Module 3

The Ideal Gas & the First Law of Thermodynamics

Session Slides with Notes

Macrostate Functions

Pressure -

F/A $\quad N/m^2 = 1$ Pascal

1 atm = 101,000 Pa

1×10^5 Pa

= 760 torr

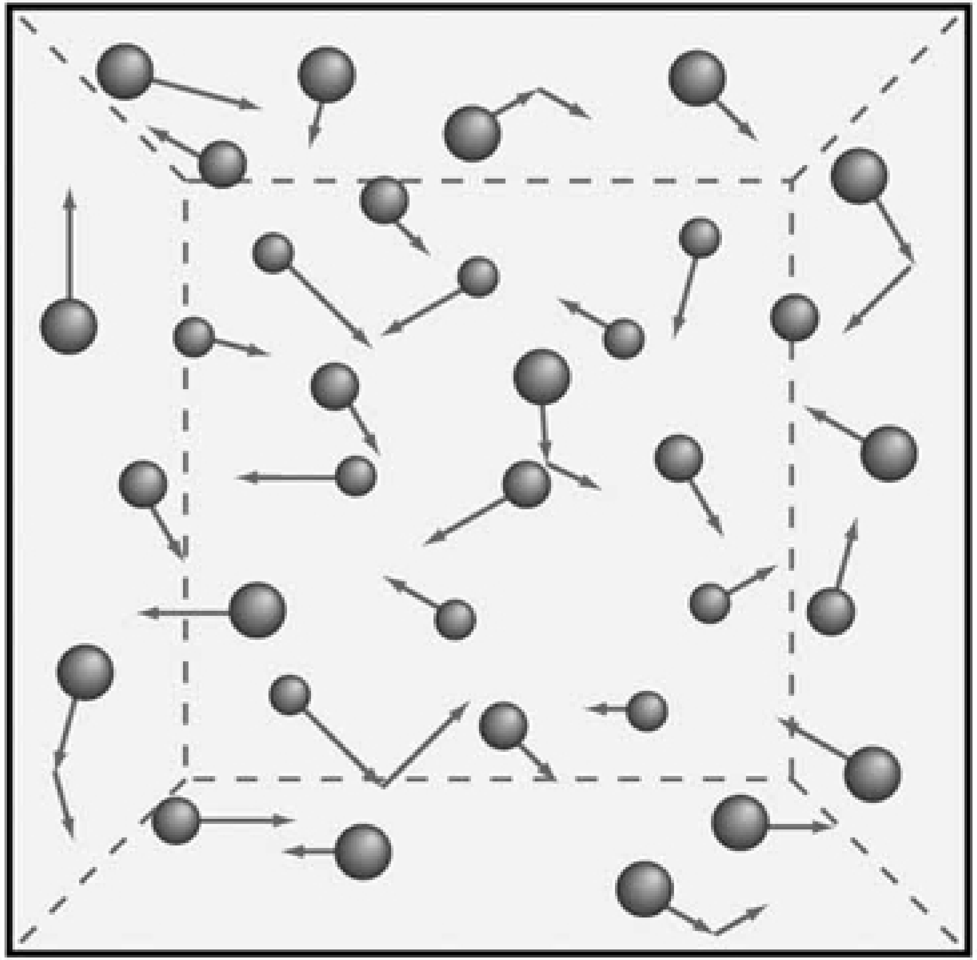
Volume -

$m^3 = 1000L$

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

Temperature

$\frac{1}{2} m \bar{v}^2 = \frac{3}{2} kT$



Ideal Gas & Kinetic Theory

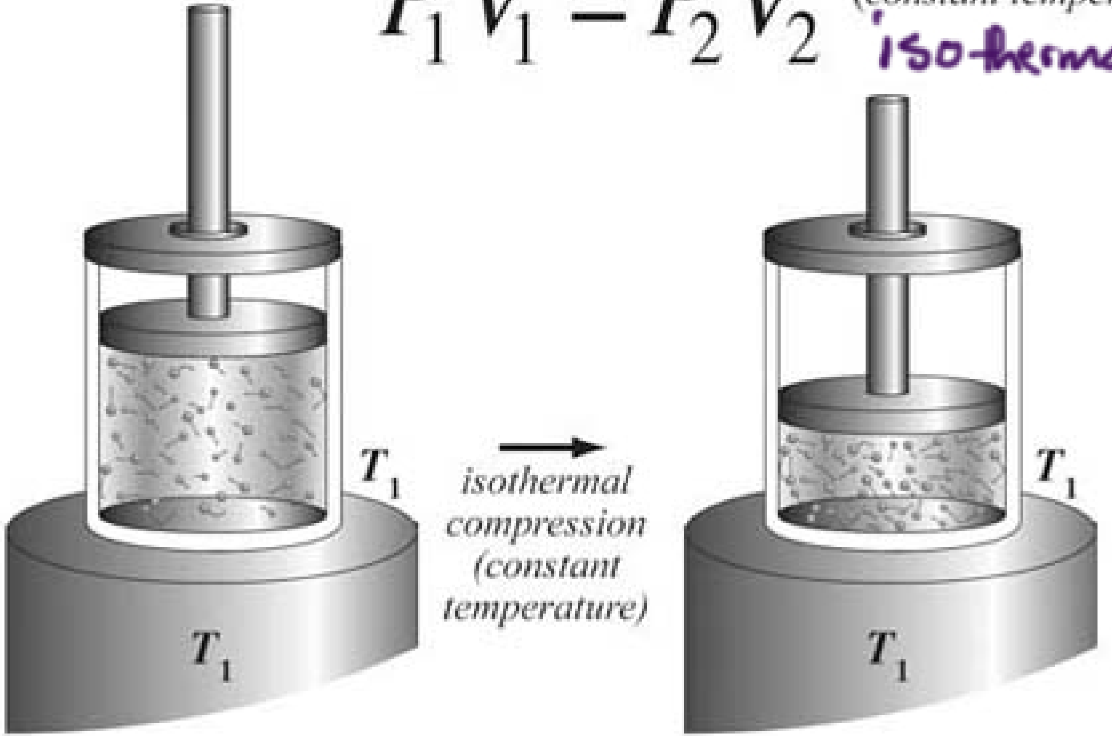
+ 1st law of thermodynamics

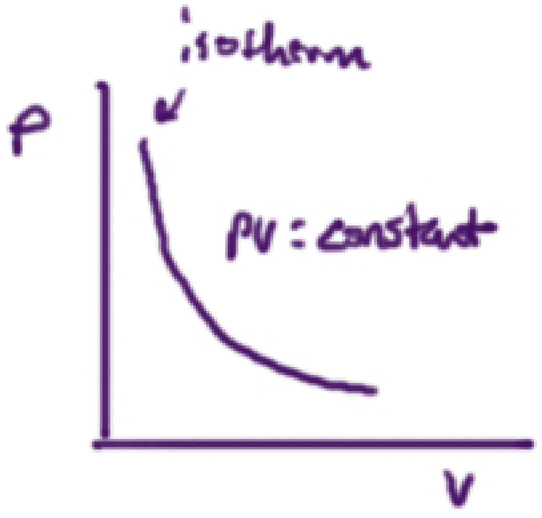
- point masses
- elastic collisions
- no action-at-a-distance forces

