Thermodynamics: Temperature and Pressure

'Q': Energy that moves from an object of high temperature to an object of lower temperature.

$$W = -P(\Delta V)$$

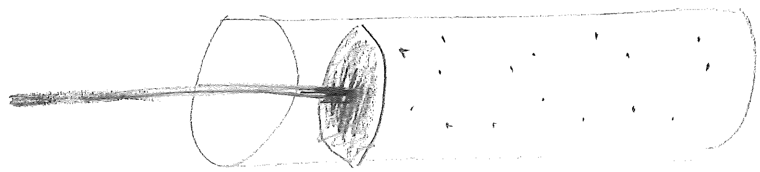
'Q' is heat and is measured in Joules.

Energy is the ability to do work

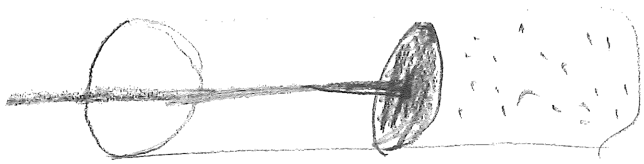
Work = Force × displacement $= \left(\frac{F}{Area}\right) \cdot Area \cdot \Delta X =$ Pressure × $\overset{m \times m}{(Area \cdot \Delta X)}$

Work = Pressure × Volume

Piston (a)



Piston (b)



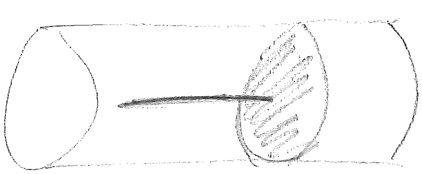
Internal Energy of a Substance: U

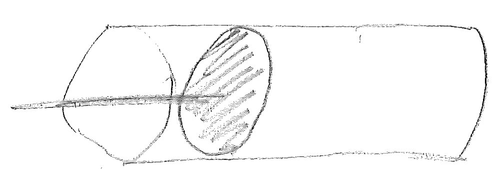
- Measured in Joules
- The sum of the molecular kinetic energy of all the molecules, plus all the potential energy of the molecules (forces that act between molecules/atoms), plus rotational and vibrational energy.

$$U = Q + (\pm W)$$

+W if work is done "ON" the system

−W if work is done "BY" the system





Temperature : a method to measure the average kinetic energy of all the molecule in an object.

Common Temperature Scales:

- Fahreheit F° water freezes @ 32 F° and boils at 212 F°
- Celsius C° water freezes @ 0 C° and boils at 100 C°
- Kelvin K water freezes @ 273.15 K and boils at 373.15 K

Convert C° to K

1. 15° C

2. -273° C

3. 0°C

Convert K to C°

4. 15 K

5. 273 K

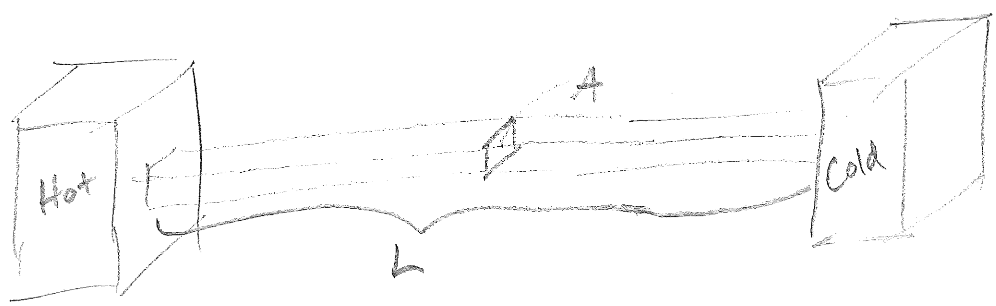
6. 0 K

Heat Transfer (3 kinds)

1. Radiation: energy moves in the form of electromagnetic waves, requires no medium for energy to travel. Can move through a vacuum
2. Convection: thermal energy is moved from place to place by the bulk movement of a fluid, hot stuff rises, cool stuff sinks.
3. Conduction: heat is transferred directly through a material. Elastic collisions of the molecules transfer kinetic energy.

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

K = thermal conductivity
A = cross sectional area
ΔT = difference in temperature
L = distance that the heat must travel



$A = .04\,m^2$ $\Delta T = 100\,°C$ $K = 240$ $L = .5\,m$ $t = 1$ sec.

1. Q = ? =

2. If area doubles....

3. If L is halved....

* Hot Al can into ice bath demo.

Kinetic Molecular Theory: The idea that gases can be understood in terms of molecules having elastic collisions with each other as well as with the walls of the container that the gas is in.

- Temperature is a way to measure the kinetic energy.
- Energy by definition is the ability to do work.
- Work done by a gas is Work = $\Delta(PV)$
- Pressure, Volume, Temperature, change in Energy and work are all related to each other.

