Good morning!

Lab 9 is in B9

If you are here, please pick up YOUR exam!!

→ to prove your presense!

Please, login into webassing, locate LectureMCQ_L23 (PY105) and answer question 1 (but ONLY Q1!).

current topics (do not read this slide)

Temperature, temperature scales, thermal contact, thermal conduction, thermal equilibrium, measuring temperature, heat, internal energy, meaning of temperature, meaning of heat, thermal expansion, coefficient of thermal expansion (CTE), linear, areal, and volumetric CTE, heat capacity, specific heat (capacity), thermally insulated system, heat balance equation (an equation for thermal equilibrium), phase transition, critical temperature, latent heat (capacity), method for solving thermal equilibrium problems, convection, thermal radiation, thermal conduction, thermal conductivity, the ideal gas, absolute temperature, a mole, the Avogadro's number, the universal gas constant, RMS values, the ideal gas law, iso – laws, graphs for gas processes (PV, VT, PT diagrams), the Boltzmann's constant, the meaning of the absolute temperature, the meaning of the pressure, degree of freedom, the equipartition theorem, monatomic, diatomic, polyatomic gas, calculating internal energy, the first law of thermodynamics, work done by gas, calculating specific heat (Cv, Cp), isothermal process, adiabatic process, thermodynamic cycle, work done over a cycle, heat engine, entropy, second law of thermodynamics, heat engine efficiency, the Carnot cycle, maximum (ideal) heat engine efficiency, a heat pump and a refrigerator(***the last topic of test 3***)

c_W = 4000 J/(kg °C); c_{ice} = 2000 J/(kg °C);
$L_f = 3 \times 10^5$ J/kg

$$Q = \pm Lm$$

$$Q = cm(T_f - T_i)$$

You need to make 20 ice cubes (5 g each) at -5^0 C. You pour 25^0 C water into an ice tray and place it in a freezer. How much heat should water ….?

Webassign: L23 Q2

1. Absorb
2. Release

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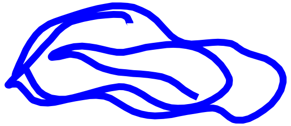
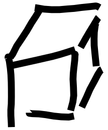


$t_w = 25°C$

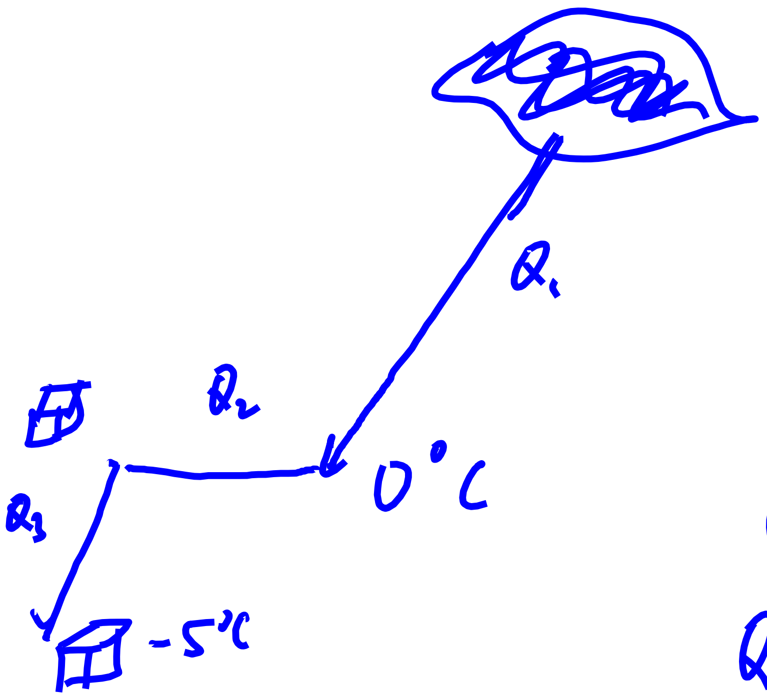
$Q = c \cdot m \cdot \Delta t$

$Q = 4000 \cdot 20 \cdot 0.005 \cdot (-5 - 25) \rightarrow$ done

WRONG!



$t_{ice} = -5°C$



1. Objects
2. processes → ΔT or $T = const$
3. $Q = \ldots$

$$Q_1 = c_w \cdot m \cdot (0-25) = -4000 \cdot 20 \cdot 0.005 \cdot 25 \text{ J}$$

$$Q_2 = -L_i\, m = -300000 \cdot 20 \cdot 0.005 \text{ J}$$

$$Q_3 = c_i \cdot m(-5-0) = -2000 \cdot 20 \cdot 0.005 \cdot 5 \text{ J}$$

$$Q = Q_1 + Q_2 + Q_3$$

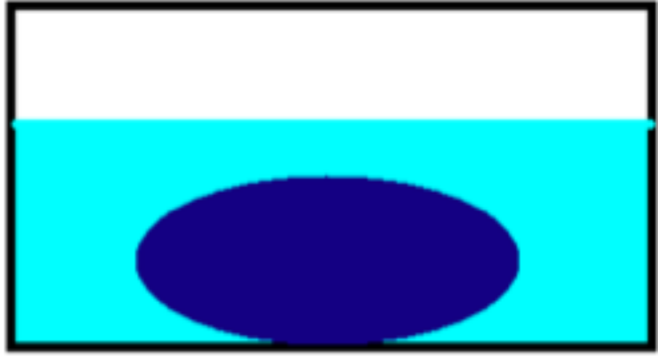
$$Q = -4000 \cdot 20 \cdot 0.005 \cdot 25 - 300000 \cdot 20 \cdot 0.005 -$$

$$- 200 \cdot 20 \cdot 0.005 \cdot 5 = -4 \cdot 20 \cdot 5 \cdot 25 - 300 \cdot 20 \cdot 5 -$$

$$- 2 \cdot 2 \cdot 5 \cdot 5 = -100 \cdot 100 - 300 \cdot 100 - 4 \cdot 25 =$$

$$= -10000 - 30000 - 100 = -40100 \text{ J}$$

A solid object is placed into a liquid (poured into a container). The liquid has its initial temperature of 500^0C; the solid is initially twice warmer. The solid has the mass of a third of the mass of the liquid, but its specific heat is twice of the specific heat of the liquid. The container has the mass of the quarter of the solid and its specific heat is equal to one half of the liquid's. Find the final temperature of the system.