Boyle's Law

$$P_1 V_1 = P_2 V_2$$ (constant temperature)

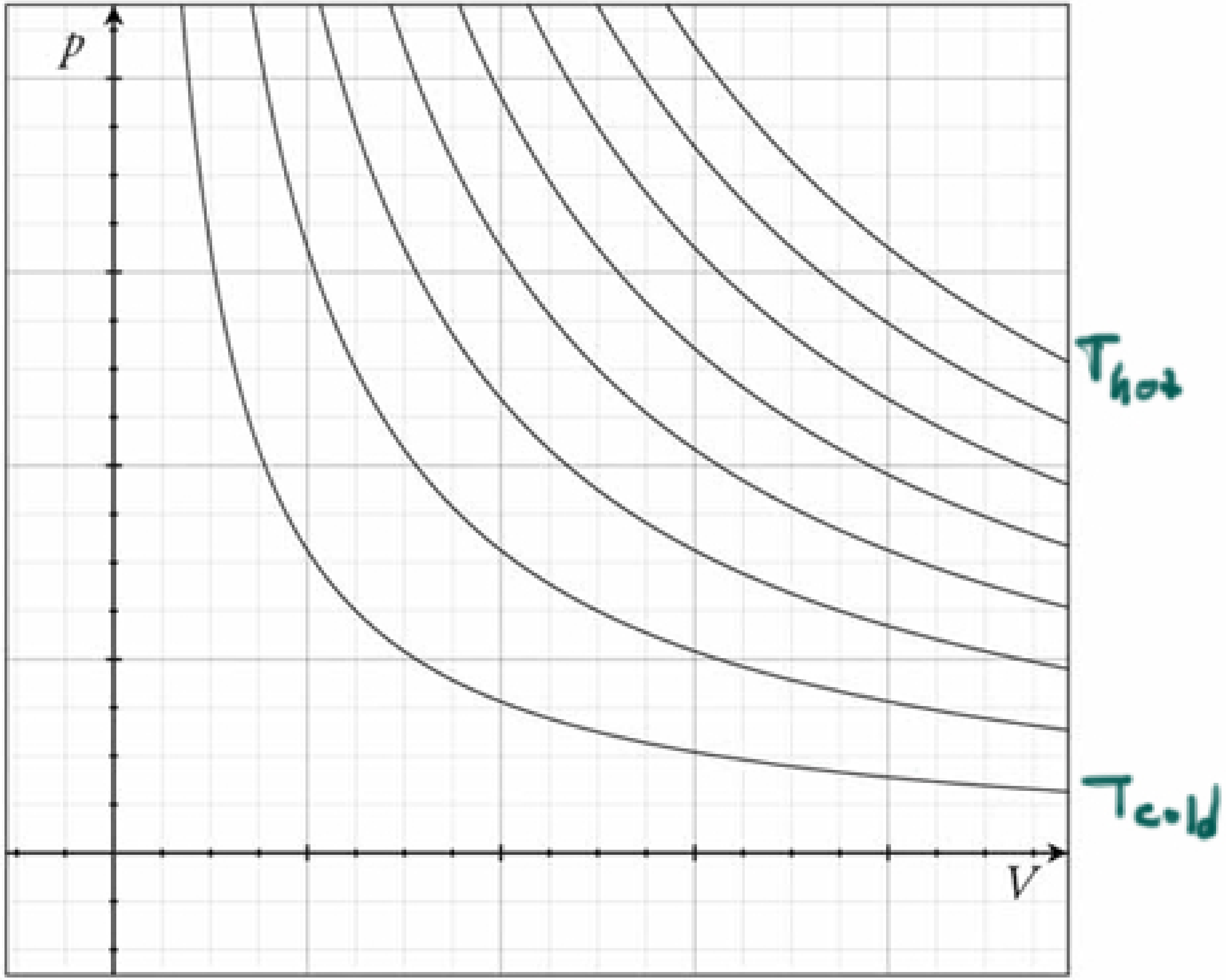
isothermal





Thermal equilibrium with the heat sink allows the gas to be compressed at constant temperature, isothermally. With constant temperature, Boyle's Law applies. The pressure and volume are inversely proportional (PV is constant). Pressure increases as volume decreases.

