

PHY 117 HS2023

Week 7, Lecture 1

Oct. 31st, 2023

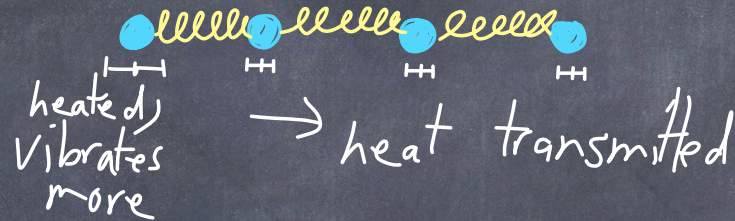
Prof. Ben Kilminster

Note: $c = \frac{C}{m}$ ← heat capacity
specific heat $\left[\frac{\text{J}}{\text{kg} \cdot \text{K}} \right]$ $\left[\frac{\text{J}}{\text{mol} \cdot \text{K}} \right]$

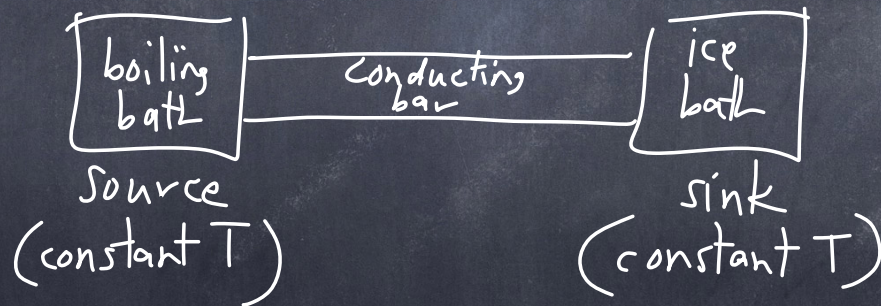
• $m = \text{mass [kg] of 1 mol}$

Note: $1 \text{ cal} = 4.184 \text{ J}$
 $1 \text{ Cal} = 1 \text{ kcal} = 4.184 \text{ kJ}$

Conduction: thermal energy transferred by interaction between atoms, molecules



Consider a solid bar connecting a bath of boiling water to a bath of ice water
(mix of dry ice CO_2 + ethanol)



Heat will flow uniformly across the bar + the temperature of the bar will vary by position.

thermal current

heat

coefficient of thermal conductivity (depends on material)

temp. difference

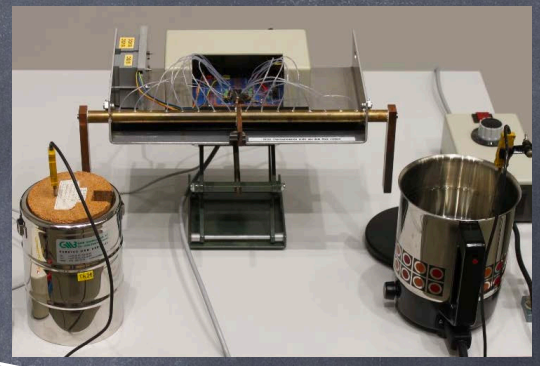
$$I = \frac{\Delta Q}{\Delta t} = \kappa A \frac{\Delta T}{\Delta x}$$

\uparrow time
 \uparrow position

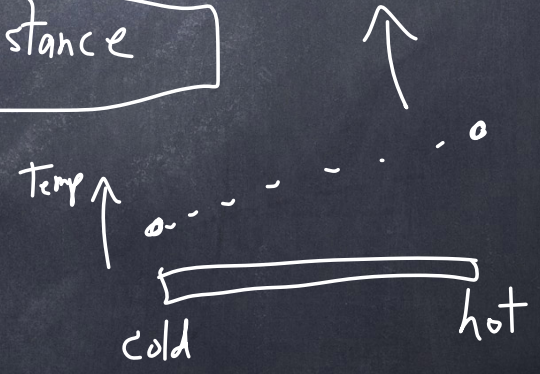
I has units of $\left[\frac{J}{s}\right] = [W]$ power