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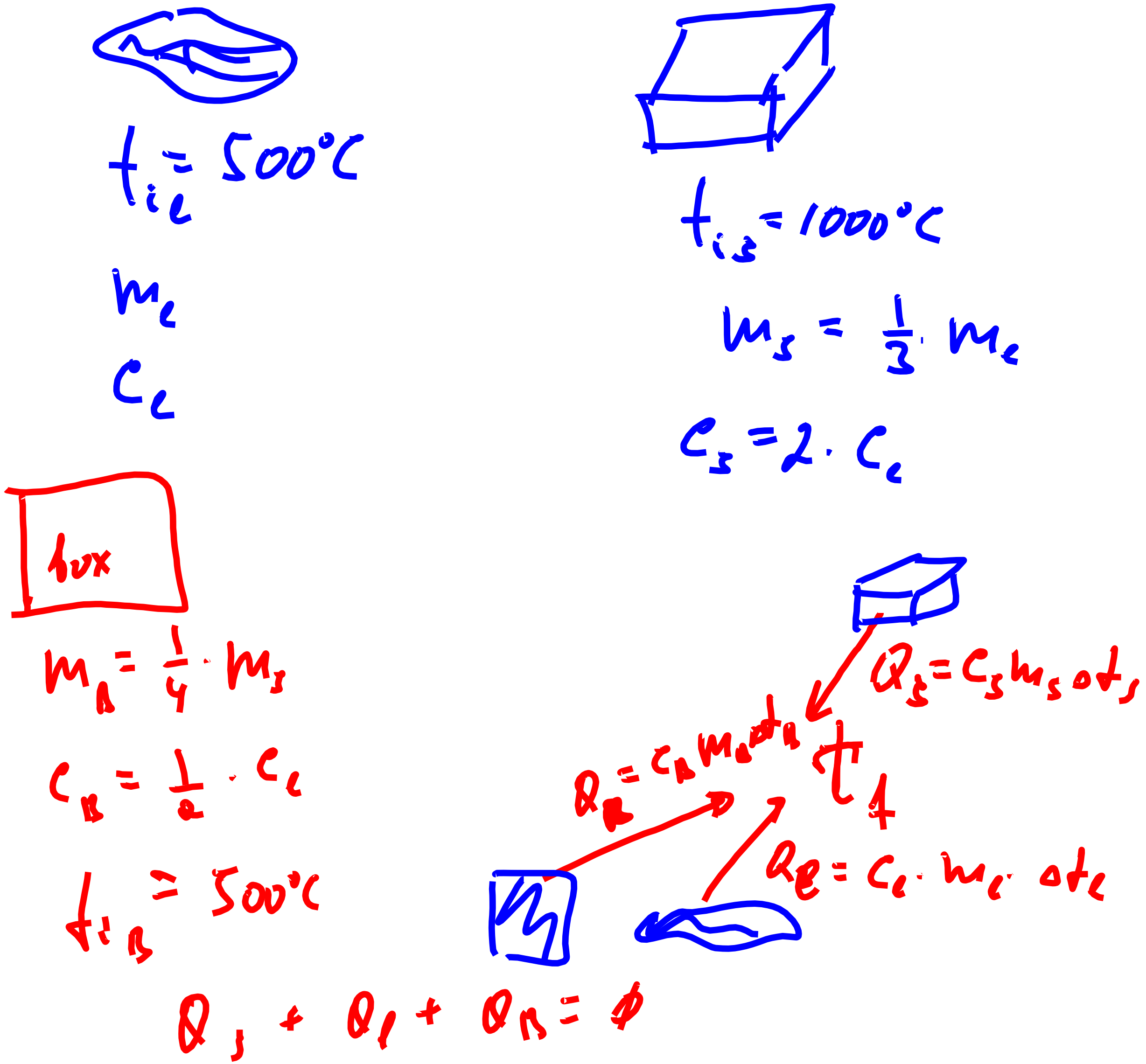


$$Q_s + Q_e + Q_B = 0$$

$$c_s m_s \Delta t_s + c_e m_e \Delta t_e + c_B m_B \Delta t_B = 0$$

$$0 = 2 \cdot c_e \cdot \frac{1}{3} \cdot m_e \cdot (t_f - 1000) + c_e \cdot m_e \cdot (t_f - 500) + \frac{1}{2} c_e \cdot \frac{1}{4} \frac{1}{3} \cdot m_e \cdot (t_f - 500)$$

$$0 = \frac{2}{3} \cdot (t_f - 1000) + t_f - 500 + \frac{1}{24} \cdot (t_f - 500)$$

↳ solve for t_f

$$0 = \frac{2}{3} t_1 - \frac{2}{3} \cdot 1000 + t_1 - 500 + \frac{1}{24} \cdot t_1 - \frac{1}{24} \cdot 500 \quad \Big| \times 24$$

$$0 = 2 \cdot 8 \cdot t_1 - 2 \cdot 8 \cdot 1000 + 24 \cdot t_1 - 24 \cdot 500 + t_1 - 500$$

$$16000 + 12000 + 500 = (16 + 24 + 1) t_1$$

$$28500 = 41 \cdot t_1$$

$$t_1 = \frac{28500}{41} = 695\,°C$$

Last topics (do not read this slide)

The ideal gas, absolute temperature, a mole, the Avogadro's number, the universal gas constant, RMS values, the ideal gas law, iso – laws, graphs for gas processes (PV, VT, PT diagrams), the Boltzmann's constant, the meaning of the absolute temperature, the meaning of the pressure, degree of freedom, the equipartition theorem, monatomic, diatomic, polyatomic gas, calculating internal energy, the first law of thermodynamics, work done by gas, calculating specific heat (Cv, Cp), isothermal process, adiabatic process, thermodynamic cycle, work done over a cycle, heat engine, entropy, second law of thermodynamics, heat engine efficiency, the Carnot cycle, maximum (ideal) heat engine efficiency, a heat pump and a refrigerator(***the last topic of test 3***)

Structure of Matter

As we know now, all objects around us (solid or fluid) are made of a huge amount of tiny and very light particles (atoms and molecules).

For example, an oxygen atom has the weight of

$$m_0 = 2.66*10^{-26} \text{ kg}$$

The mass of an atom or a molecule

If we take m = 1 gram of oxygen, the total number N of atoms in it is

$$N = m/m_0 = 3.76*10^{22}$$

Avogadro's Number

An amount of a matter having **6.02×10^{23}** particles is named a **MOLE**

A mole is very similar to a dozen, in the sense that it stands for a certain number of things.
A dozen means 12, while a mole means 6.02×10^{23}.

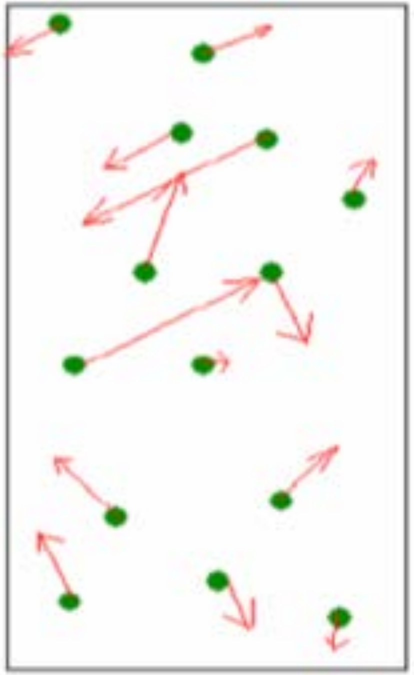
This number is also known as *Avogadro's number*, N_A.

$$N_A = 6.02 \times 10^{23}$$

1 mole = N_A particles

Every material has the same number of particles in 1 mole, but the mass of 1 mole is different to different materials.