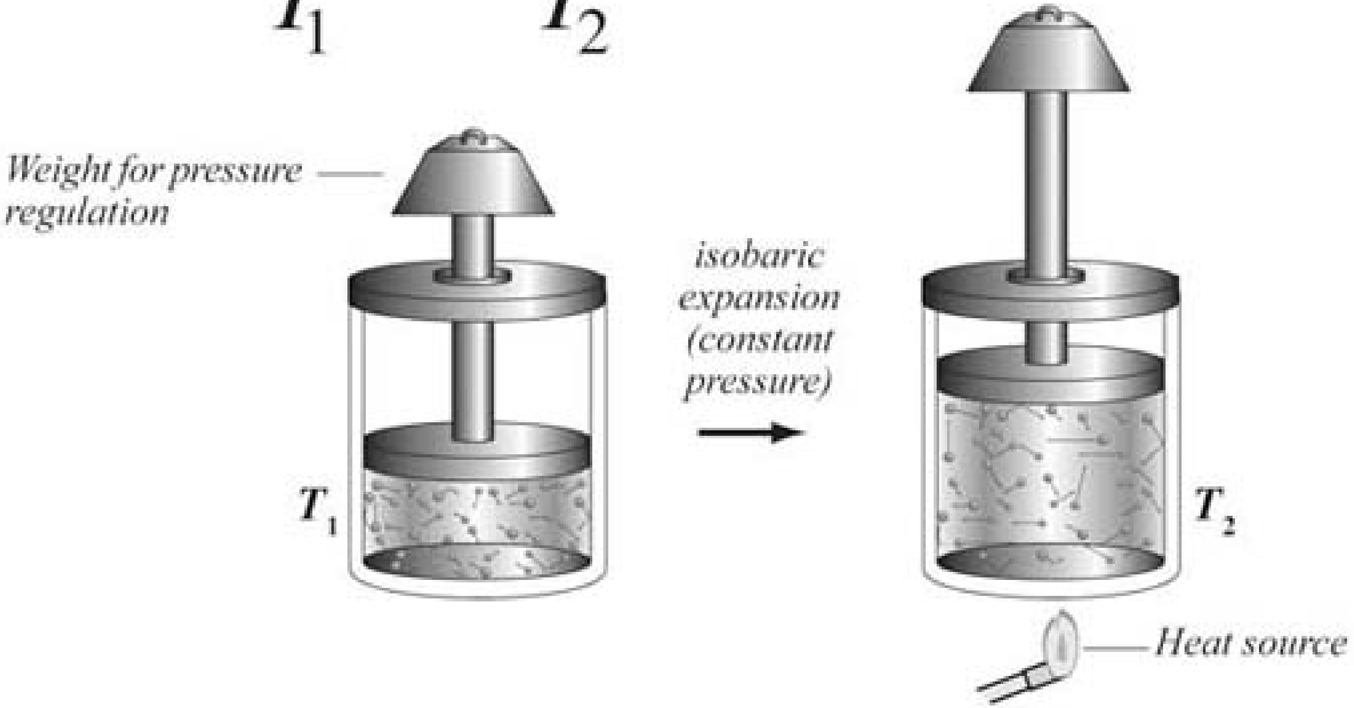
isotherms



Charles' Law

$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$ *(constant pressure)*

isobaric



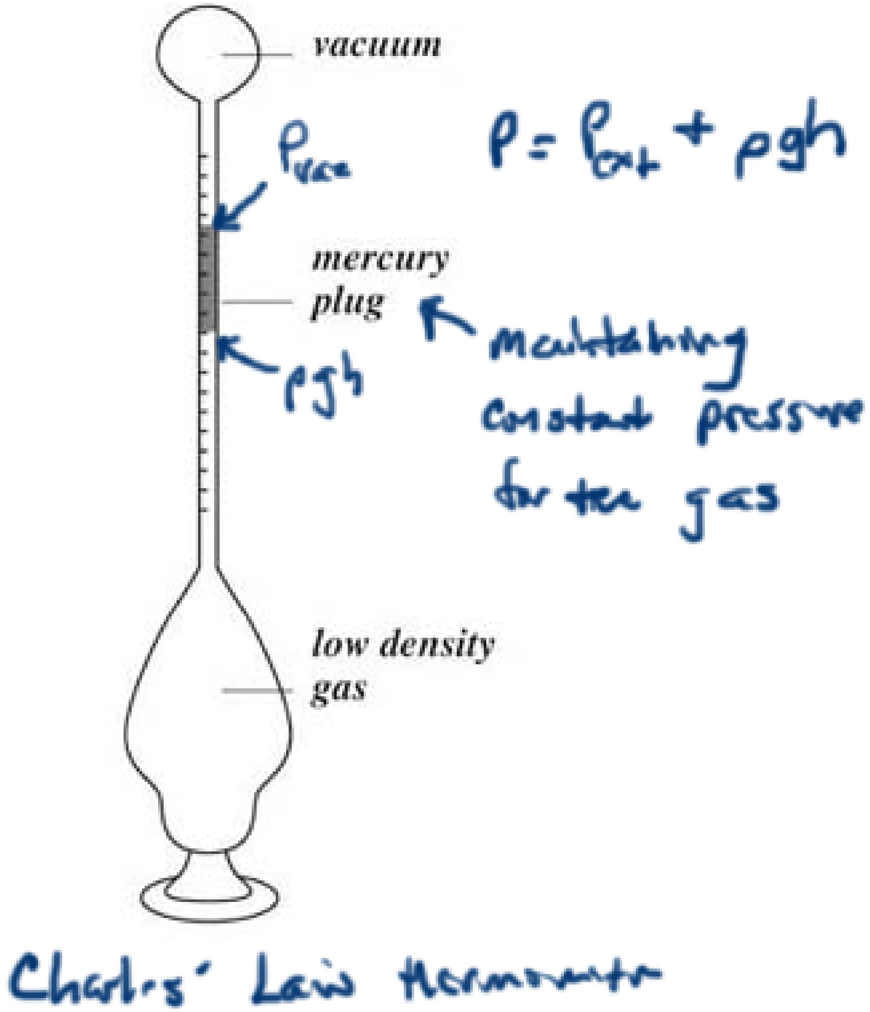
$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$$

combined gas law

Heating a gas makes its particles move faster. Collisions are stronger. Therefore, to exert the same pressure, the particles must be more spread out. The volume must have increased.

Constant P

How does the thermometer at right measure temperature?



a. It measures the pressure of the gas.

b. It measures changes in the volume of the mercury.

c. It measures the volume of the gas.

d. It measures the ratio of the density of the mercury to the density of the gas.

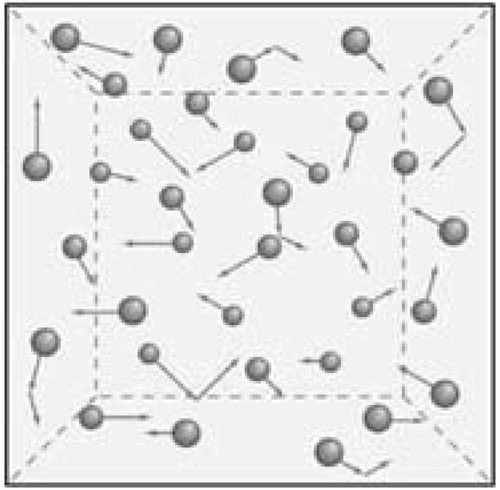
The Ideal Gas Law

• state equation of an ideal gas

Any two of P, V, T specify the state of a gas

$$PV = nRT$$

P = pressure
V = volume
T = temperature
n = # of moles of gas
R = ideal gas constant
[8.31 J/mole · K] ← 8
[0.082 liter · atm/mole · K] ← .08



1 mole of an ideal gas occupies 22.4 liters at STP.

