
- no focal point = spherical aberration, use apertures to confine spread
- light rays parallel will go through f and vice versa
- **Mirror equation:** 1f=1p+1q ; f = focal length, p = object distance; q = image distance

- **Magnification** = hiho=-fp-f=-qp





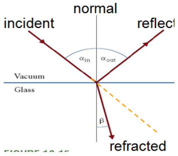
- (1) Foot of object along optical axis (2) Parallel to axis, then through F (3) Through F, then parallel

SIGN CONVENTIONS FOR MIRRORS:

p is + if the object is *in front of* the mirror (real object) p is – if the object is *behind* the mirror (virtual object)
q is + if the image is *in front of* the mirror (real image) q is – if the image is *behind* the mirror (virtual image)
R and f are + if centre of curvature is *in front* of mirror i.e. *concave* mirror ®)
R and f are – if centre of curvature is *behind* mirror i.e. *convex* mirror ® (
If M is + the image is upright
If M is – the image is inverted
If M > 1 magnification If M < 1 reduction

REFRACTION

- **Fermat principle of least time**: actual path of light rays between 2 points (in same or diff media) is such that takes less time for light to traverse path than would to traverse any other path
- **optical depth**: measure of transparency.
- **Snell's law:** sin(αin)sin(β)=n ; n = index of refraction

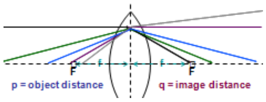


- sin(α)sin(β)=cvlight
- going TO denser = ray closer to normal
- going TO less dense = ray AWAY from normal
- **law of refraction**: $\mathbf{n_1 * \sin \alpha_1 = n_2 * \sin \alpha_2}$
- objects below surface of denser medium appear closer to surface than are
- when α such that $\alpha_2 \geq 90^{o}C$, α = threshold angle for **total reflection**

$$\frac{\sin \alpha_1}{\sin \alpha_2} = \frac{v_1}{v_2} = \frac{v_1 / c}{v_2 / c} = \frac{1 / n_1}{1 / n_2} \qquad n_1 \sin \alpha_1 = n_2 \sin \alpha_2$$

$$\sin \alpha_1 / v_1 = \sin \alpha_2 / v_2$$

- **refractive power for spherical interface:** n1p+n2q=n2- n1Radius ; **refractive power** has unit dioptre (dpt) = m^{-1}
- **refraction** for **flat**: q=-n2n1 p , when p = infinity, **q = f**
- **Magnification** = hiho=-n1*qn2*p

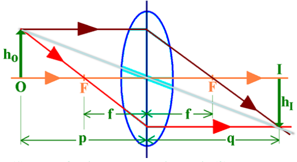


point source on optical axis

SIGN CONVENTIONS FOR LENSES

p is + if the object is *in front* of the lens (real object)
p is – if the object is *behind* the lens (virtual object)
q is + if the image is *behind* the lens (beyond lens) (real)
q is – if the image is *in front* of the lens (virtual image)
R (R_1 or R_2) is + if the centre of curvature is *behind* the lens (convex) ® (c
R (R_1 or R_2) is – if the centre of curvature is *in front of* the lens (concave) ® c)
f is + for a converging lens
f is – for a diverging lens
If M is + the image is *upright*
If M is – the image is *inverted*
If |M| > 1 magnification
If |M| < 1 reduction

- **Lens**: transparent objects with at least one partially spherical refracting surface
- **converging** (convex outer), **diverging** (concave outer)
- thin lens, single refracting plane
- focal point = where all parallel rays from infinite source intersect, light rays not too far from optical axis
- **Thin-lens formula**: 1f=1p+1q
- **Magnification** = hiho=-qp
- **Refractive power R FOR THIN LENS = 1/f**



- (1) Foot of object along optical axis (2) Parallel to axis, then through F (3) Through F, then parallel (4) Through center