A molar mass **$\mu = m_0 N_A$** ***is the mass of 1 mole of the substance.*** **(note: Use μ or M)**



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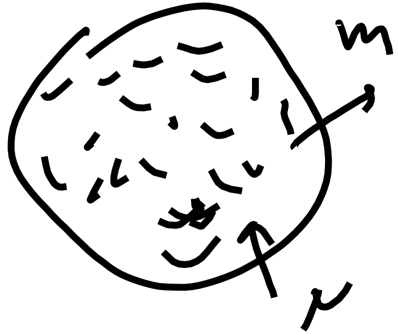
# of moles

$$n = \frac{N}{N_A} = ??$$



$$n = \frac{N \cdot m_0}{N_A \cdot m_0} = \frac{m}{M}$$

$$M = \mu = m_0 N_A$$

m_0 = the mass of an atom or a molecule

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gram/mol

# of moles

Mass of the gas

$$n = \frac{N}{N_A} = \frac{m_0 N}{m_0 N_A} = \frac{m}{M} = \frac{m}{\mu}$$

Molar mass

(note: Use μ or M)

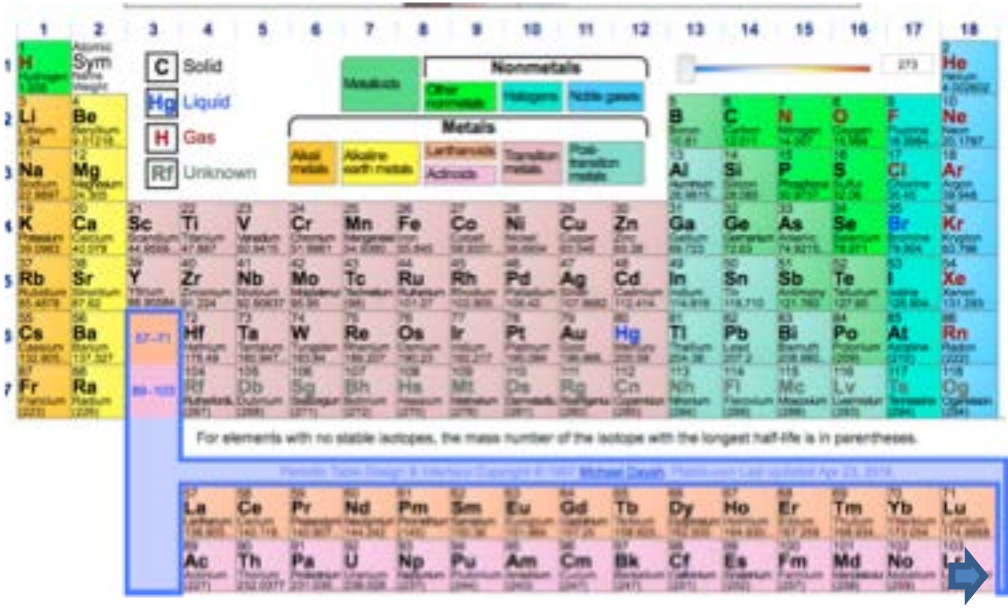
Webassign: L23 Q3

Molar mass of H_2 =

1. 1 kg/mol
2. 2 kg/mol
3. 3 kg/mol

…

9. None of the above



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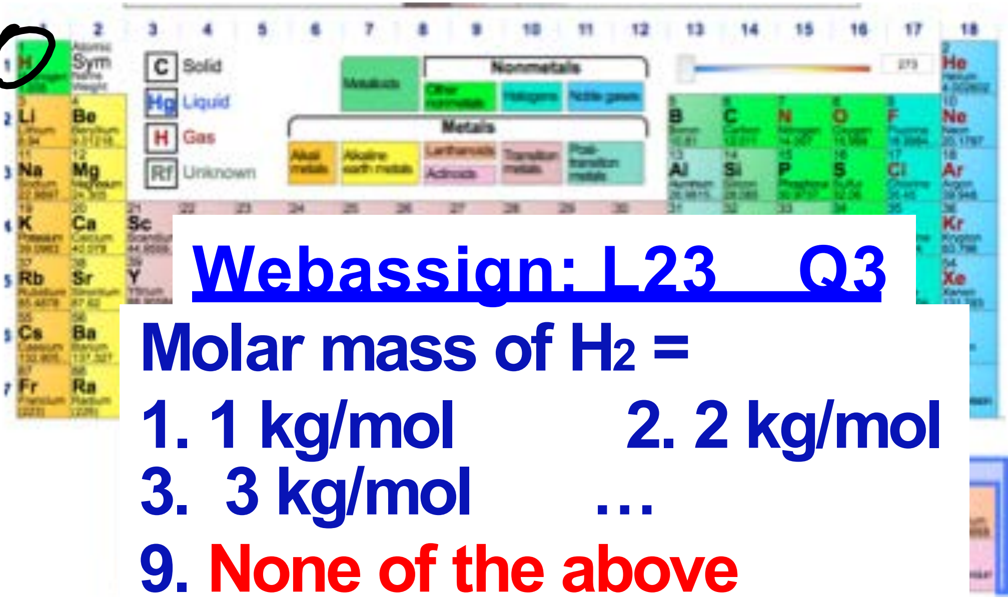
gram/mol

\# of moles — Mass of the gas

$$n = \frac{N}{N_A} = \frac{m_0 N}{m_0 N_A} = \frac{m}{M} = \frac{m}{\mu}$$

Molar mass

(note: Use μ or M)



Webassign: L23 Q3

Molar mass of H_2 =

1. 1 kg/mol
2. 2 kg/mol
3. 3 kg/mol
…
9. None of the above

H_2 ; $2 \cdot m_H \rightarrow$

$\mu = 2.1 \cdot \frac{g}{mol}$

$M_{H_2} = 2 \frac{g}{mol} = 0.002 \frac{kg}{mol}$

The Ideal Gas Law

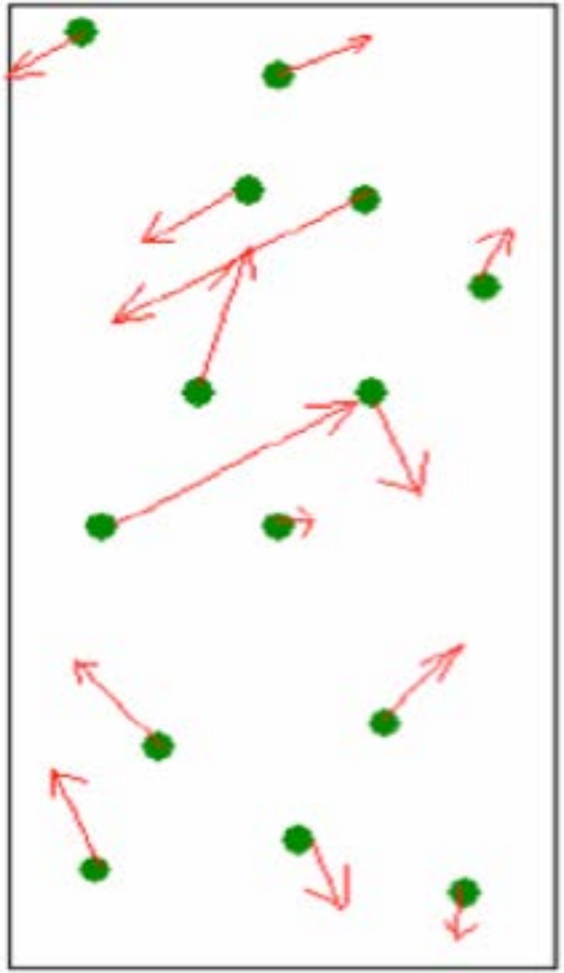
An ideal gas satisfies these conditions:

1. It consists of **a large** number of identical particles (atoms, molecules).
2. The volume occupied by the particles themselves is negligible compared to the volume of the container they're in (**particles are dots or made of dots**).
3. The particles move in **random** motion.
4. The particles obey Newton's laws of motion; they experience forces only during collisions; any collisions are completely elastic, and instantaneous (take a negligible amount of time).