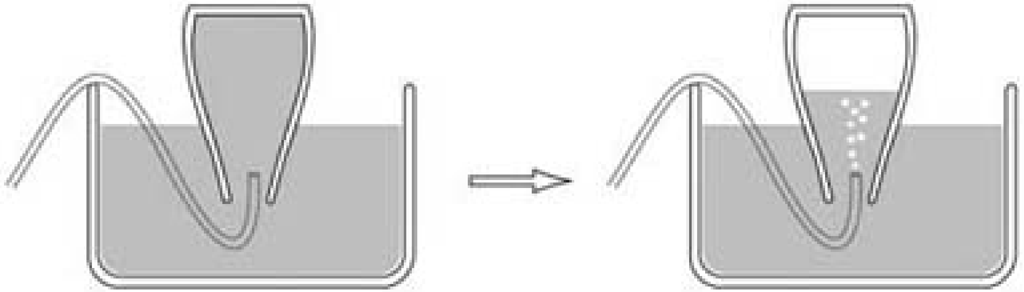
standard T

STP – 273 K

298 K – standard state T

1 atm P

To serve as an apparatus for collecting gaseous substances a flask is completely filled with water and inverted with its mouth submerged within a larger container of water.



$PV = nRT$

$V = \frac{n}{P} RT$

Student A collects methane gas (CH_4) in this manner, and student B collects propane gas (C_3H_8). After each has collected one gram of substance:

a. the gaseous phase in student A's flask has greater volume

b. the gaseous phase in student B's flask has greater volume

c. the volume of the gaseous phases of both flasks are equal

d. the gaseous phase in student B's flask has greater pressure

The Temperature of an Ideal Gas Depends on the Average Translational Kinetic Energy of the Particles

$$\frac{1}{2}m\overline{v^2} = \frac{3}{2}kT$$

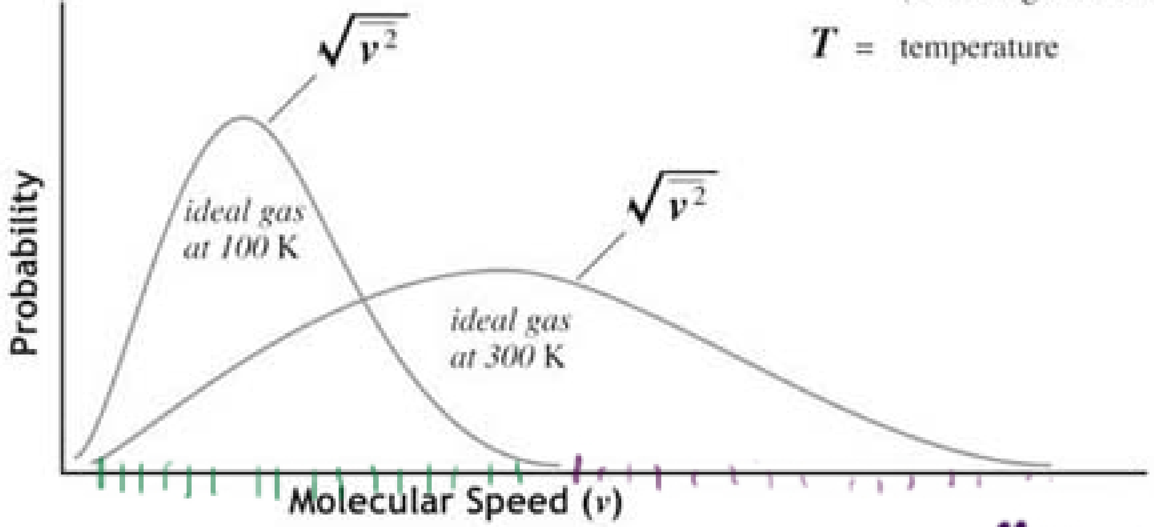
m = mass

$\overline{v^2}$ = average square speed

k = Boltzmann's constant

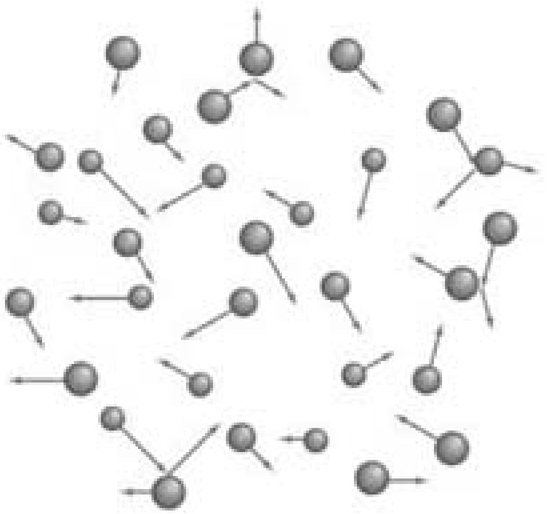
(R / Avogadro's number)

T = temperature



The difference in the velocity distribution curves for ideal gas particles at 100 K and 300 K shows the dependence of the average translational kinetic energy of the particles on temperature.

The Internal Energy of an Ideal Gas Depends on Temperature



$$\frac{U}{N} = \frac{3}{2}kT$$

$$\frac{1}{2}m\bar{v}^2 = \frac{3}{2}kT$$

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

U = internal energy
N = number of molecules
k = Boltzmann's constant
= ***R*** / Avogadro's number
T = temperature

n = moles of gas
R = ideal gas constant

RMS Particle Speed Is Inversely Proportional to the Square Root of Particle Mass *(for a given temperature)*

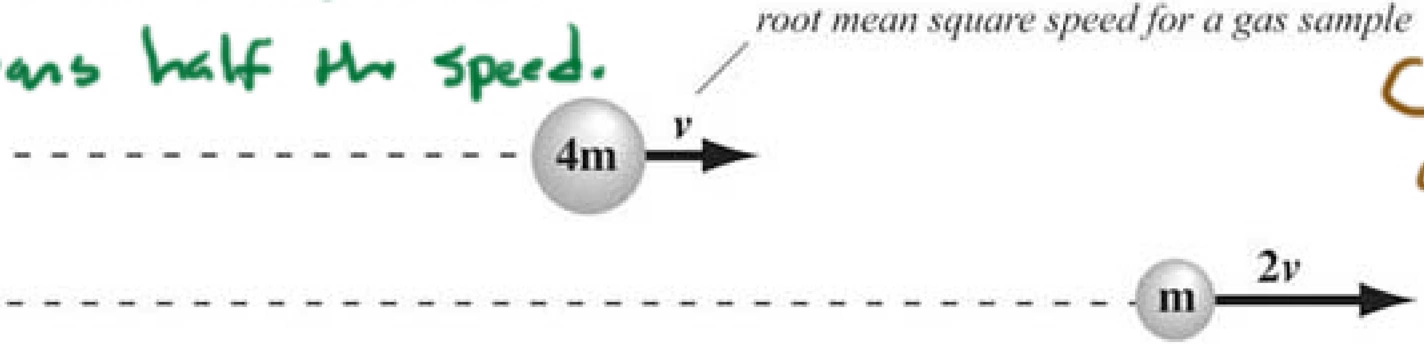
$\frac{1}{2} m_A \bar{v}_A^2 = \frac{1}{2} m_B \bar{v}_B^2$