Lets find out how Pressure, Volume and Temperature are related.

What happens to the temperature if we lower pressure and keep Volume constant?

$$P : T$$

What happens to volume if we lower the pressure while keeping temperature (relatively) constant?

$$P : V$$

$$P : \frac{T}{V}$$

We could stop here, but let's check how Temperature and volume are related to each other.

How are temperature and volume related while keeping pressure constant?

Common form $PV = nRT$

n = moles

* indicates the amount of gas that is present which is measured in moles of gas.

R = gas constant = 8.314 J/mol·K

* makes units match up.

Rather than using number of moles, n with R, we could use number of particles, N and Boltzmann's constant k_b. $k_b = 1.381 \times 10^{-23}$ J/K

$nR = Nk_b$ thus

$PV = nRT$ or $PV = Nk_bT$

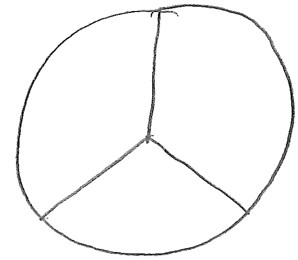
Rather than just plug in a bunch of numbers on our calculator, lets see how changing 1 or more variable(s) affects the others.

Before	After
P V = nR T	P V = nR T
P V = nR T	P V = nR T
P V = nR T	P V = nR T
P V = nR T	P V = nR T

Laws of Thermodynamics (summary)

- Zeroth Law of Thermodynamics:

If 2 samples, A & B, are in thermal equilibrium with each other AND Sample B is also in thermal equilibrium with sample C, then A must be in thermal equilibrium with sample C.



- 1st Law of Thermodynamics:

$\Delta U = Q + W_{\text{(on the system)}}$

This is used to measure lots of stuff like:

a.) how much work does it take to add or remove heat

b.) how much heat does it take to do work

c.) Ties into the ideal gas law $PV = nRT$

- 2nd Law of Thermodynamics:

a.) Thermal energy only flows from hot to cold never in reverse.

b.) Nothing is ever 100% efficient.

c.) It is impossible to remove thermal energy, Q from a system at a single Temperature and convert it into mechanical Work without changing the surrounding system in some way.

Important Vocab.

i. Isochoric: When there is no change in Volume. (implications, No work is done)

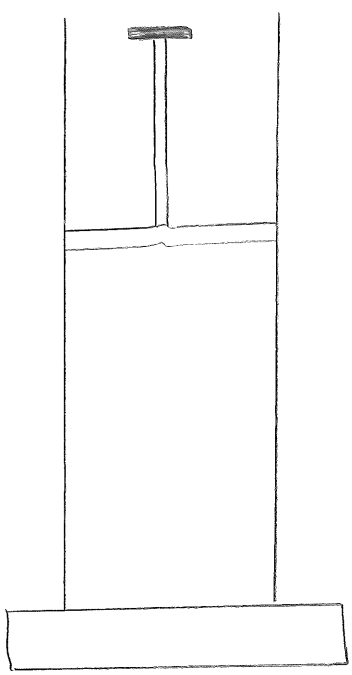
ii. Isobaric: When there is no change in pressure.

iii Iso thermic: When there is no change in Temperature (implications: there's no change in U, the internal energy, thus $Q + W = \text{zero}$)

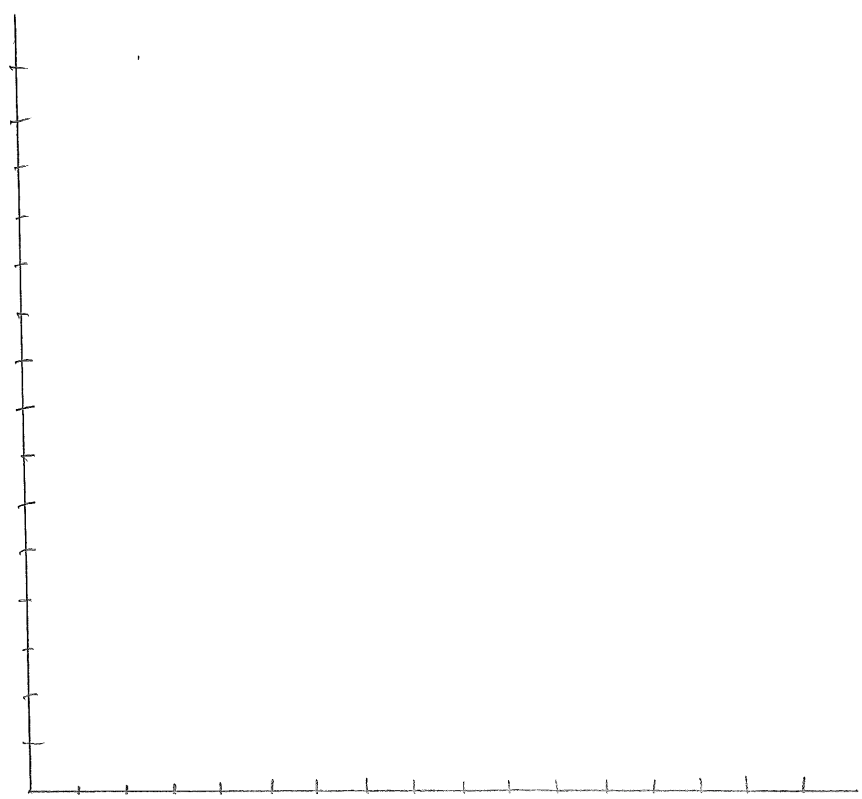
iv. Positive Work, $+W$, means that work is done ON the system.