What is the average ***velocity*** of the ideal gas particles (for $T > 0$)?

$$\frac{1}{N}\sum \vec{v} = ?$$

Webassign: L23_Q4



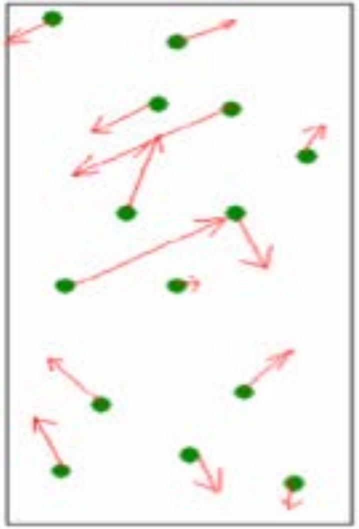
$T > 0$

1) It depends on the temperature of the gas.
2) Zero.
3) It points to the right.
4) It is immeasurable.

Webassign: L23_Q4

What is the average *velocity* of the ideal gas particles (for $T > 0$)?

$$\frac{1}{N}\sum \vec{v} = ?$$



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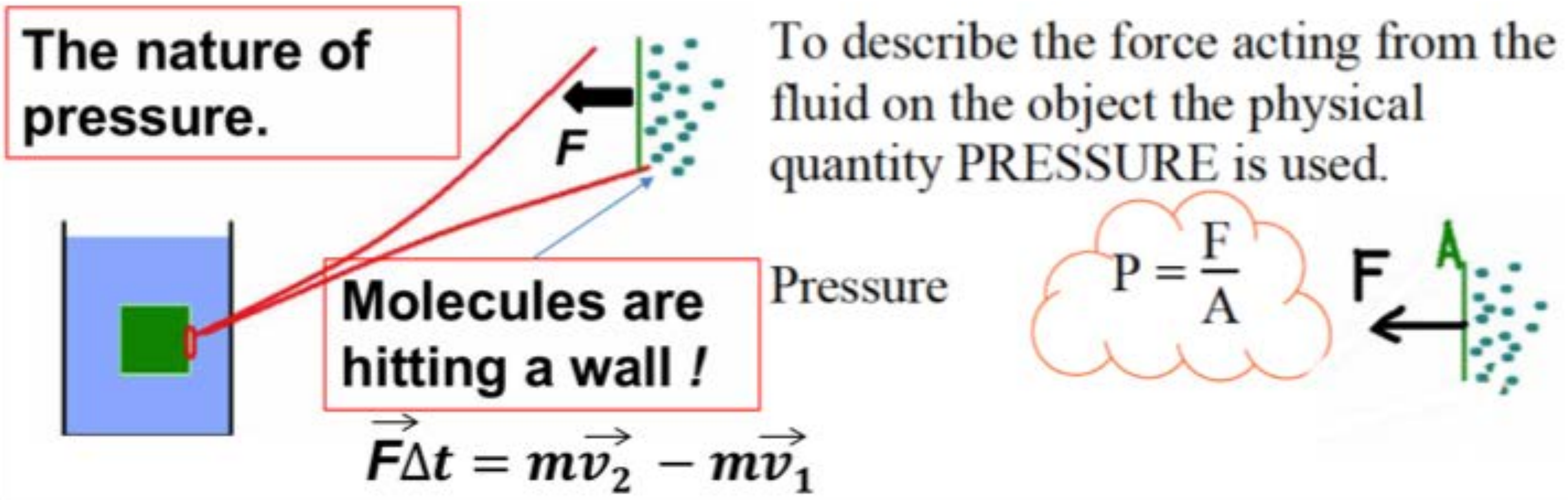

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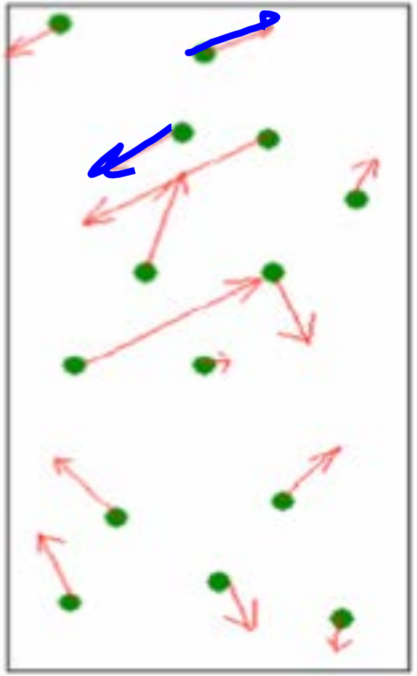

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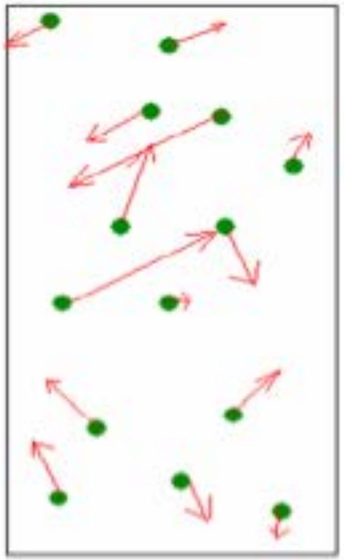
$$\frac{1}{N}\sum \vec{v} = ?$$

The *average translational Kinetic Energy (T > 0)*

$$KE_{tr\_ave} = \frac{\frac{mv_1^2}{2} + \frac{mv_2^2}{2} + \frac{mv_3^2}{2} + \ldots \frac{mv_N^2}{2}}{N} > 0$$

Always positive!

What is the average velocity of the ideal gas particles?



T > 0

2) **Zero.**

For the huge number of particles $\frac{1}{N}\sum \vec{v} = 0$

The average velocity is zero, because, on average, the velocity of particles going in one direction is cancelled by the velocity of particles going in the opposite direction.

Vector addition - when all vectors point in all possible directions!