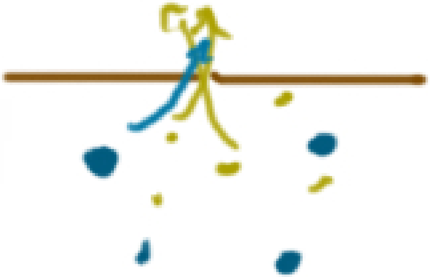
$$\frac{\bar{v}_A}{\bar{v}_B} = \frac{\sqrt{m_B}}{\sqrt{m_A}}$$

m = mass
$\bar{v}$ = root mean square speed (square root of average square speed)

Four times the mass means half the speed.

Graham's Law of effusion

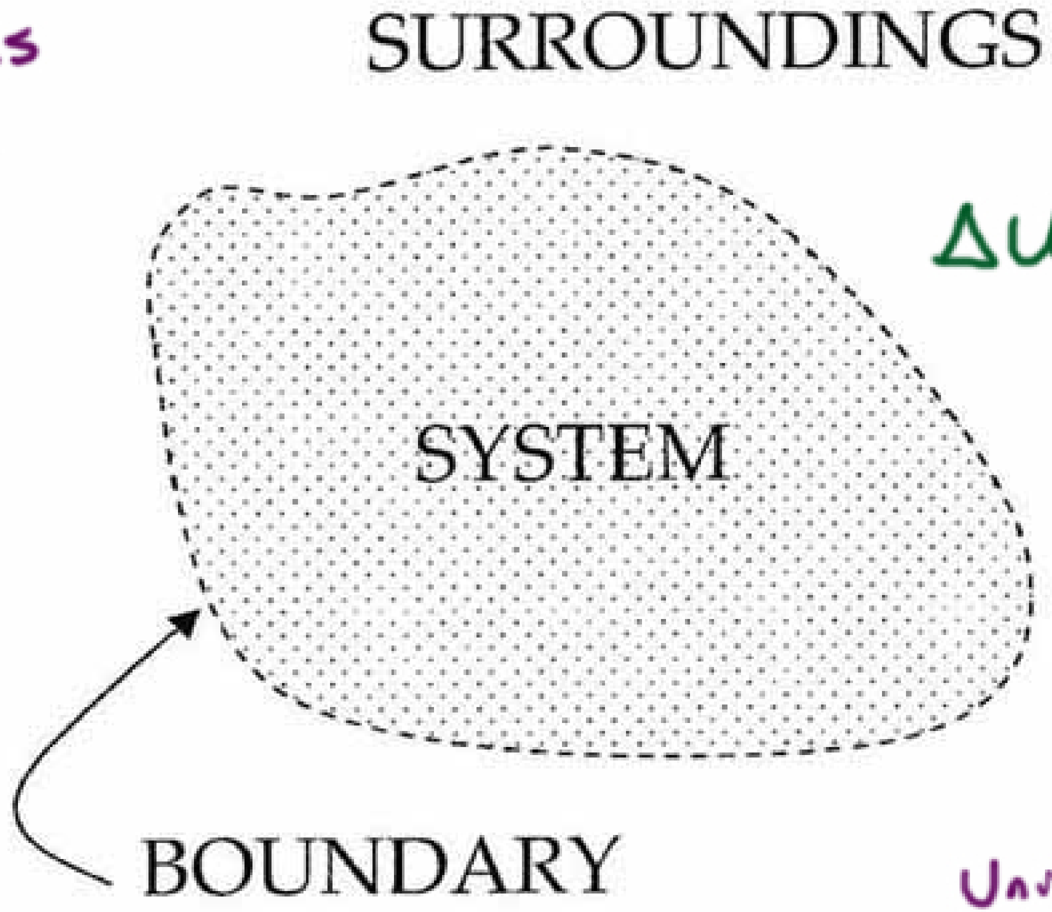




'Average' (root mean square) speed is inversely proportional to the square root of molecular mass. For two samples of ideal gas at the same temperature, if the molecules of one gas are four times larger, the root mean square speed is half as great.