Newton's Laws of Mechanics

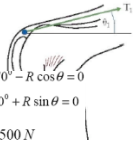
1) Object is in mechanical equilibrium if the forces that act on the object are balanced, resulting in no change of its velocity
2) If instead a set of unbalanced forces that act on the object, it accelerates proportional to the magnitude and direction of F_{net} .: $\mathbf{F_{net} = ma}$
3) Any 2 interacting objects exert equal but opposite forces upon each other; such forces are called an action-reaction pair
- **Contact-free forces**: act over a distance; Gravity e.g. attraction between Earth and Sun; Weight e.g. object falling to surface of Earth; Electric force e.g. static electricity; Magnetic force e.g. alignment of compass needle; Nuclear force e.g. radioactive decay
- **Contact forces**: act only when physical contact between objects is established – result from large number of microscopic interactions; External force e.g. your hand pushing an object; Normal force e.g. table holding an object up; Tension e.g. pulling an object with a string; Buoyant force e.g. fluid supporting a floating object; Friction e.g. resistance against fluid flow in a tube
- **Normal force**: acts in the direction normal (perpendicular) to a surface
- **Newton's law of gravity**: $F_{gravity} = GmM/r^2$; G = 6.67×10^{-11} [N m^2/kg^2] .: **weight**: force of object ALWAYS directed vertically down

- Tension : force when exerted by a massless string attached to the object of interest, always acts in direction of string
- Newton (N): 1 N = 1 kg * m/s^2
- exert a force through **INTRINSIC property** (mass) or **contact**
- UNITS (SI): length (m, metre); time (s, second); mass (kg); temp (K, kelvin); electric current (A, ampere)

THE EYE - cornea: contains convex external interface, concave internal interface
- lens suspended by fibres stretched/loosened by ciliary muscles
- iris defines opening of lens to visible area pupil, vary diameter to adjust total light intensity reaching retina
- refractive power: (near) REFRACTIVE = 1/f = 72 dot; (far) REF = 58 dpt ; REF (cornea) = 40 dpt
- lens stiffens with age, can't relax as much in order to increase radius and decrease focal length, .: lose nearest vision
- **Hyperopia** (FAR) = lens can't relax enough, need help to refract or else focus is PAST retina
- **Q**. near point = 50 cm. what f for glasses to see 25 cm clearly? p = +25 cm; q = -50 cm .: f
- **Myopia** (NEAR) = lens can't tighten/flatten enough, need help to refract or else focus is BEFORE retina
- **Q**. can't see clear when past 50 cm. what f for glasses to see clearly? q < -50 cm ; p = infinity .: f = -50
- Q. inuit strikes closer to boat than where fish is
- Q. prove light ray into slab = parallel to ray out; n1sin1=n2sin2; n2sin2 = n2sin3, etc
- Q. A 1.80 m tall dancer stands in front of a mirror in hopes of seeing her full height, no more and no less. If her eyes are 0.10 m from the top of her head, what is the minimum height and length of the mirror? ½ CF = ½ (0.10m) = 0.05 m ; ½ (1.80 m – 0.10 m) = 0.85 m ; 1.80 – 0.85 – 0.05 = 0.90
- Q. **TO CORRECT MYOPIA (NEAR)**: p is infinite distance away, virtual image located at farthest point eye can see clearly.
- Q. **TO CORRECT HYPEROPIA (FAR)**: object at desired nearpoint must form virtual image at actual nearpoint.

Example:

Assume that the magnitude of the tension in the quadriceps tendon of a bent knee is T = 1500 N. What are the magnitude and the



S

$$F_{net,x} = T_1 \cos 30^0 + T_2 \cos 70^0 - R \cos\theta = 0$$

$$F_{net,y} = T_1 \sin 30^0 - T_2 \sin 70^0 + R \sin\theta = 0$$

$$with\ T_1 = T_2 = T = 1500\ N$$

Find θ:

$$T_1 \cos 30^0 + T_2 \cos 70^0 = R \cos\theta$$

$$-T_1 \sin 30^0 + T_2 \sin 70^0 = R \sin\theta$$

Divide Second line by first line

$$\frac{\sin\theta}{\cos\theta} = \tan\theta = \frac{-\sin 30^0 + \sin 70^0}{\cos 30^0 + \cos 70^0} = 0.364 \quad \Rightarrow \quad \theta = 20^0$$

For R: square each equation and add

$$R\sqrt{\left(\sin^2\theta + \cos^2\theta\right)} = T\sqrt{\left(\cos 30^0 + \cos 70^0\right)^2 + \left(\sin 30^0 - \sin 70^0\right)^2}$$

$$R = 1930\ N$$

Alternative approach: substitute θ in (I) or (II)