v. Negative Work, $-W$, means that work is done BY the system.

$\Delta U = Q + W_{\text{(on the system)}}$ $\qquad W = -P(\Delta V)$

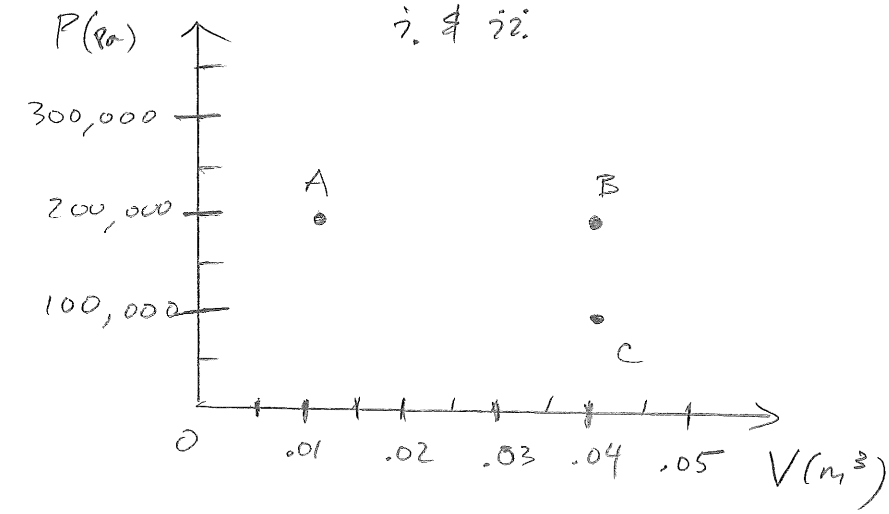


Insulated & Frictionless



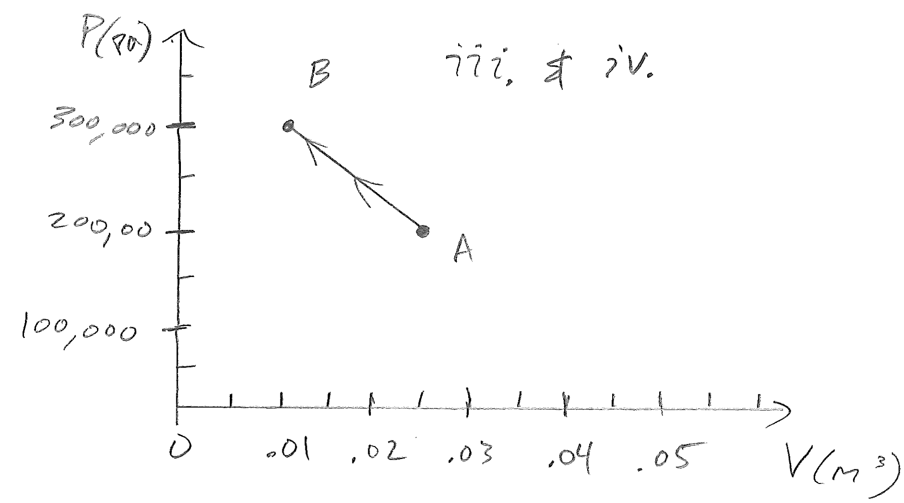
A .4 mol sample of gas is taken from pt. a to pt. b while 5000 J of thermal energy is added. i) Find the temperature at points a and b.

ii) Calculate the work done by the gas and the total change in internal energy, U.