1st Law of Thermodynamics

- Conservation of energy



heat flow

$$\Delta U = Q - W$$

thermodynamic work

$P\Delta V$

Universe = System + Surroundings

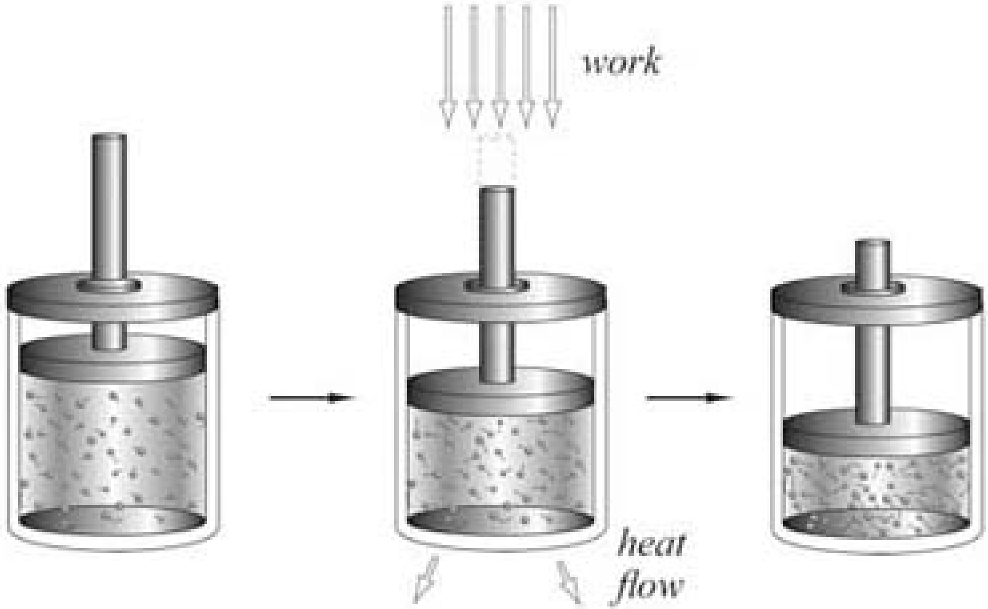
The Universe

The First Law of Thermodynamics

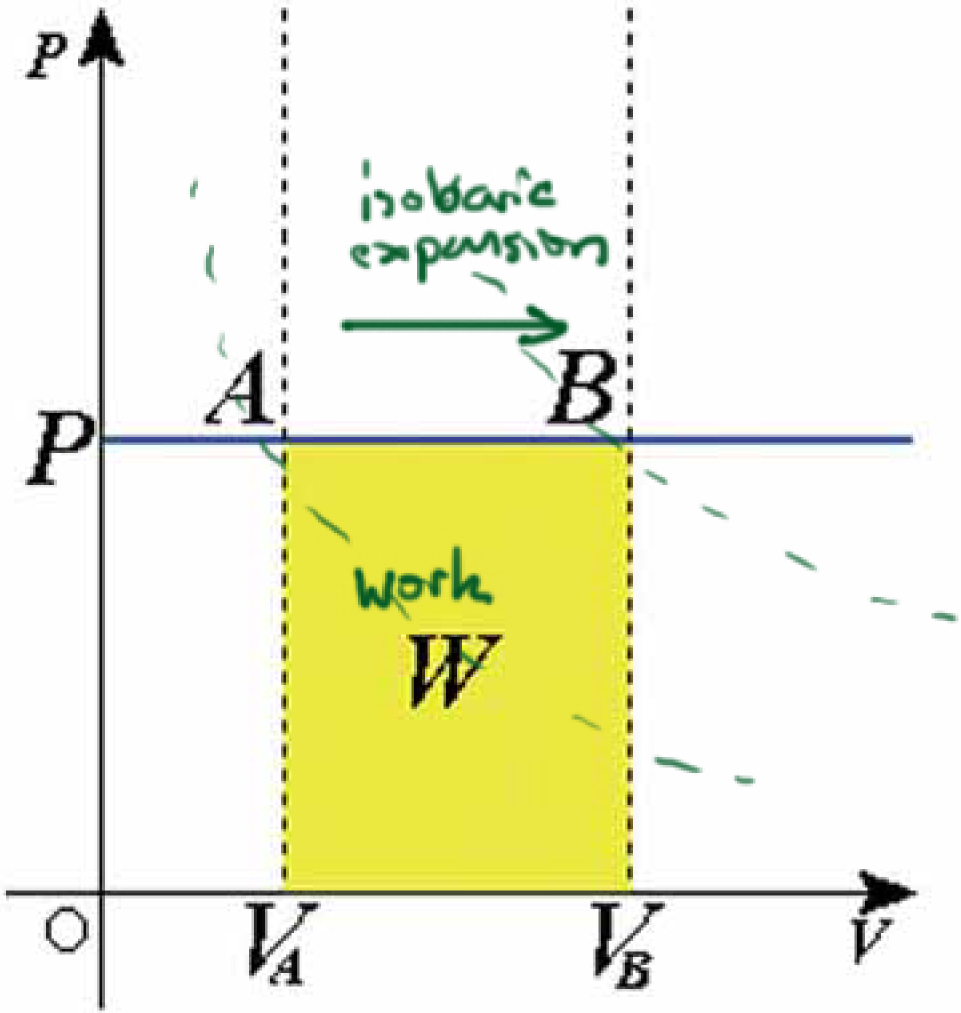
$$\Delta U = Q - W$$
$$= Q - P^{*}\Delta V$$

ΔU = internal energy change
Q = heat flow
W = macroscopic work

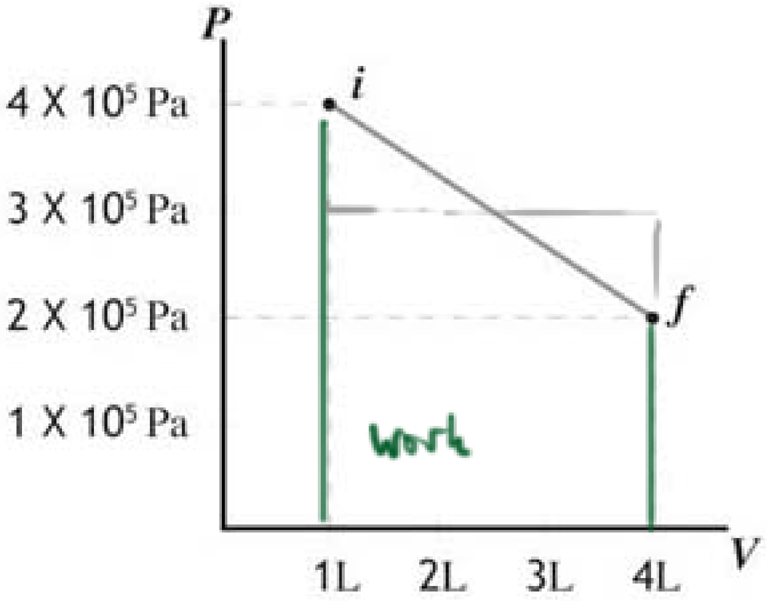
P^{*} = constant pressure
ΔV = volume change



Internal energy change results from the combination of heat flow and work between the system and its surroundings. In this example, the internal energy of our ideal gas system became greater (the particles are moving faster in the final state) because more energy entered the system through work than departed the system as heat flow.


P
isobaric expansion
A
B
P
work
W
O
V_A
V_B
V

The straight line on the graph shows the path between the initial and final states in the expansion of a gas. How much work is performed by the gas during the expansion?



