T261, T263

THERMAL PHYSICS

THERMOMETER

BRING LN2 IF POSSIBLE + BALLOONS +

→ TEMPERATURE: SAME FOR TWO OBJECTS AFTER BEING IN CONTACT FOR SUFFICIENTLY LONG

THERMAL EQUILIBRIUM: TWO OBJECTS
RELAXATION TIME: TIME IT TAKES TO REACH EQUILIBRIUM

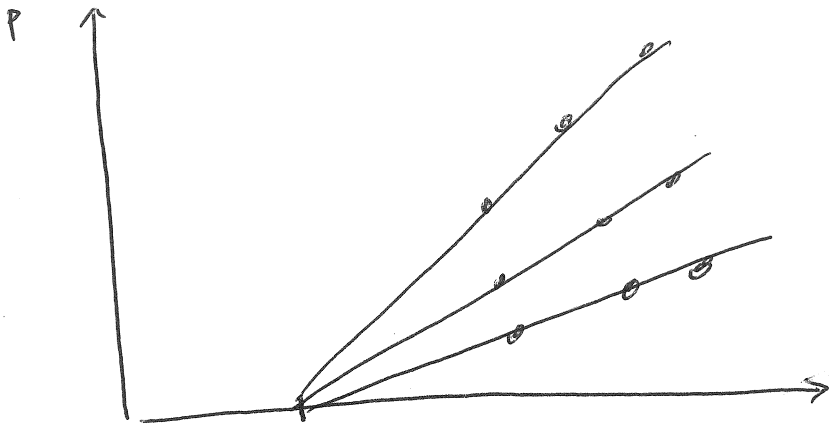
HOW DO I MEASURE TEMPERATURE?

- EXPANSION — Hg thermometer, METALLIC STRIPS
- VOLTAGE — THERM. COUPLE, S. DIODE
- RESISTANCE — Pt, THERMISTER, CARBON RESISTER
- NOISE
- PRESSURE — CONSTANT VOLUME GAS

SCALE CELCIUS SCALE

100°C BETWEEN MELTING POINT + BOILING POINT OF WATER AT 1 atm

DEMO BALLOON



$-273.15°C$

$0K = -273.15°C$

IDEAL GAS LAW

$PV = nRT$

n: MOLES OF GAS

$R = 8.31\ J/mol \cdot K$

1 mole CONTAINS 6.02×10^{23} ATOMS

$PV = NkT$

$k \cdot N_A = R$

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

IDEAL GAS LAW

$pV = nRT$

2.
- n: moles of GAS UNIT mole
- R = 8.31 J/mol·K.
- ~~B~~: T: TEMPERATURE IN KELVINS

1.
- P: PRESSURE IN Pa : N/m^2
- V: VOLUME IN m^3

1' PV = N·m : FORCE × DISTANCE
= J
ENERGY!

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1 MOLE CONTAINS 6.022×10^{23} ~~ATOMS (OR~~ MOLECULES)

PV = NkT N: # OF MOLECULES

$$k = 8.31\ J/mol \cdot K \times \frac{1\ mol}{6.022 \times 10^{23}\ \cancel{\text{ATOMS}}\ \text{MOLECULES}}$$

$k = 1.38 \times 10^{-23}\ J/K$: BOLTZMANN'S CONSTANT

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nR = Nk

FOCUS ON IDEAL!