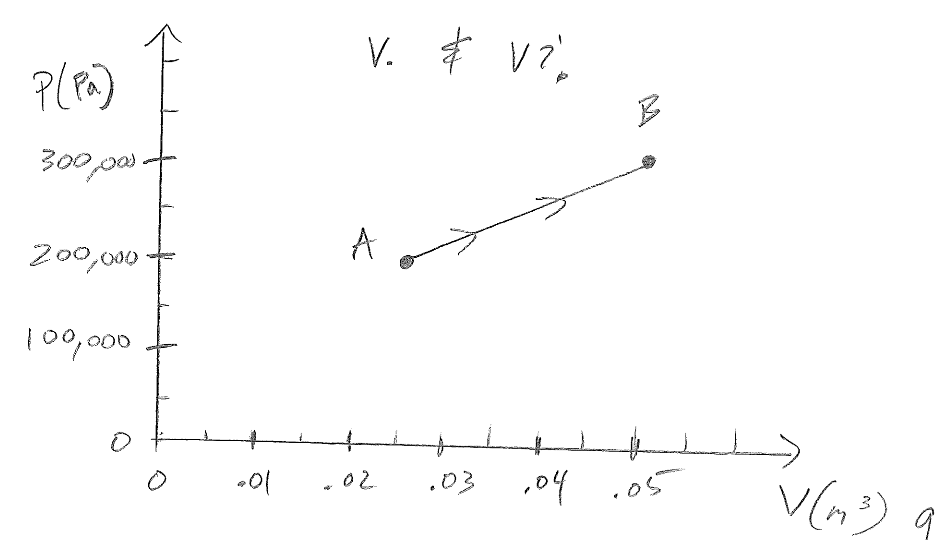
iii) Is the work done positive or negative?

iv.) Calculate the work done.

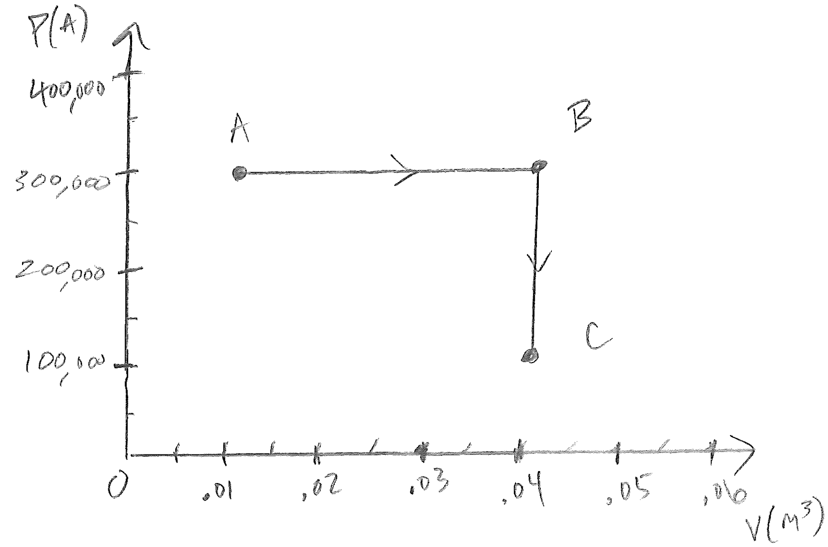


v.) Is the work done positive or negative?

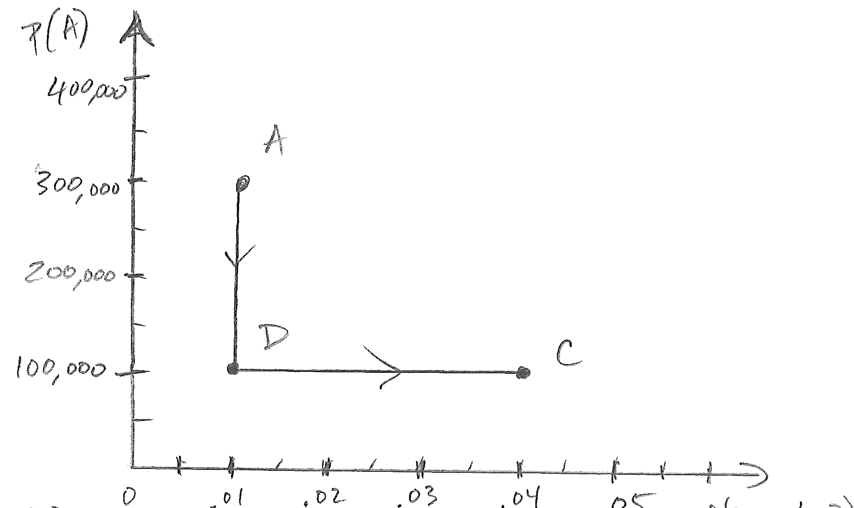
vi.) Calculate the work done.