Ideal Gas Equations

The definition of absolute Temperature

Kinetic Theory of Ideal Gas

$E_{tr\ K\text{-}AVE}$ is Av Tr KE of *N* particles

$$\vec{F}\Delta t = m\vec{v}_2 - m\vec{v}_1$$

$$E_{K\text{-}AVE_{tr}} = \frac{3}{2}kT$$

$$T = t + 273.15$$

$$PV = \frac{2N}{3}E_{K\text{-}AVE_{tr}}$$

k **– Boltzmann constant**

$k = 1.38 \cdot 10^{-23}$ J/K

the ideal gas law

$$PV = NkT$$

The Ideal Gas Law

$$PV = nRT$$

$R = 8.31$ J/(mol K)

For curios people

$$PV = NkT$$

It is convenient to rewrite the law: $n = \frac{N}{N_A}$

$N = n * N_A$, n is the number of moles: $PV = n N_A kT$

Let's define $N_A k = R$, the universal gas constant:

$R = 8.31$ J/(mol K)

$$PV = nRT$$

The Ideal Gas Law

The number of moles

The Ideal Gas Law

$$PV = nRT$$

$$\frac{PV}{RT} = \frac{nRT}{RT}$$

$$\frac{PV}{nT} = ???$$

$$\frac{PV}{RT} = n; \quad \frac{PV}{nT} = R = \text{const}$$

Webassign: L23 Q5

$$\frac{PV}{T} = \cdots$$

1. Always constant
2. Sometimes constant
3. Always change
4. None of the above

The Ideal Gas Law

$$PV = nRT$$

$$\frac{PV}{nT} = R = 8.31 \text{ J/(mol K)}$$

Always constant

$$n = \nu = \frac{N}{N_A} = \frac{m}{M}$$

$$R = 8.31 \text{ J/(mol K)}$$

Webassign: L23 Q5

$$\frac{PV}{T} = \ldots$$

1. Always constant
2. Sometimes constant
3. Always change
4. None of the above

$$\frac{PV}{T} = n \cdot R$$

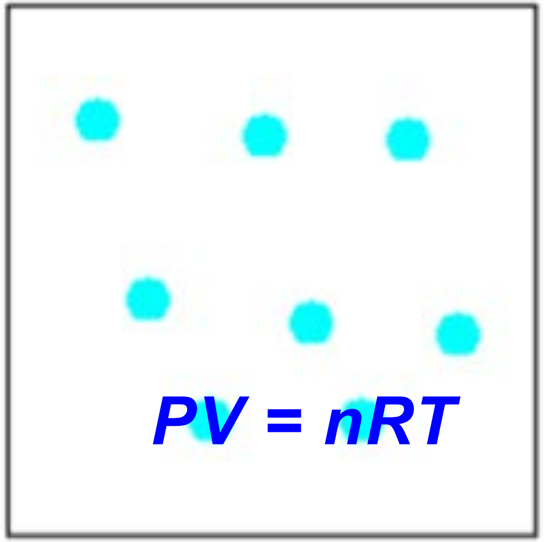
n → amount of gas → May change

$$PV = nRT$$

$$\frac{PV}{T} = nR$$

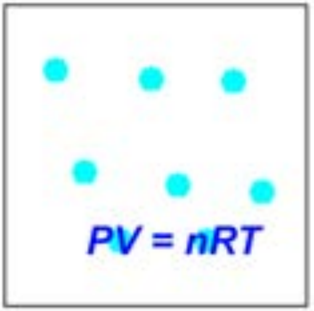
2. Sometimes constant

When the amount of gas does *NOT* change => n = const => PV/T = const



An ideal gas is in a container at the temperature of 127 ^{0} C.

Find the new temperature if the volume of the container was tripled, the pressure was decreased to the half of the initial, and a quarter of the gas was lost to the environment.



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$t_i = 127^0C$

$t_f = ?$

Change!

i → $P_iV_i = n_iRT_i$

f → $P_fV_f = n_fRT_f$

$V_f = 3 \cdot V_i$

$P_f = \frac{1}{2} P_i$

$n_f = n_i - \frac{1}{4} n_i = \frac{3}{4} n_i$

$$\frac{P_iV_i}{P_fV_f} = \frac{n_iRT_i}{n_fRT_f} \Rightarrow \frac{P_iV_i}{\frac{1}{2}P_i \cdot 3 \cdot V_i} = \frac{n_i \cdot R \cdot T_i}{\frac{3}{4} n_i \cdot R \cdot T_f} ; \quad \frac{2}{3} = \frac{4}{3} \cdot \frac{T_i}{T_f} ; \quad T_f = 2 \cdot T_i$$

$T_f = 2 \cdot T_i = 2 \cdot 127 = 254$ WRONG

$\downarrow$ K $\quad \downarrow$ K_i

$T_i = 127 + 273 =$

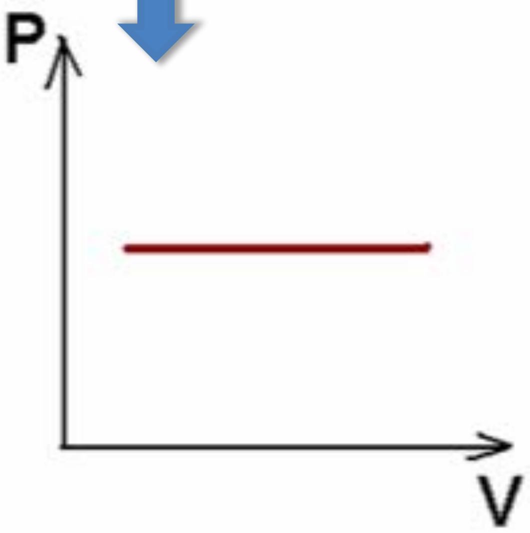
$= 400K$

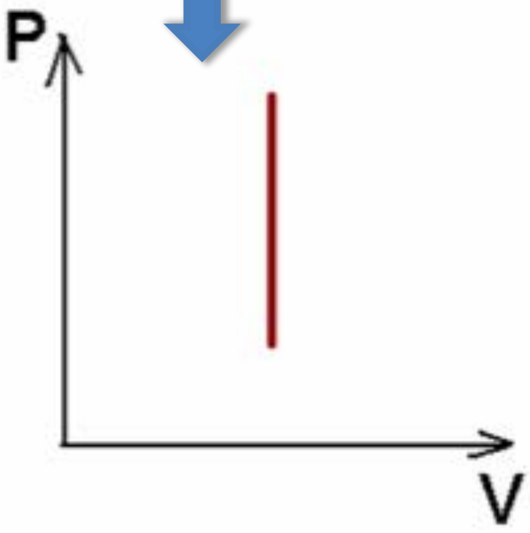
$T_f = 2 \cdot 400 = 800K$

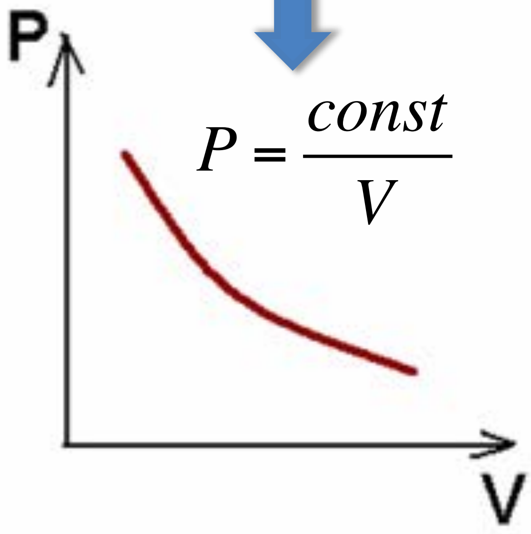
$t_f = 800 - 273 = 527°C$

Three standard processes (n = const):