$$\Delta T = I R \quad \text{where } R = \frac{\Delta x}{\kappa A}$$

is the thermal resistance



$$I = \frac{dQ}{dt} = \kappa A \frac{dT}{dx}$$



coefficient of thermal conductivity, k

material $k \left[\frac{W}{m \cdot K} \right]$

air 0.026 ← heat insulator

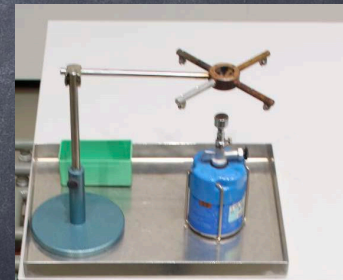
ice 0.592

Copper 401

wood 0.11 - 0.15

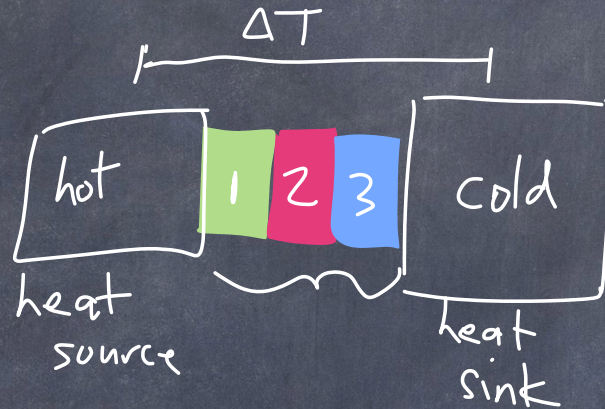
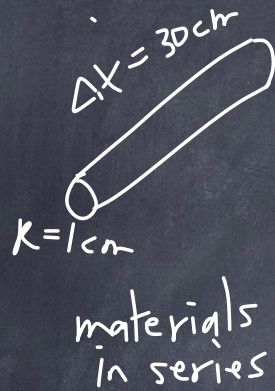
glass ~ 0.8

aluminum 237
↑
conducts heat well



What is R for a cylinder of copper, $\Delta x = 30 \text{ cm}$, $R = 1 \text{ cm}$?

$$R = \frac{\Delta x}{kA} = \frac{0.3 \text{ m}}{\left(400 \frac{\text{W}}{\text{m} \cdot \text{K}}\right) \pi (0.01 \text{ m})^2} = 2.4 \frac{\text{K}}{\text{W}}$$



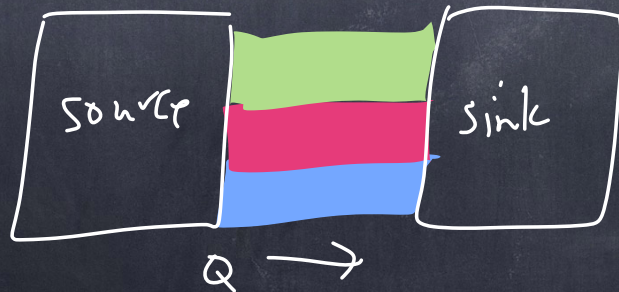
$$R_{\text{eq}} = R_1 + R_2 + R_3 + \dots$$

$$\Delta T = R_{\text{eq}} \cdot I$$

R_{eq} increases, I decrease

$Q \rightarrow$

materials in parallel

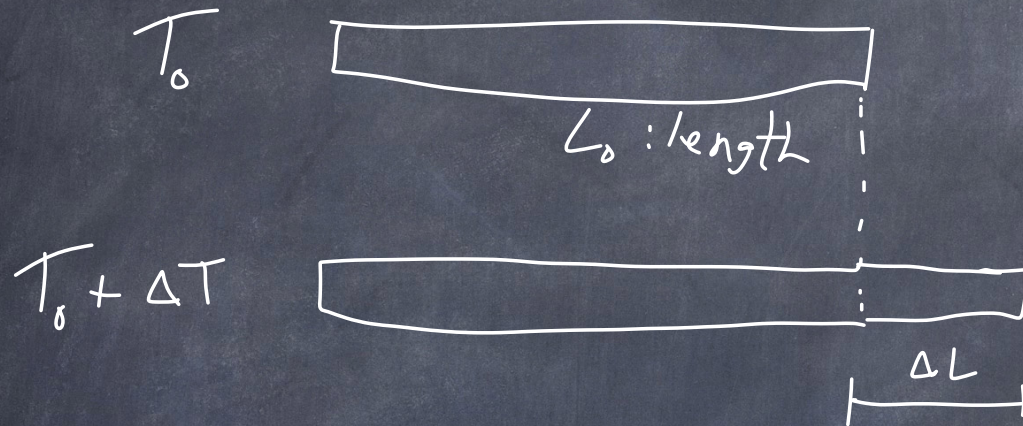


$$\frac{1}{R_{\text{eq}}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \dots$$