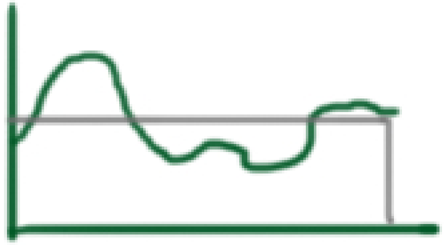
a. 900 J

b. 1150 J

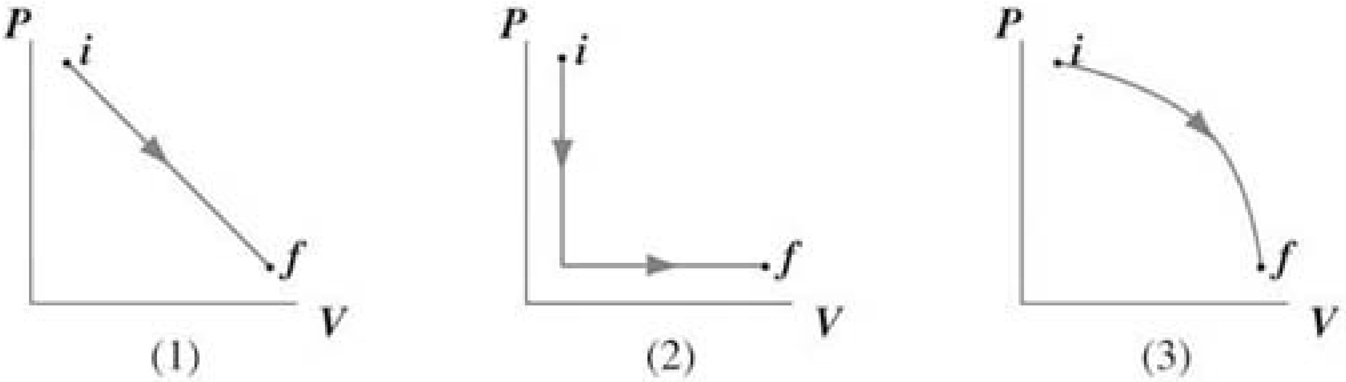
c. 90,000 J

d. 9 X 10^5 J

$(3\times10^5\,Pa)(3\times10^{-3}\,m^3)$



An ideal gas is taken from the same initial state and same final state by the three alternative pathways:



Which of the following are equal for all three pathways.

$\Delta U = Q - W$

same　different　different

~~I.~~ work done by the gas

~~II.~~ heat flow between the gas and the surroundings

III. internal energy change　$U = \frac{3}{2} nRT$

IV. temperature change

state functions

a. II only

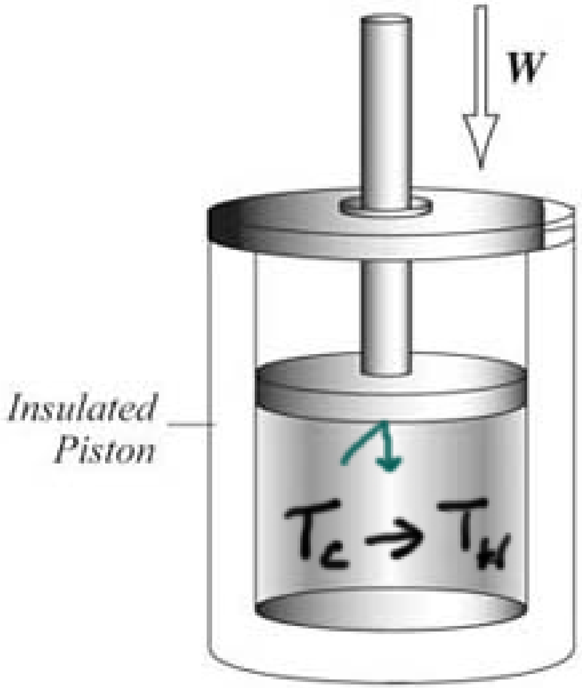
b. II and IV

c. III and IV

d. I, II, III, and IV

Adiabatic Process

↖ no heat flow



No Heat Flow

$$Q = 0$$

$$\Delta U = -W$$

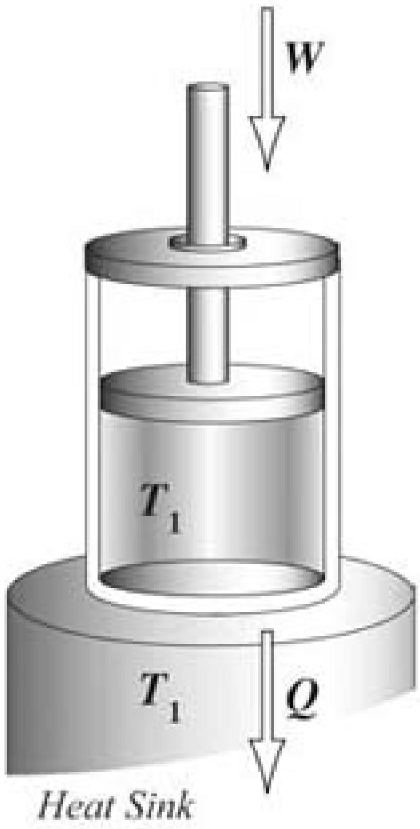
First law of thermodynamics for an adiabatic process

Q	=	heat flow
ΔU	=	internal energy change
W	=	macroscopic work

In an adiabatic process, no heat flow occurs, so internal energy change directly corresponds to the work performed.