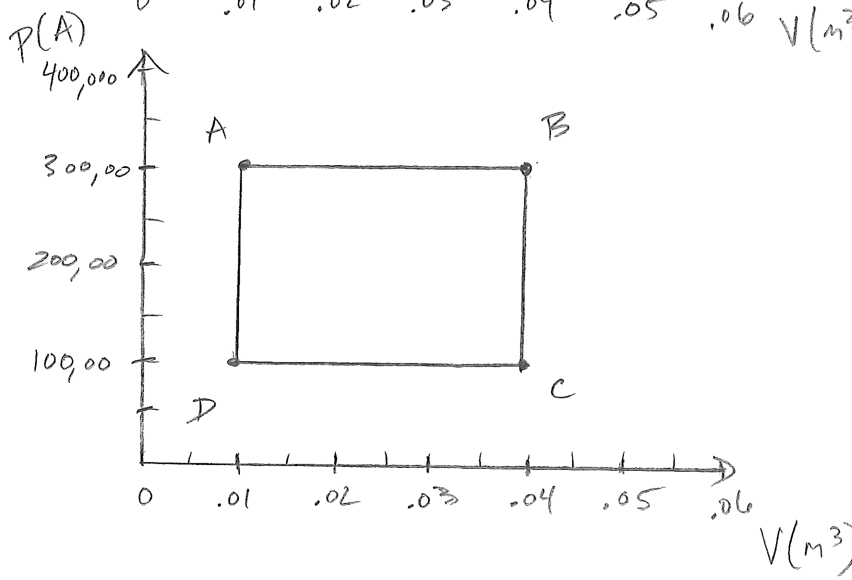
a.) Work from A to B to C



b.) Work from A to D to C

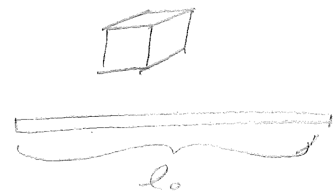


c.) Work from A to B to C to D and back to A.



① Thermal Expansion

Linear Expansion



$\Delta l = \alpha \, l_o \, \Delta T$

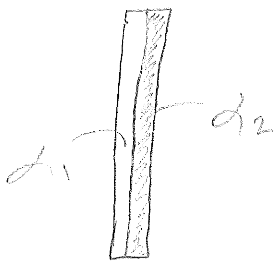
α = coeff. of linear expansion

ΔT = temperature change in °C or K

$$\alpha = \frac{\Delta l}{l_o \cdot \Delta T}$$

α unit : $\frac{1}{°C}$ or $°C^{-1}$, α depends on material

Bimetallic Strip:



If $\alpha_1 \neq \alpha_2$, what will happen to the strip when heated? When cooled?

② Steel railroad tracks are laid at 5°C. What size expansion gaps are needed between 12 meter long rail sections, if temperature range is −10°C to 55°C?

$\alpha_{steel} = 12 \times 10^{-6} \, °C^{-1}$

③ Volume expansion: for liquid, gas and solid

$\Delta V = \beta \cdot V_o \cdot \Delta T$

V = volume, ΔT in °C or K

β : coeff. of volume expansion (units: $\frac{1}{°C}$)

4) A brass cup filled to the brim with 240 ml of water at 4°C is heated to 95°C. How much water would overflow?

$\beta_{brass} = 56 \times 10^{-6}\ °C^{-1}$, $\beta_{H_2O} = 210 \times 10^{-6}\ °C^{-1}$

5) About Ideal Gas:

1. There are a very large number of molecules
2. Molecules move in random directions with a variety of speeds.
3. The average separation of molecules is much greater than the size of each molecule.
4. The molecules obey the laws of classical mechanics and they interact only when they collide.
5. Collisions are perfectly elastic.
6. Ideal gas molecules do have mass.

Ideal Gas Law: $PV = NkT = nRT$

n = the # of mol.

N = the # of molecules $= nN_0$

Universal gas constant $R = 8.31\ J/mol \cdot K = 0.0821\ atm \cdot L/mol \cdot K$

Boltzmann's Constant k_B or $k = R/N_0 = 1.38 \times 10^{-23}\ J/K$

Avogadro's #: $N_0 = 6.02 \times 10^{23}$ molecules/mol

6) An ideal gas is contained in a 3L container at 20°C and 1atm. A piston of area .02 m² is pressed with force F to change the volume to. 1L when the temperature is raised to 40°C.

a.) What is the new Pressure? b.) What is the force 'F'?

(7) A tire is filled to a gauge pressure of 300 kPa at 5°C. Then the temperature goes up to 40°C. What fraction of the air must be let out to reduce the gauge pressure back to 300 kPa?

An oxygen cylinder starts with a pressure of 139 atm. After some use, the pressure drops to 50 atm under the same temperature. What fraction of the oxygen is left?

(8) 2 containers: A 5 mol. He B 7 mol. Ne

A has 3 times the volume of B and ½ the pressure of B.