$$\Delta T = R_{\text{eq}} \cdot I$$

R_{eq} decreases, I increases

Thermal expansion of solids

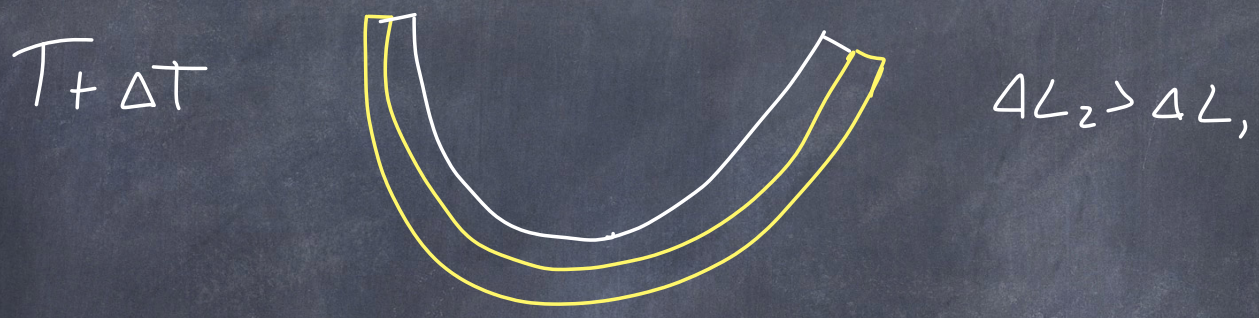
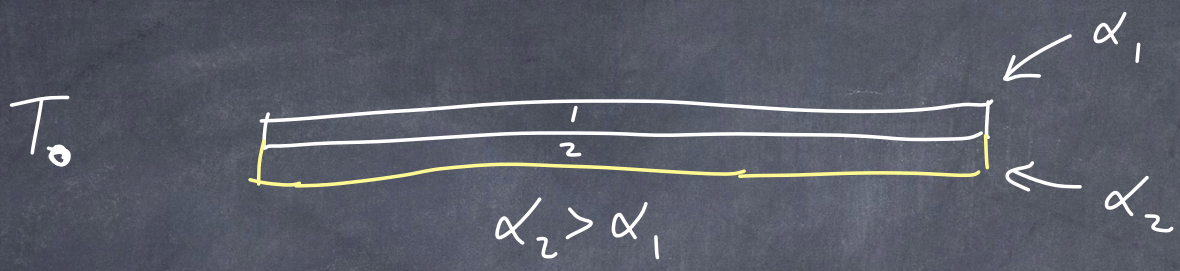


T_0 : initial temp.
 L_0 : initial length
 ΔT : change temperature

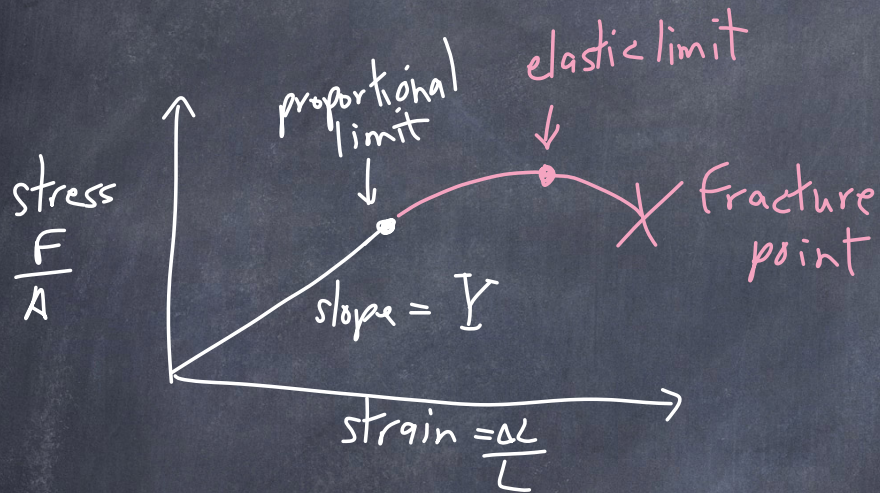
$$\Delta L = \alpha L_0 \Delta T \quad \Rightarrow \quad dL = \alpha L_0 dT$$

α : coefficient of linear expansion
units $\left[\frac{1}{K} \right]$ or $\left[\frac{1}{^{\circ}C} \right]$