Isothermal Process

constant T

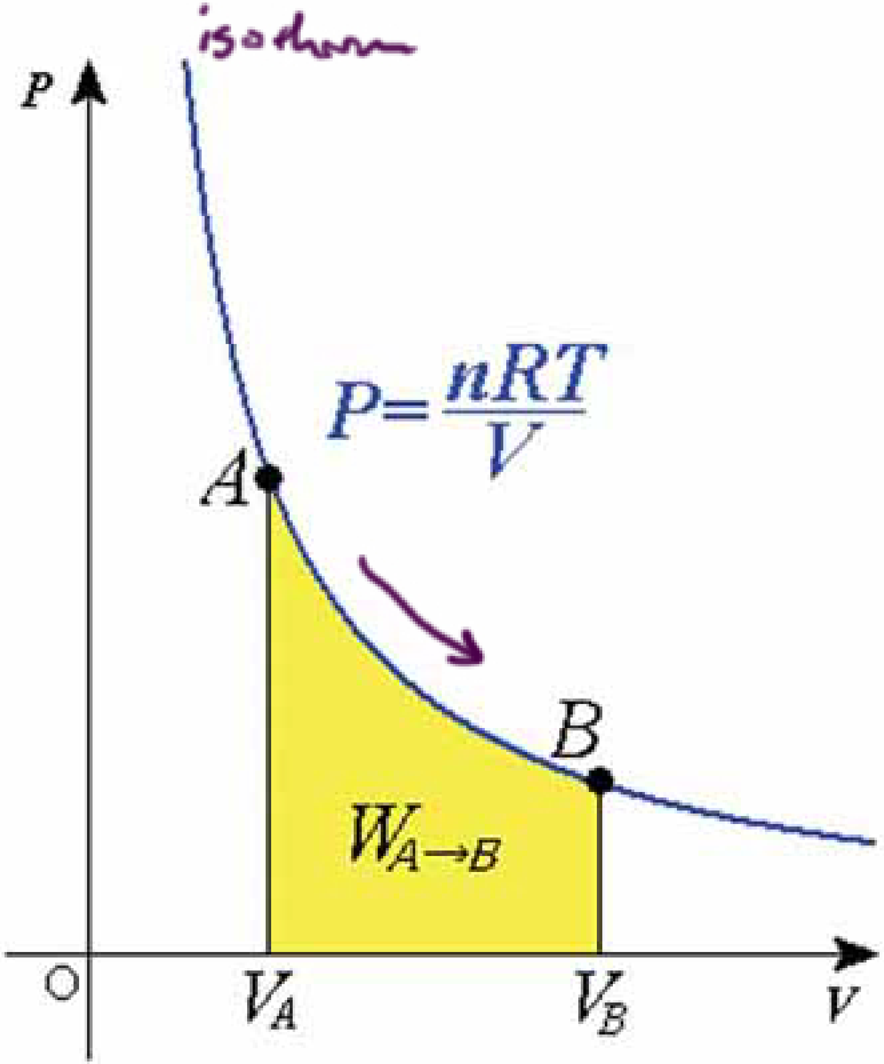


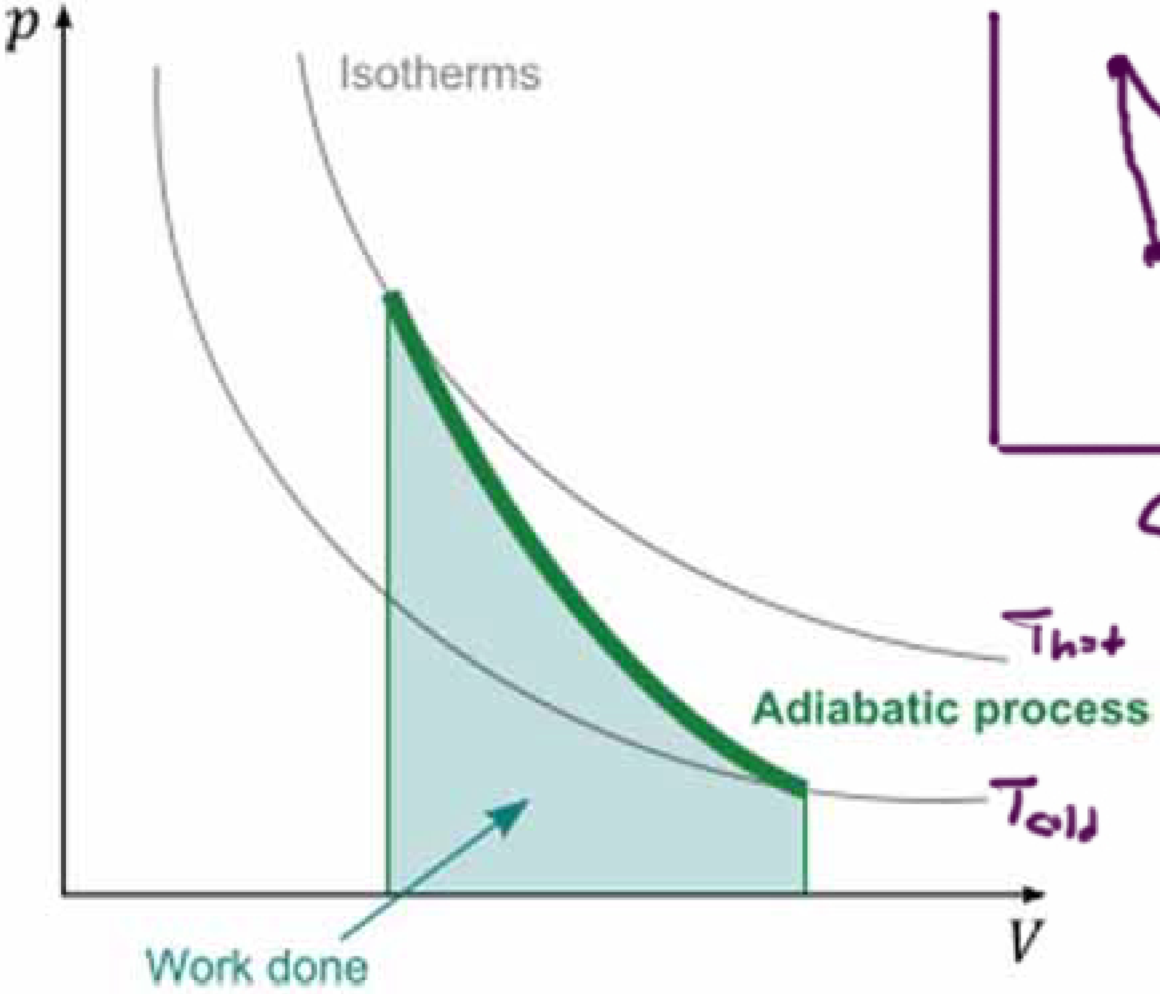
$$\Delta U = 0$$
$$Q = W$$

First law of thermodynamics for an isothermal process

ΔU = internal energy change
Q = heat flow
W = macroscopic work

In an isothermal process on an ideal gas, the temperature is constant. Because temperature is constant, internal energy must be constant. If internal energy is constant, any work that occurs must be balanced by heat flow.


isotherm
P
$P = \frac{nRT}{V}$
A
B
$W_{A \to B}$
O
V_A
V_B
V



Carnot cycle

Isovolumetric Process

isochore

Work $P\Delta V$

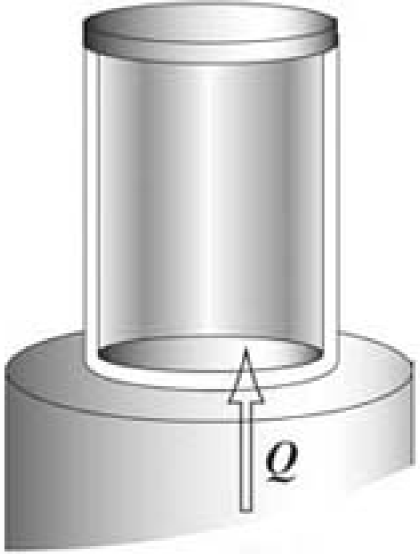
$\Delta V = 0$

no work

$$W = 0$$

$$\Delta U = Q$$

First law of thermodynamics for an isovolumetric process



Heat Sink

W	=	macroscopic work
ΔU	=	internal energy change
Q	=	heat flow

In an isovolumetric process, no thermodynamic work occurs. The only way internal energy changes is through heat flow.