WEIRD STUFF HAPPENS LIKE AT 0 K V = 0

BUT ~~IT~~ GAS MOLECULES HAS SIZES

$$\left(p + \frac{n^2 a}{V^2}\right)(V - nb) = nRT$$

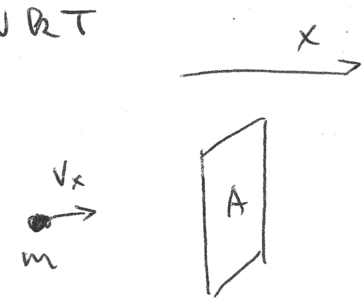
INTERACTION BETWEEN ~~##~~ MOLECULES

~~SPACE~~ VOLUME 0

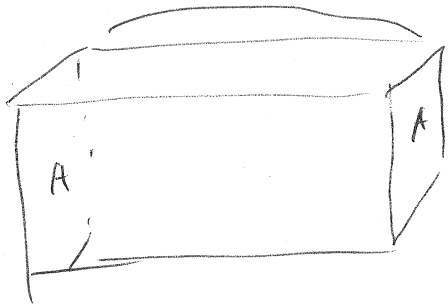
MICROSCOPIC MODEL OF IDEAL GAS

PV = NRT

DIRECTION



$\bar{V}_x \Delta t$



MOMENTUM $\longrightarrow$ $m\bar{V}_x \hat{x}$

AFT: $\longleftarrow$ $-m\vec{V}_x \hat{x}$

$\Delta m\vec{v}$ ~~PAP~~ Δ MOM $= -2m\bar{V}_x \hat{x}$

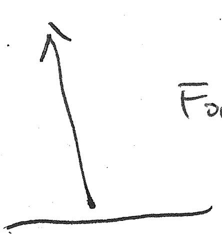
OF PARTICLES HITTING WALL IN Δt

$$\# = \frac{n \bar{V}_x \Delta t}{2}$$

$$\Delta m v \times \# = -2m\bar{V}_x \cdot \frac{n \bar{V}_x \Delta t}{2}$$

LECTURE 1

$$\Delta mv = n m \bar{V}_x^2 \Delta t$$



F ON MOLECS BY WALL $= \frac{\Delta mv}{\Delta t} = -n m \bar{V}_x^2$

$$F_{\text{ON WALL}} = n m \bar{V}_x^2$$

$$\bar{V}_x^2 = \bar{V}_y^2 = \bar{V}_z^2$$

$$\bar{V}_x^2 + \bar{V}_y^2 + \bar{V}_z^2 = \bar{V}^2$$

$$\bar{V}_x^2 = \frac{V^2}{3}$$

$$p = n\, m \frac{\overline{v}^2}{3}$$

$$pV = N\, m \frac{\overline{v}^2}{3} = N k T$$

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

VIRIAL THEOREM ?