Isobaric	Isochoric	Isothermal
P = const	V = const	T = const
V/T = const	P/T = const	PV = const







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

n = m/M

n = const

$$\frac{PV}{Tn} = R$$ **= 8.31 J/(Kmole)**

(Try to plot graphs for the same processes using PT and VT axes)

Monatomic ideal gas •

For an *atom*: KE = Tr_KE

Each particle is a *dot*. •

Only translational kinetic energy does exist, hence the internal energy is equal to just total average kinetic energy of all the particles, therefore:

$$KE_{tr\_ave} = \frac{3}{2}kT$$

Monatomic ideal gas: $E_{int} = E_{K\text{-}AVE,\,tr} N = \frac{3}{2}NkT = 3 * \frac{1}{2}NkT$

An internal energy of the gas: U = $E_{int} = E_{KE\_ave} * N$

Each direction (x, y, and z – 3 directions!) contributes ½NkT to the energy.

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An internal energy of the gas: $U = E_{int} = E_{KE\_ave}*N$

Each direction (x, y, and z – 3 directions!) contributes ½NkT to the energy.

$$PV = NkT \Rightarrow PV = nRT$$

$$U = N \cdot E_{TrKE} = N \cdot \frac{3}{2}kT = \frac{3}{2}kNT = \frac{3}{2}nRT$$

$$U = \frac{3}{2}nRT = \frac{3}{2}PV$$

$E_{tr\ K\text{-}AVE}$ is Av Tr KE of CofM of gas particles.

$$E_{tr\,K\text{-}AVE} = \frac{3}{2}kT$$

This is a definition of the absolute temperature

***k* – Boltzmann constant;**

***k* = 1.38*10^-23^ J/K**

For an *atom*: KE = Tr_KE

Energy of a GAS made of *N atoms*.

$$U = N \cdot E_{K-AVE} = N\frac{3}{2}kT = nN_A\frac{3}{2}kT = \frac{3}{2}nN_AkT = \frac{3}{2}nRT$$

$$U = \frac{3}{2}nRT$$

Internal energy for a *monatomic* gas

For a ***molecule***: KE = Tr_KE + Rot_KE

For *a diatomic* (two atoms make one molecule) molecule there are *three translation directions*, and *rotational kinetic energy also contributes*, but *only* for rotations about two of the three perpendicular axes. The *five* contributions to the energy (five degrees of freedom) give: 

(we ignore possible oscillations)

$$\text{Diatomic ideal gas: } E_{int} = \frac{5}{2}NkT = U = \frac{5}{2}nRT$$

Polyatomic gas: 

$$U = E_{int} = \frac{6}{2}NkT = \frac{6}{2}nRT$$

i (the number of degrees of freedom) depends on the type of the particles:

$i = 3$  for point-like particles

$i = 5$  for dumbbell-like particles (no oscillations)

$i = 6$  for big particles made of 3 or more atoms (no oscillations)

$$\text{Ideal gas:} \qquad U = E_{int} = \frac{i}{2}\frac{N}{N_A}N_A kT = \frac{i}{2}nRT = \frac{i}{2}PV$$

In General: ⇨

$$\text{Ideal gas:} \qquad U = \frac{i}{2}nRT$$

Convenient connections

$$U = \frac{i}{2} nRT$$

$$PV = n \cdot R \cdot T$$

$$U = \frac{i}{2} \cdot PV$$

Convenient connections

$$U = \frac{i}{2} nRT$$

Internal energy

$$PV = nRT$$

$$U = \frac{i}{2} PV$$

$$\Delta U = \frac{i}{2} R\Delta(nT) = \frac{i}{2} \Delta(PV)$$

$$\Delta U = \frac{i}{2}\Delta(VP)$$

or

$$\Delta U = \frac{i}{2}nR\Delta T$$

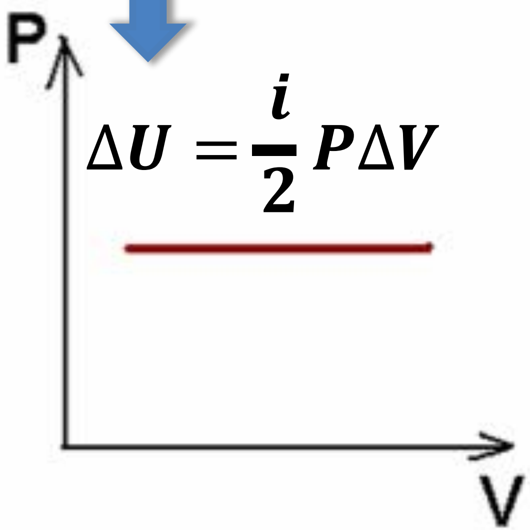
always

Three standard processes (n = const):

Isobaric

P = const

V/T = const

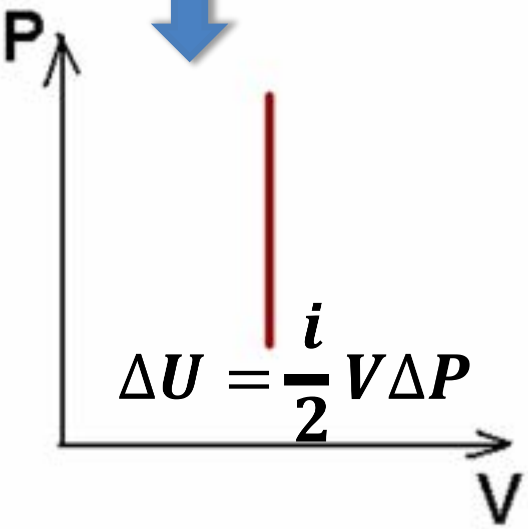


$$\Delta U = \frac{i}{2}P\Delta V$$

Isochoric

V = const

P/T = const

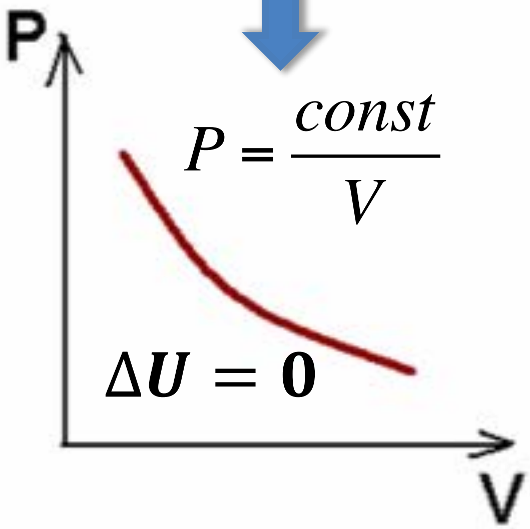


$$\Delta U = \frac{i}{2}V\Delta P$$

Isothermal

T = const

PV = const



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

$$\Delta U = 0$$

n = m/M

n = const

$$\frac{PV}{Tn} = R$$ **= 8.31 J/(Kmole)**

(Try to plot graphs for the same processes using PT and VT axes)

PY105 HW3 P4 (9141550)