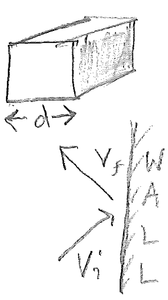
(He: 4 g/mol Ne: 20 g/mol) $\frac{T_A}{T_B} = ?$

2 containers have the same temperature C: H_2 D: N_2
C has twice the number of moles of D and 5 times the pressure of D. (H_2: 2 g/mol. N_2: 28 g/mol.)

$$\frac{\rho_C}{\rho_D} = ?$$

⑨ A diving bell is lowered slowly to 40 m below the sea surface. The inside has diameter 2 m and height 3 m. The air temperature at the surface is 30°C and the temperature drops to 15°C at 40 m deep. ($\rho_{\text{sea water}} = 1025 \ kg/m^3$). How high does the sea water rise in the bell at the 40 m depth?

⑩ Kinetic theory for ideal gas: N molecules in a cubic box



Derivation:

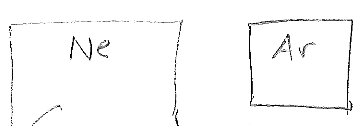
(11) .2 mol O_2 gas at 300 kPa, .005 m^3 = Volume

a.) Find average translational KE per molecule.

b.) Find total translational KE.

(12) Find the V_{rms} of 2.5 mol of H_2 at 4 atm and 300 K (H_2 2 g/mol)

(13) 2 containers with rigid walls with the same number of moles:



3 times the volume
1/5 the pressure

Ne : 20 g/mol.
Ar : 40 g/mol.

>, <, or =

T: Ne ___ Ar

$\overline{KE}$: Ne ___ Ar

Total KE: Ne ___ Ar

V_{rms} : Ne ___ Ar

Heat needed to raise 1 K:

Ne ___ Ar

(14) Heat = the energy transferred from one body to another because of a difference in temperature.

Internal energy = the sum of all the energy of all the molecules in a stationary object

Thermal Energy = the part of the internal energy that results in the system temperature.

4.186 J = 1 cal   4186 J = 1 Cal = 1 kcal

(15) 3 way for heat transfer : Conduction, Convection & Radiation

Conduction – can be partially explained by atomic/molecular collisions

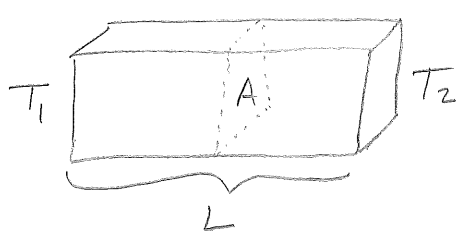
$$H = Q/\Delta t = K \cdot A \cdot (T_1 - T_2)/L$$

Q = heat transferred , Δt = time interval

A = cross sectional area of object

K = thermal conductivity, depends on material

L = distance between two ends which are at T_1 & T_2



Convection – the process by which heat is transferred by the mass movement of molecules from one place to another.

- forced convection
- natural convection

Radiation – does not require any medium. Consists essentially of electromagnetic waves.

(16) The 0^{th} Law of Thermodynamics:
If bodies A & B are in thermal equilibrium (having zero net heat exchange, i.e. having the same temperature) with a 3^{rd} body C, then A and B are in thermal equilibrium with each other.

1^{st} Law of Thermodynamics: Conservation of Energy

$\Delta U = Q + W_{on\ system}$

ΔU: change in internal energy of a closed system.

Q: the net heat added to the system

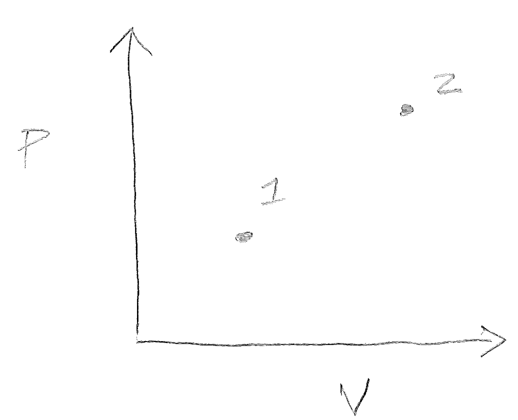
$W_{on\ system}$: the net work on the system

Assume 500 J of heat is added to a system and -200 J of work is done to the system. $\Delta U = ?$

(17) U, P, V, n, T are state functions, Q & W are not.

Heat reservoir: a body whose heat capacity is so large that its temperature remains unchanged when heat is added to or extracted from the body.