<u>Material</u>	α $\left[\frac{1}{K} \right]$	(Kelvin)
Aluminium	$24 \text{ E-}6$	
Steel	$11 \text{ E-}6$	
copper	$17 \text{ E-}6$	
brass	$19 \text{ E-}6$	
ice	$51 \text{ E-}6$	
water (20°C)	$0.207 \text{ E-}3$	
alcohol	$1.1 \text{ E-}3$	



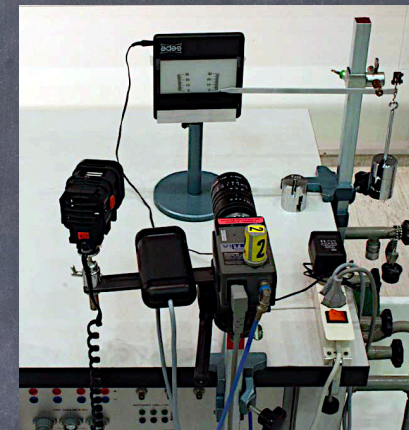
A change in $\frac{\Delta L}{L}$, called a "strain", exerts a force per area, $\frac{F}{A}$, called a "stress" on the material. The reverse is also true.



$$\frac{\text{stress}}{\text{strain}} = \text{Young's modulus} = Y = \frac{\frac{F}{A}}{\frac{\Delta L}{L}}$$

up to point A, the curve is linear & has a slope of Y

→ but then it deforms and later fractures



material

$$\underline{\gamma} \left[\frac{GN}{m^2} \right]$$

$$G = 10^9$$

steel

200

lead

16

gold

8

we can create a strain with a thermal expansion, and this will generate a stress according to $\underline{\gamma}$.



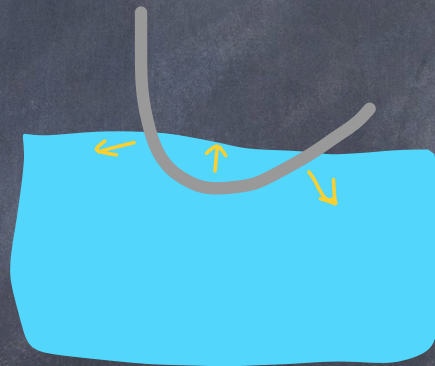
work done by heat



shape memory alloys
remember their original molecular
configuration at high temperatures

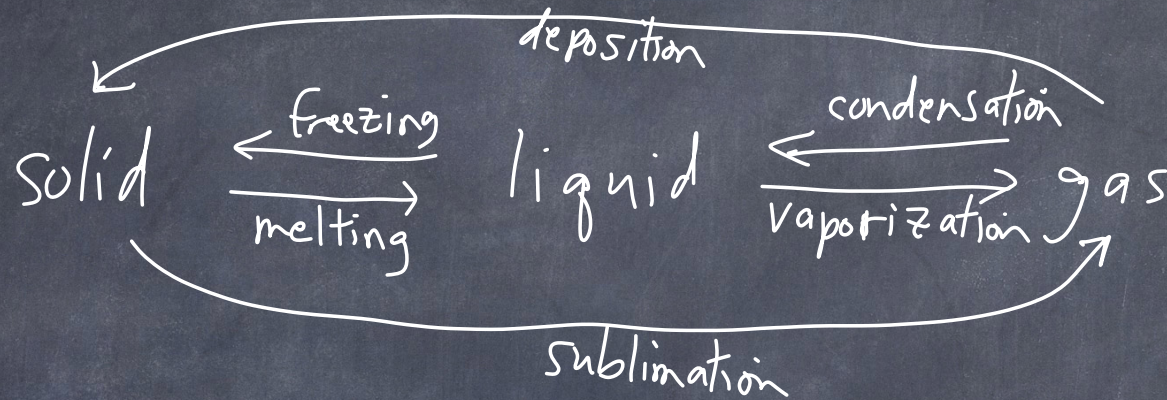
thermobil

asymmetric
forces tending
to straighten
the wire
when heated



most materials don't do this.

Sometimes when heat is absorbed or emitted, the material undergoes a phase change.