Previewer Tools

Show New Randomization **Open in Editor** **Print**

Show: All, None ☑ Assignment Score ☑ Key ☑ Solution ☑ Help/Hints ☑ Mark ☐ Answer Format Tips

Current Score: 0/9 **Due:** Thu Jun 30 2016 11:00 PM EDT

Question	1	2	3	4	5	6	7	Total
Points	0/2	0/1	0/1	0/2	0/1	0/1	0/1	0/9

Description
Gases, work and energy, 1LT, 2LT, engines

1. **0/2 points** OSColPhys1 13.P.036.WA. [26

Two insulated cylinders *A* and *B* with volumes V_A = 1.4 m^3 and V_B = 5.2 m^3 contain chlorine gas at different pressur temperatures. The cylinders are insulated (no heat is lost to or gained from the outside) and connected by a valve. Init the valve is closed and the gas in the two cylinders has the following values:

$$P_A = 4.0 \times 10^5\ \text{N/m}^2,\quad T_A = 190\ \text{K},\quad P_B = 2.5 \times 10^5\ \text{N/m}^2,\quad T_B = 500\ \text{K}.$$

6. **0/1 points** OSColPhys1 15.P.019.WA. [261175

Calculate the net work output of a heat engine following path ABCDA in the figure below, where V_1 = 6.6 × 10^{-3} m^3 and V_2 = 26.4 × 10^{-3} m^3.

Calculate the internal energy and the pressure of 1 kg of a Hydrogen gas at the room temperature held in a 1 L jar.

$$PV = nRT$$

$$U = \frac{i}{2} nRT$$

$$U = \frac{i}{2} PV$$

$$n = \frac{m}{M}$$

$t \sim 20°C \Rightarrow T = 273 + 20 = 293 K$

$V = 1 L = 10^{-3} m^3$

$$n = \frac{m}{M} = \frac{1 kg}{2 \cdot \frac{g}{mol}} = \frac{1000 g}{2 g} mol = 500 mol$$

$$PV = nRT$$

$$P = \frac{500 \cdot 8 \cdot 293}{10^{-3}} = 1.17*10^{9} Pa$$

$$V = \frac{5}{2} \cdot nRT = \frac{5}{2} \cdot 500 \cdot 8 \cdot 293 = 2.9*10^{6} J$$

Calculate the *change* in the internal energy of a Hydrogen gas that expands from an initial volume of 3 L and initial pressure of 300 kPa to a final volume of 7 L at *constant temperature*.

Webassign:L23 Q6

$1.\ \Delta U > 0 \qquad 2.\ \Delta U = 0 \qquad 3.\ \Delta U < 0$

$$U = \frac{i}{2} nRT \qquad PV = nRT$$

$$U = \frac{i}{2} PV$$

$$n = \frac{m}{M}$$

Calculate the *change* in the internal energy of a Hydrogen gas that expands from an initial volume of 3 L and initial pressure of 300 kPa to a final volume of 7 L at *constant temperature*.

Webassign:L23 Q6

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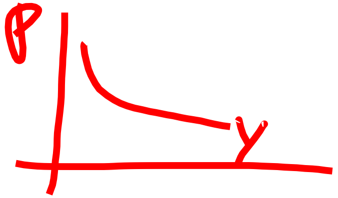


$$U = \frac{i}{2} nRT$$

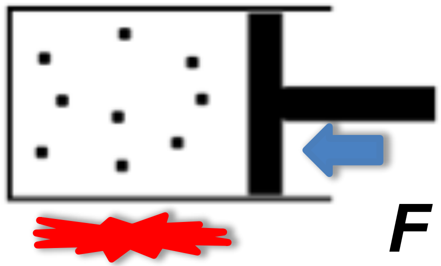
Two ways to change *U*

$$U = \frac{i}{2} PV$$

Thermal contact

Do work

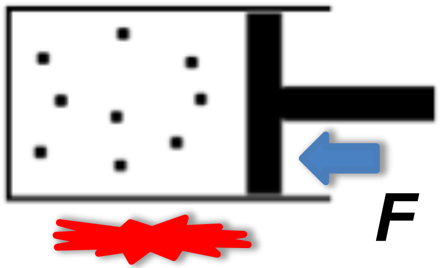
$$\Delta U = Q + W_{on\ system}$$



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

$$W_{on\ system} = -W_{by\ system}$$

N3L!



$$U = \frac{i}{2} nRT$$

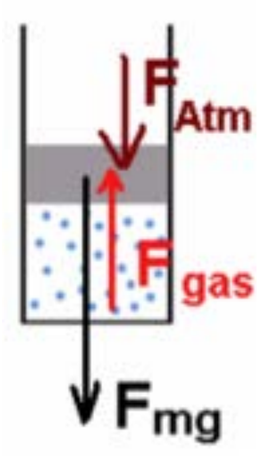
$$\Delta U = Q - W_{by\ system}$$

The First Law of Thermodynamics

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

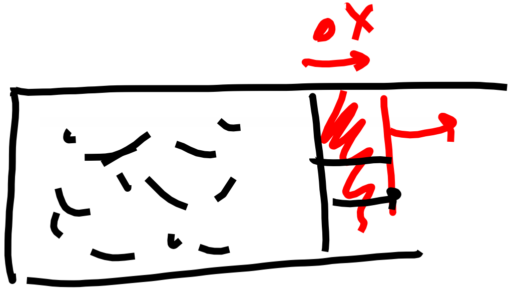
For example: The heat *absorbed* by the system can be *spent* => ΔU or $W_{by\ system}$.

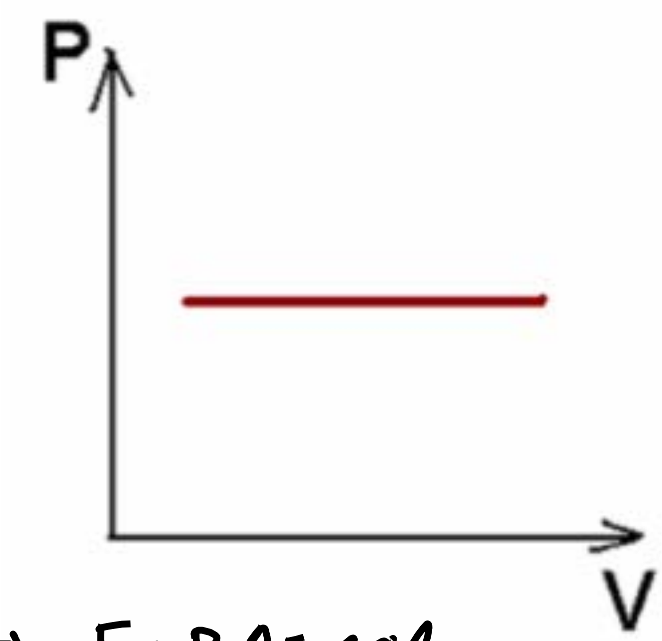
WORK done *by* a gas.