PV diagram for a closed system: n and R constant

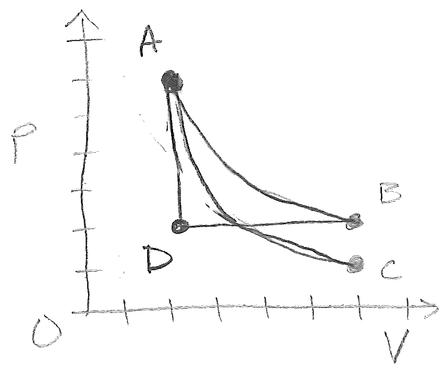


$PV = nRT$

$PV \propto T$

The larger the PV, the greater the temperature.

18. Isobaric Process (pressure remains the same)



19. Isothermic Process (temperature remains the same)

20. Isochoric (or isovolumetric) Process (volume remains constant)

21. Adiabatic Process (no heat exchange with the environment)
$Q = 0$

(22) A gas loses 1400 J of heat while it contracts from .003 m^3 to .001 m^3 under a constant pressure of 2 atm. Find:

a.) heat added to the gas

b.) work done on the gas

c.) the ΔU

d.) Does the temperature increase or decrease?

(23) A gas is compressed in an adiabatic process.

a) Does its internal energy increase or decrease?

b.) Does its temperature go up or down?

If the internal energy of the gas increases by 50 J...

c.) How much heat is added to the gas?

d.) How much work is done by the gas?

(24) For a monatomic gas:

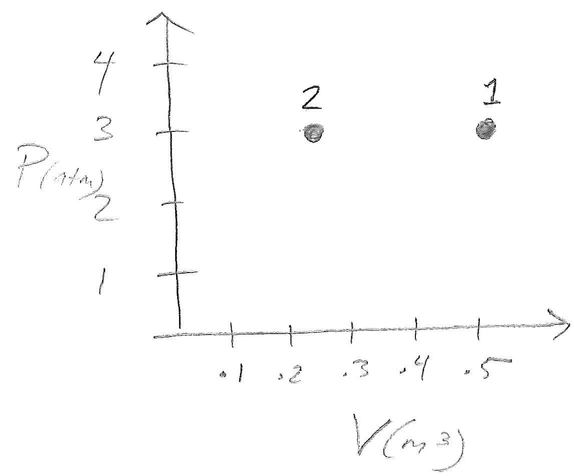
a.) If 1 to 2 is isobaric:

i.) draw PV diagram

ii.) Work done by gas = ?

iii.) ΔU = ?

iv.) Q = ?



b.) If 1 to 2: isochoric from 1 to a state with same temperature as 2, then isothermal to 2

i.) Draw the PV diagram

ii.) ΔU = ?

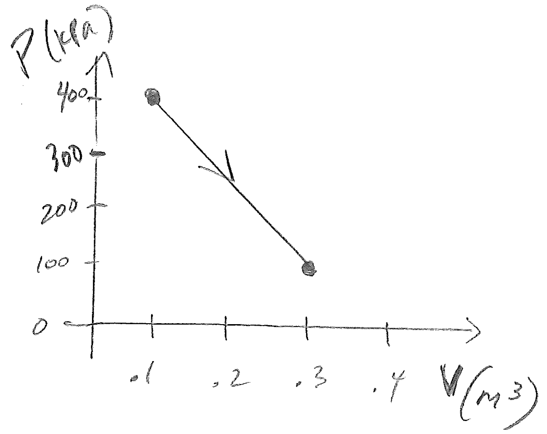
(25) An ideal gas has a pressure of 400 kPa and a volume of .1 m^3. a) Find the total translational KE of the ideal gas. b.) If the gas is monatonic, find:

i.) Work on gas = ?

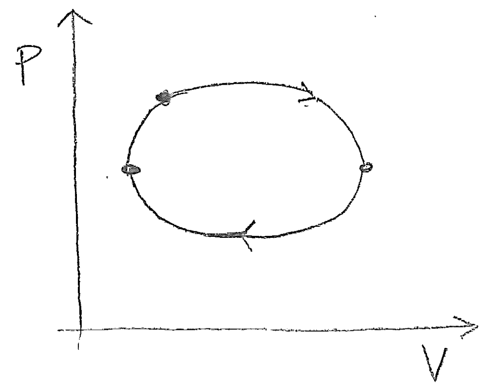
ii.) ΔU = ?

iii.) How much heat is added to or removed from the gas?

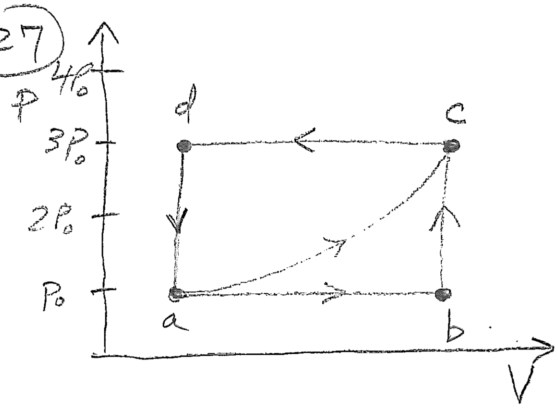
iv.) Does its temperature increase or decrease?