Freezing or melting

$$Q = m L_f$$

↑ heat required to change phase (+) or (-)

↑ mass of material

↑ latent heat of fusion of material

Condensation or vaporization

$$Q = m L_v$$

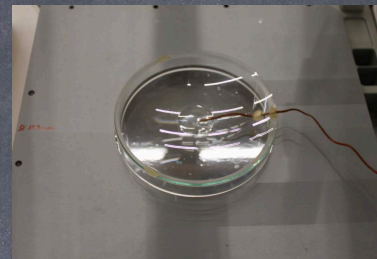
↑ latent heat of vaporization

	Melting point [K]	latent heat of Fusion L_f [$\frac{kJ}{kg}$]	Boiling point [K]	latent heat of vaporization L_v [$\frac{kJ}{kg}$]	specific heat C [$\frac{kJ}{kg \cdot K}$]
Gold	1336	62.8	3081	1701	0.126
water	-	333.5	373.15	2257	4.18
lead	600	24.7	2023	858	0.128
alcohol	159	109	351	879	2.4
ice	273.15	333.5	-	-	2.05

melts easy
bullets

During evaporation, the liquid loses heat and decreases in temperature

Experiment.



Macroscopic: we put liquid alcohol in a dish, & measured the liquid temperature as the alcohol evaporated.

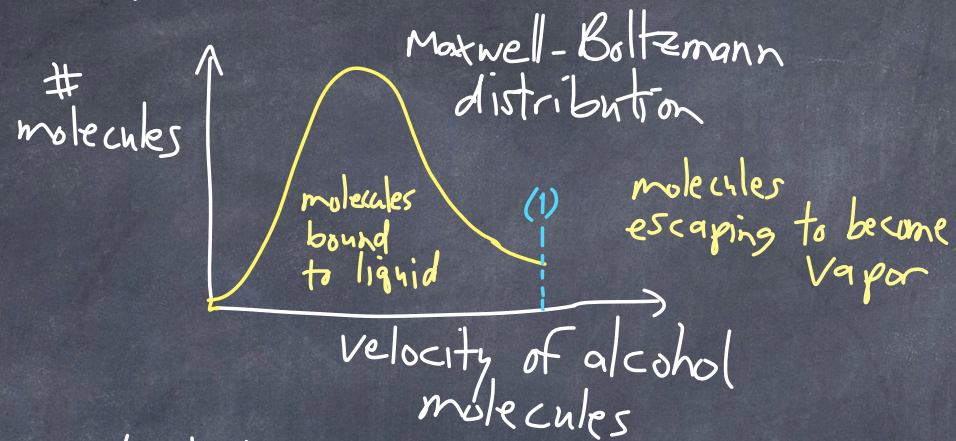
The temp. decreased from $28^{\circ} \rightarrow -6^{\circ} \text{C}$

$$\Delta Q_{\text{liquid}} = \Delta m L_v$$

heat loss depends on how much mass, Δm , evaporates.

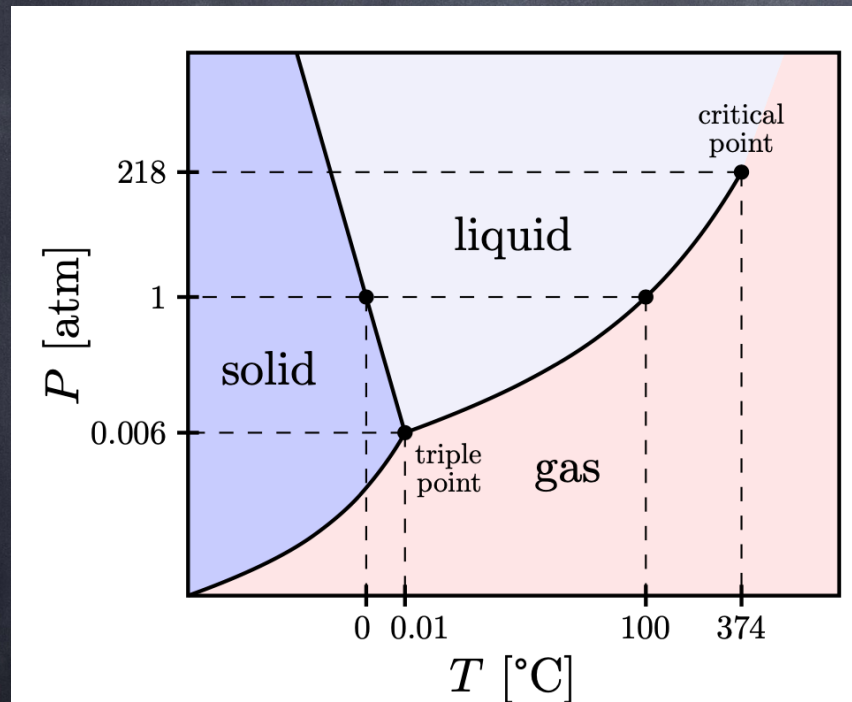
This changes the temperature of the liquid according to $\Delta Q_{\text{liquid}} = m_r C \Delta T$
remaining mass of liquid, m_r