3 DEGREES OF "FREEDOM" $\frac{1}{2} kT$ EACH

AT 300K

$$kT = (1.38 \times 10^{-23}\ J/K)\ 300K = 4.14 \times 10^{-21}\ J$$

$$1\,eV = 1.6 \times 10^{-19}\ J$$

$$kT\ @\ 300K \sim 0.026\,eV \simeq \frac{1}{40}\ eV$$

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

$$\cancel{\sqrt{v^2}} = V_{RMS} = \sqrt{\overline{v^2}} = \sqrt{\frac{3kT}{m}}$$

CLICKER Q5

EQUIPARTITION THEOREM

GIVEN TEMPERATURE T, AVERAGE ENERGY OF ANY QUADRATIC DEGREE OF FREEDOM IS $\frac{1}{2}kT$

IF YOU REMEMBER THERE ARE THINGS THAT LOOK LIKE

$$\frac{1}{2}mv^2, \quad \frac{1}{2}I\omega^2, \quad \frac{1}{2}kx^2$$

CLICKER QUESTION 2

~~$U_{THERMAL}$~~

IF A SYSTEM HAS N MOLECULES
EACH w/ f DEGREES OF FREEDOM

THEN TOTAL THERMAL ENERGY IS

$$U_{THERMAL} = N \cdot f \cdot \frac{1}{2}kT$$

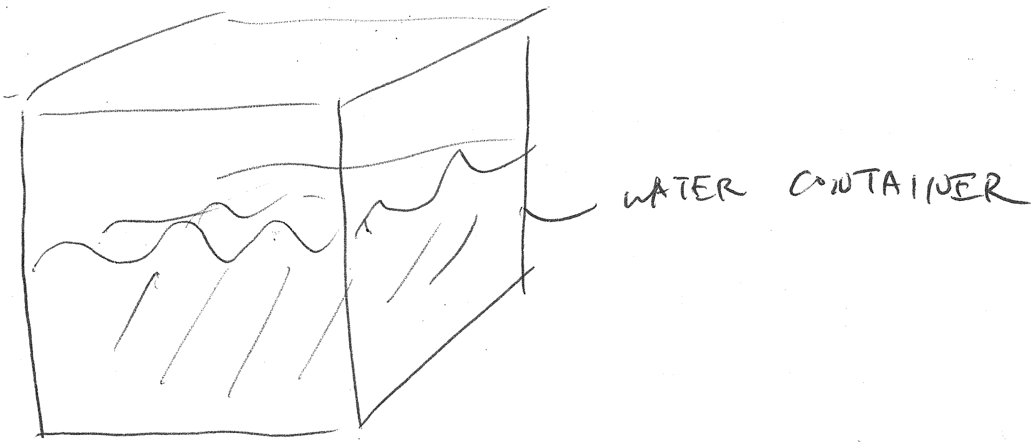
EXAMPLE Ar GAS $f = 3$

H_2, O_2 OR N_2

$$3 + \underset{\text{ROTATION}}{2} + \underset{\text{VIBRATION}}{2} = f$$

↑ IF TEMP HIGH ENOUGH

TEMPERATURE ENERGY HEAT



ENERGY OF THIS ~~CAN~~ CONTAINER CANNOT ~~INCREASE~~ CHANGE
~~UNLESS VIA HEAT OR WORK~~.
BY ITSELF UNLESS ENERGY IS TRANSFERRED TO IT

TWO WAYS TO CHANGE ENERGY CONTENT

HEAT AND WORK

HEAT : SPONTANEOUS FLOW OF ENERGY FROM ONE TO THE OTHER CAUSED BY ΔT BETWEEN OBJECTS

WORK : ANY OTHER TRANSFER OF ENERGY

Q : HEAT

W : WORK

$$\boxed{\Delta U = Q + W}$$

1ST LAW OF THERMODYNAMICS

SHOW PPT EXAMPLES

ENERGY JOULE $1\,kg\,m^2/s^2$

1 cal HEAT NEEDED TO RAISE THE TEMPERATURE OF A GRAM OF WATER BY 1°C

1 cal 4.186 J

JOULE STORY FOR A BREAK

COMPRESSION WORK

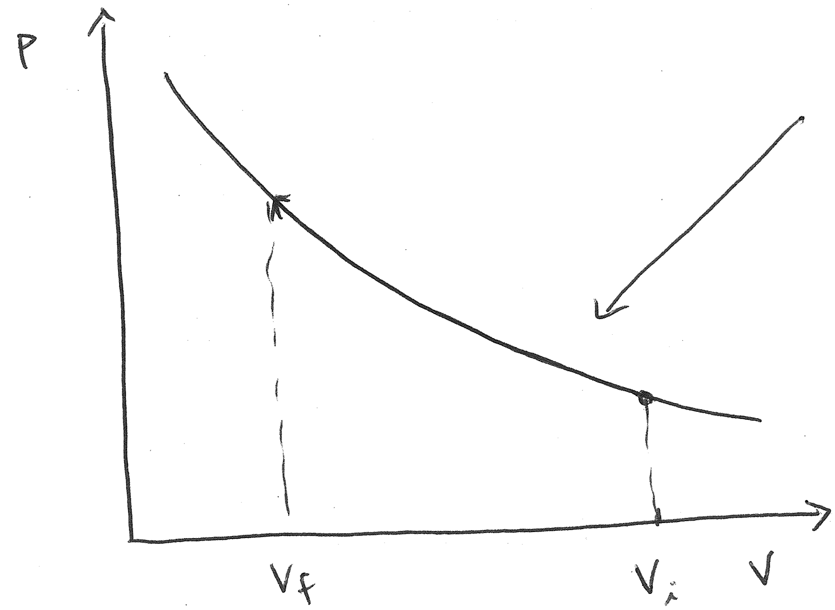
- ADIABATIC PROCESS : NO HEAT IN OR OUT
- ISOTHERMAL PROCESS.

ISOTHERMAL PROCESS : SO SLOW THAT TEMPERATURE DO NOT RISE

ADIABATIC PROCESS SO FAST THAT HEAT DOES NOT ESCAPE

A LOT OF PROCESSES ARE CLOSER TO THIS

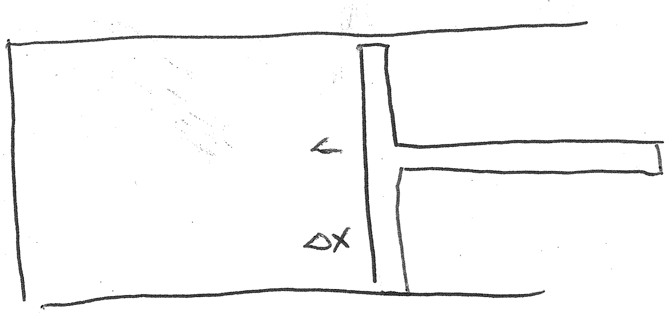
ISOTHERMAL COMPRESSION OF GAS



$PV = \cancel{NRT}\ nRT$

$T = \text{CONSTANT}$

WORK DONE ?