(26) Cyclic Process: $\Delta U =$



(27)



$a \to c : W_{on\,gas} = -100\,J,\ Q = 210\,J$

$abc : W_{on\,gas} = -70\,J,\ \Delta U =$

$Q =$

$cda : W_{on\,gas} = +\text{area} =$

$\Delta U =$

$Q =$

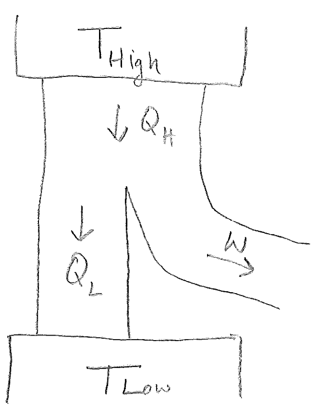
$abcda : W_{on\,gas} =$ $\Delta U =$ $Q =$

$acda : W_{on\,gas} =$ $\Delta U =$ $Q =$

(28) 2nd Law of Thermodynamics

- Heat flows spontaneously from a hot object to a cold one, but not the reverse. (Rudolf Clausius) cold fridge $\overset{heat}{\Rightarrow}$ warm kitchen
- There can be no 100% efficient heat engine - that is, one that can change a given amount of heat completely into work. (Lord Kelvin)
- Natural processes tend to move toward a state of greater disorder or greater entropy. (Ludwig Boltzmann) entropy, function of state
- A perpetual motion machine of the second kind is impossible. (Max Plank)

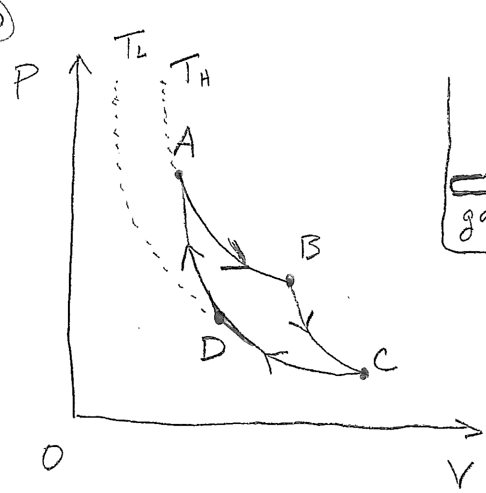
(29)

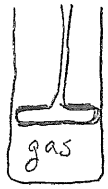


Heat Engine

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

(30)





Carnot or Ideal Engine

A $\xrightarrow[\text{isothermal}]{}$ B $\xrightarrow[\text{adiabatic}]{}$ C $\xrightarrow[\text{isothermal}]{}$ D $\xrightarrow[\text{adiabatic}]{}$ A

(31) A heat engine does 5000 J of work while producing 9000 J of heat. Find the efficiency of this heat engine.

The exhaust temperature of that engine is 80 °C. The maximum efficiency of a heat engine working between the same temperature range is 60 %. What must the high temperature of that heat engine be?

(33)

An ideal gas has pressure P and density ρ. Its $V_{rms} = ?$

a.) $\sqrt{\frac{P}{\rho}}$ b.) $\sqrt{\frac{P}{2\rho}}$ c.) $\sqrt{\frac{2P}{\rho}}$ d.) $\sqrt{\frac{3P}{\rho}}$ e.) $\sqrt{\frac{6P}{\rho}}$

2 containers at the same temperature

one has volume V_0 3 moles of He

the other has volume $2V_0$ 1 mole of Ne

Question: $\frac{KE_{He}}{KE_{Ne}} = ?$

a.) $\frac{1}{20}$ b.) $\frac{1}{6}$ c.) $\frac{1}{5}$ d.) 1 e.) 3

An ideal gas has its volume halved while its pressure quadruples. By what factor does its V_{rms} change?

a.) $\frac{1}{4}$ b.) $\sqrt{\frac{1}{2}}$ c.) $\sqrt{2}$ d.) $\frac{1}{2}$ e.) 2

(34) The thermal conductivity of a brick wall is .8 $\frac{\text{watts}}{\text{m} \cdot \text{K}}$. The thermal conductivity of wood is .1 $\frac{\text{watts}}{\text{m} \cdot \text{K}}$. If we wish to replace a 20 cm thick brick wall with a solid wooden wall while keeping the same wall area, the same temperature difference across the walls, and the same rate of heat flow through the walls. How thick should the wooden wall be?

A heat engine operates between 500 °C and 200 °C. The power input to the engine is 800 W. What is the maximum possible rate at which this engine can do work?