Microscopic scale:



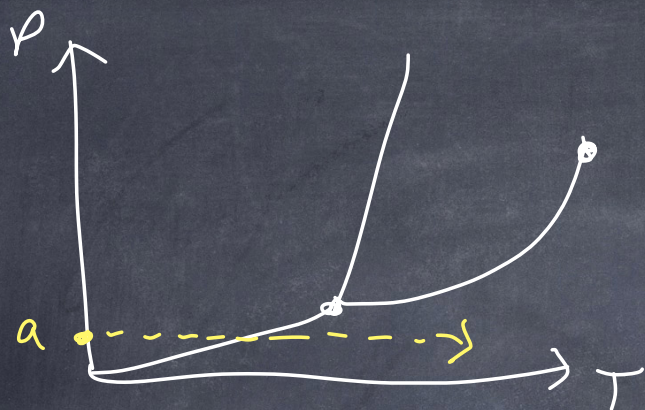
The alcohol liquid is composed of molecules, with a velocity distribution like the one above. The molecules are bound to the liquid by a potential energy barrier. Above a certain velocity (1), molecules have enough velocity to overcome the potential barrier holding them. Since the fastest ones escape, (the hottest ones), the remaining liquid must get cooler. This is why sweating cools the body.

Phase diagram for a material (P vs. T)
one can determine the phase or state of a material.



P_c : critical pressure
 T_c : critical temperature

- 1) Along the solid black lines, two phases can exist.
Away from the lines, only 1 phase exists.
- 2) At triple point, all 3 phases can exist at the same time.
- 3) At T_c, P_c (critical point) density of liquid + gas phases are the same.
For $T > T_c + P > P_c$, there is no distinction between liquid + gas

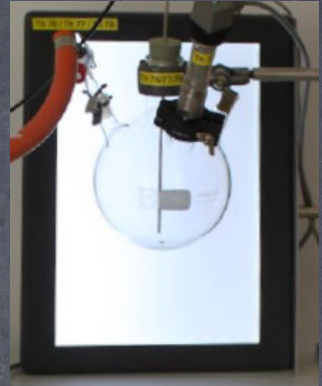


If we move along line (a), we heat at constant pressure. We are below the triple point pressure, so we go from solid to gas.

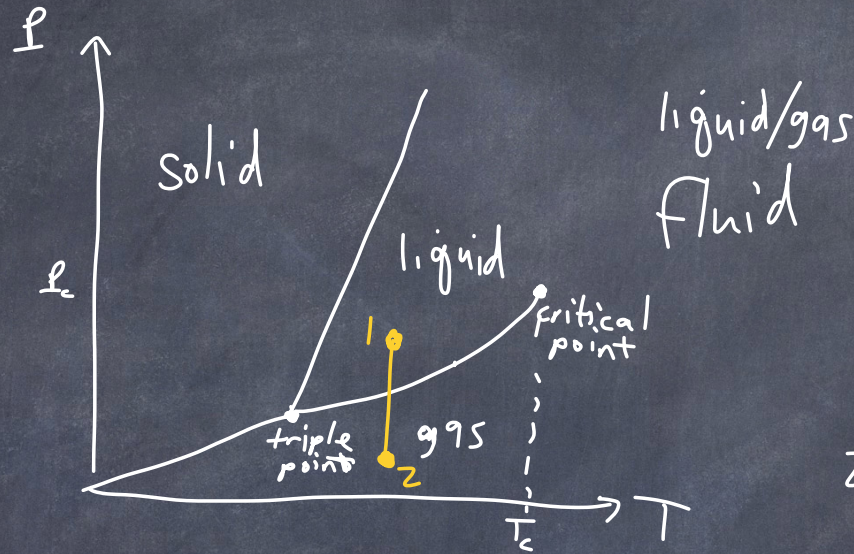
CO_2 sublimates from solid to gas at 1 atm.

The triple point of CO_2 has P of 5.1 atm.