Isobaric

P = const





$P = const \Rightarrow F = P \cdot A = const$

$|W| = F \cdot \Delta s \cdot \cos 0 = P(A \cdot \Delta s)$

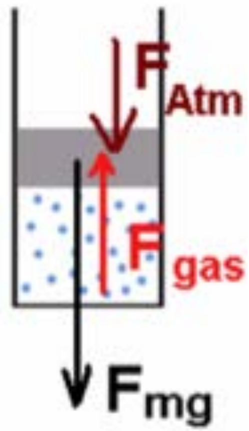
$|W| = P \cdot \Delta V$

const

WORK done *by* a gas.

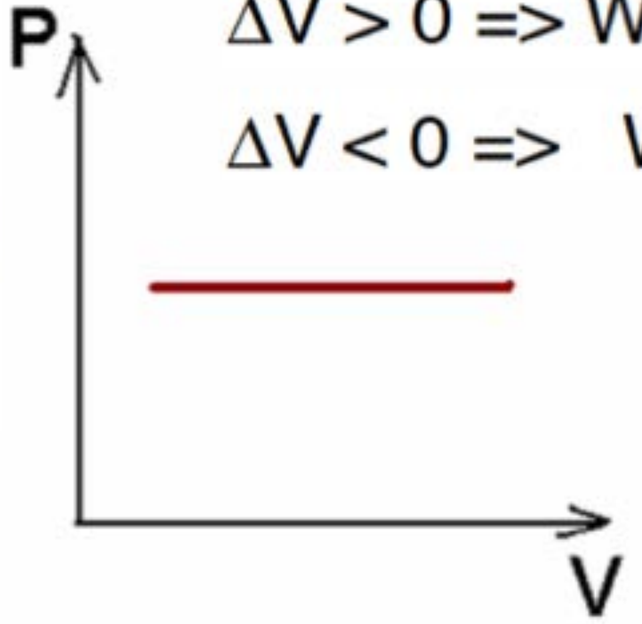
Isobaric

$F = const \quad \Leftarrow P = const$



$W = F * \Delta x \qquad V/T = const$

$F = P * A$, so:



$\Delta V > 0 \Rightarrow W > 0$

$\Delta V < 0 \Rightarrow W < 0$

$W = P * A * \Delta x = P * \Delta(Ax) = P * \Delta V$

$PV = nRT$

At constant pressure the work done by the system is the pressure multiplied by the change in volume.

If there is a change in volume and the pressure changes the work done by the system is the area under the P-V graph.

$$PV = nRT$$

This is why P-V diagrams are so useful in thermodynamics.

$\Delta V > 0 \Rightarrow W > 0$ | $\Delta V < 0 \Rightarrow W < 0$

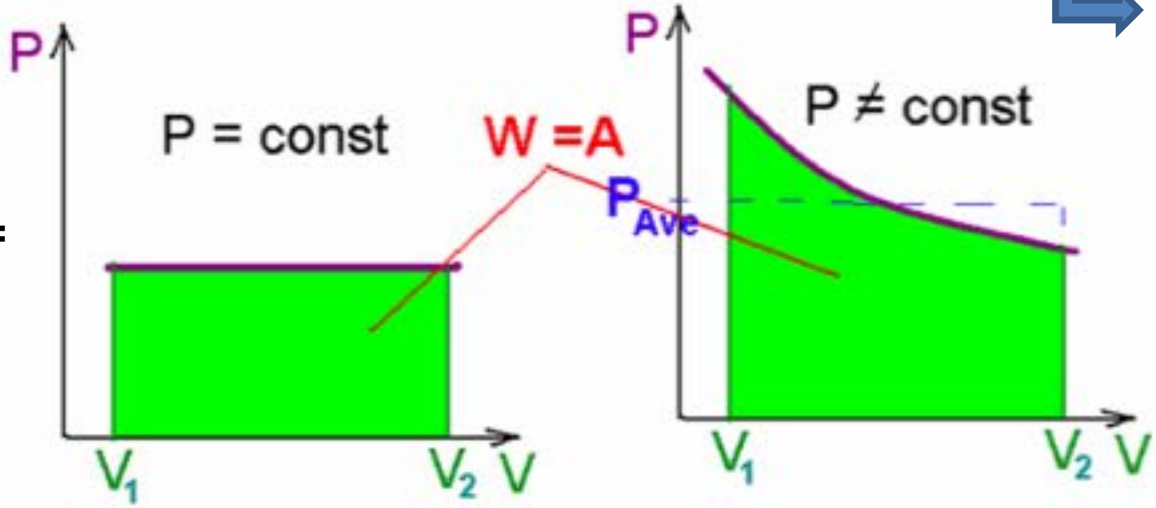
$P = \text{const}$ => $F = PA = \text{const}$

$W = P^*\Delta V = P^*(V_2 - V_1)$

$P \neq \text{const}$

$W = P_{Ave}{}^*\Delta V = \text{Area (P-V graph)}$ → + or -

$$W_{P=const} = \\ = P\Delta V = \\ = nR\Delta T$$



$V_i = V_f$

$W = 0$!

The summary of the 97 % of the last topics

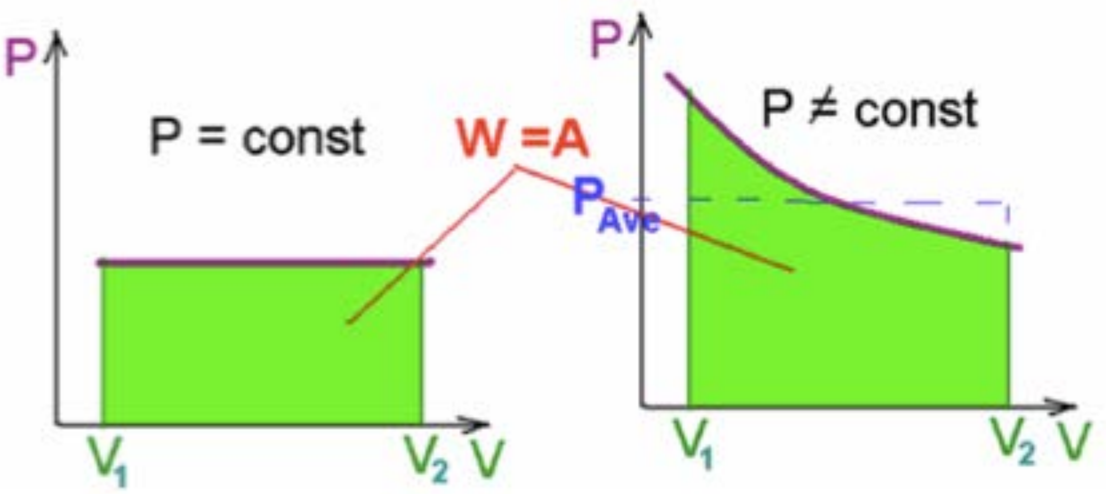
$$Q = \Delta U + W_{by\ system}$$

$$PV = nRT$$

$$U = \frac{i}{2}PV$$

$$U = \frac{i}{2}nRT$$

$$n = \frac{m}{M}$$



$$W = P_{Ave} * \Delta V = \text{Area (P-V graph)}$$

$i = 3$ • for point-like particles

$i = 5$ •—• for dumbbell-like particles (no oscillations)

$i = 6$ for big particles made of 3 or more atoms (no oscillations)