$W = PA\,\Delta x = -P\Delta V$

$\Delta U = Q + W$

$U = N f \frac{1}{2} kT$ SO IF $\Delta T = 0$

$\Delta U = 0$

$Q + W = 0$ FOR ISOTHERMAL COMPRESSION OF IDEAL GAS

$$W = -\int_{V_i}^{V_f} P\,dV = -NkT \int_{V_i}^{V_f} \frac{1}{V}\,dV$$

$$= -NkT\left(\ln V_f - \ln V_i\right)$$

$$W = NkT \ln \frac{V_i}{V_f}$$

$V_i > V_f$ SO W POSITIVE ✓

$$Q = -W = NkT \ln \frac{V_f}{V_i}$$

FOR COMPRESSION $Q < 0$

HEAT LEAVES GAS

ADIABATIC COMPRESSION OF IDEAL GAS

WORK IS DONE TO THE GAS

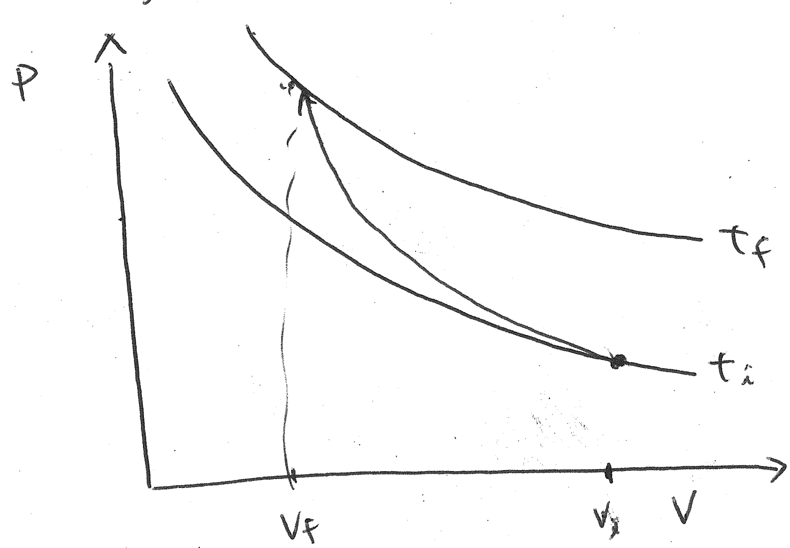
$\Delta U = Q + W = W > 0$

$Q = 0$

$U = N f \frac{1}{2} k T$

$\Delta U = N f \frac{1}{2} k \Delta T \qquad \Delta T > 0$

SO TEMPERATURE INCREASES



$$dU = \frac{f}{2} N k \, dT$$

$$dU = -P \, dV$$

$$\frac{f}{2} N k \, dT = -P \, dV$$

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

$$\frac{f}{2} N k \, dT = -\frac{NkT}{V} dV$$

$$\frac{f}{2} \frac{dT}{T} = -\frac{dV}{V}$$

$$\frac{f}{2} \int_{T_i}^{T_f} \frac{dT}{T} = -\int_{V_i}^{V_f} \frac{dV}{V}$$

$$\frac{f}{2} \ln \frac{T_f}{T_i} = -\ln \frac{V_f}{V_i}$$

$$\left(\frac{T_f}{T_i}\right)^{f/2} = \frac{V_i}{V_f}$$

$$T_f^{f/2} V_f = V_i T_i^{f/2}$$

$$\cancel{V_i T} \quad V T^{f/2} \text{ CONST}$$

$\boxed{14}$

$PV = NkT$ so

$V(PV)^{f/2} = \text{CONST}$

$P^{f/2} V^{\frac{2+f}{2}} = \text{CONST}$

$P V^{\frac{2+f}{f}} = \text{CONST}$

$P V^{\gamma} = \text{CONST}$

γ: ADIABATIC EXPONENT