Expt: Boiling by vacuum.



phase diagram for water



1: 24°C , 1000 hPa \swarrow 1 atm
2: 24°C , 30 hPa

In this experiment, we move from $1 \rightarrow 2$ on the phase diagram. we see the water boil.

Back to ideal gas. we can add heat while keeping the pressure constant or the volume constant. The heat will change the internal energy differently (different temp. change).

C_v : heat capacity $[\text{J/mol}\cdot\text{K}]$ at constant volume.

C_p : heat capacity at constant pressure.

There is a relationship between the two.

At constant volume, we can add heat to a gas.

$$Q = \Delta U + \cancel{W} \quad (\text{no work done, since } \bar{V} \text{ is constant})$$

$$\Delta U = Q = C_v \Delta T \quad \text{As } \Delta T \rightarrow 0, \quad dU = C_v dT$$

$$\boxed{C_v = \frac{dU}{dT}} \quad \textcircled{1}$$

At constant pressure, we add heat to a gas.
The gas will expand + do work.

$$Q = \Delta U + W$$

$$C_p \Delta T = \Delta U + P \Delta V$$

For small changes: $C_p dT = dU + P dV$ (2)

rewrite $P dV$: $PV = nRT$

$$P dV = nR dT$$
 (3)

put (1) + (3) into (2):

$$C_p dT = C_v dT + nR dT$$

$$\boxed{C_p = C_v + nR}$$

for an ideal gas

$$C_p > C_v \text{ by } nR$$

The ratio of the heat capacities $\frac{C_p}{C_v} = \gamma$

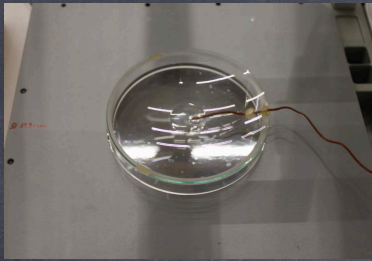
For an ideal monatomic gas

$$\text{So } \gamma = \frac{C_p}{C_v} = \frac{5}{3}$$

$$C_v = \frac{3}{2}nR, \quad C_p = \frac{5}{2}nR$$

For an ideal diatomic gas,

$$C_v = \frac{5}{2}nR, \quad C_p = \frac{7}{2}nR \Rightarrow \gamma = \frac{7}{5}$$



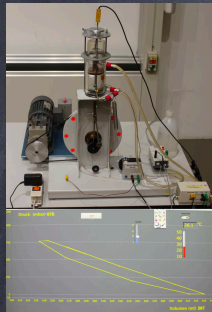
Th81



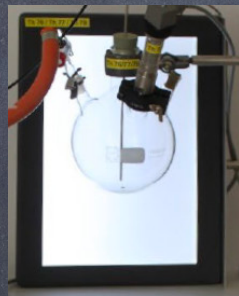
Th34



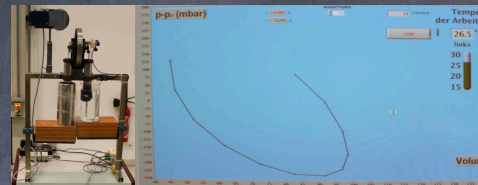
Th55



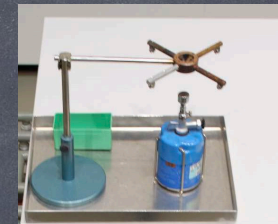
Th70



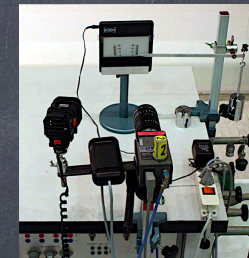
Th77



Th68



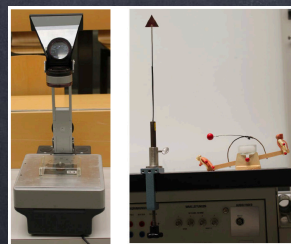
Th20



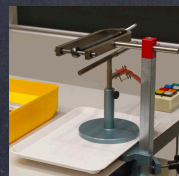
E12



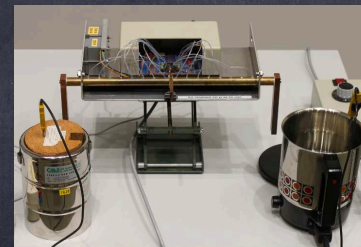
Th19



Th14



Th2



Th22