

PHY 117 HS2024

Week 7, Lecture 1

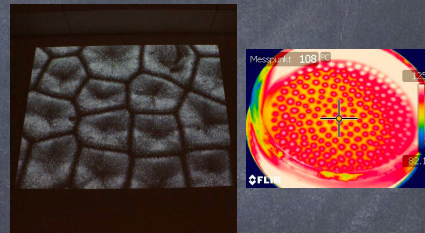
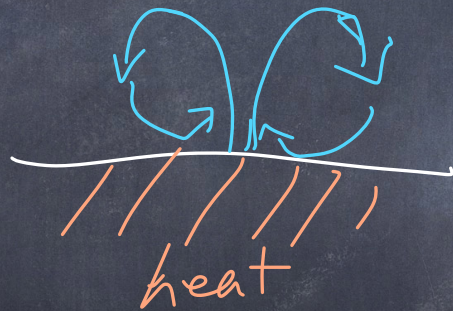
Oct. 29th, 2024

Prof. Ben Kilminster

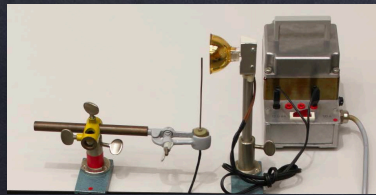
Note: $1 \text{ cal} = 4.184 \text{ J}$
 $1 \text{ Cal} = 1 \text{ kcal} = 4.184 \text{ kJ}$

Transfer of thermal energy is done by
3 main processes: 1) convection
2) radiation
3) conduction

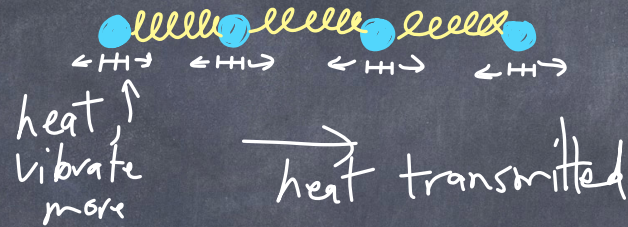
1) convection: heat transported by a mass of material moving. For instance, hot air is less dense than cool air and it rises.



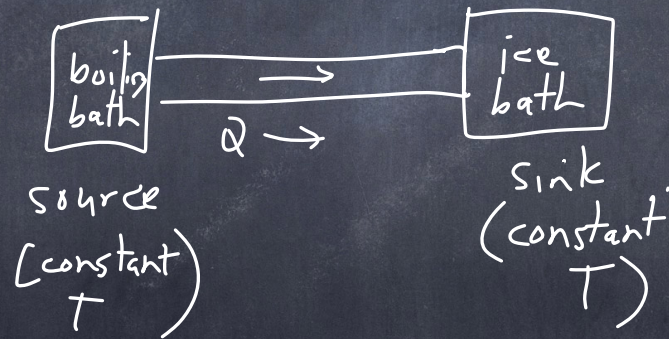
2) radiation: energy absorbed & emitted in the form of electromagnetic radiation (visible, infrared, UV, X-rays)



3) 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 (dry ice + ethane C_2H_6)



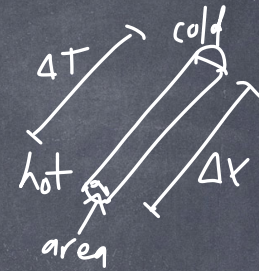
Heat will flow uniformly across the bar and the temperature of the bar will vary according to position.

Conduction!

thermal current

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

Annotations for the equation above:
- ΔQ : heat
- Δt : time
- κ : material property: coefficient of thermal conductivity
- A : cross-sectional area
- ΔT : temp.
- Δx : position



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

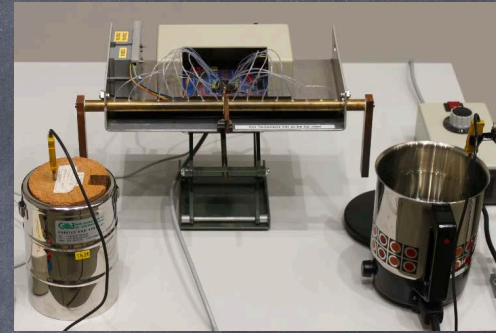
$$\Delta T = IR$$

where

$$R = \frac{\Delta x}{\kappa A} \text{ is thermal resistance}$$

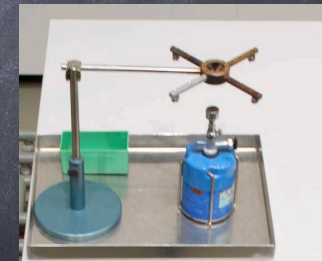
small increments

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



coefficient of thermal conductivity, k

<u>materials</u>	<u>k</u>	units $\left[\frac{W}{m \cdot K} \right]$
air	0.026	
ice	0.592	
Copper	401	
wood	0.11 - 0.15	
glass	~ 0.8	
aluminum	237	

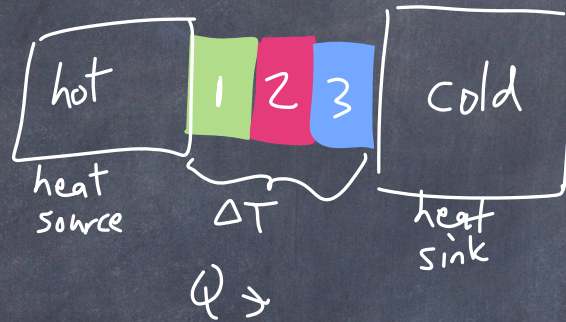


what is R for a cylinder of copper?



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

materials
in series

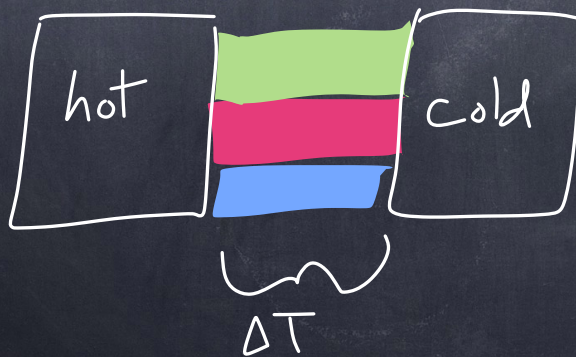


$$R_{\text{eq}} = R_1 + R_2 + R_3 + \dots$$

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

more $R_{\text{eq}} \rightarrow I$ decrease

materials
in parallel

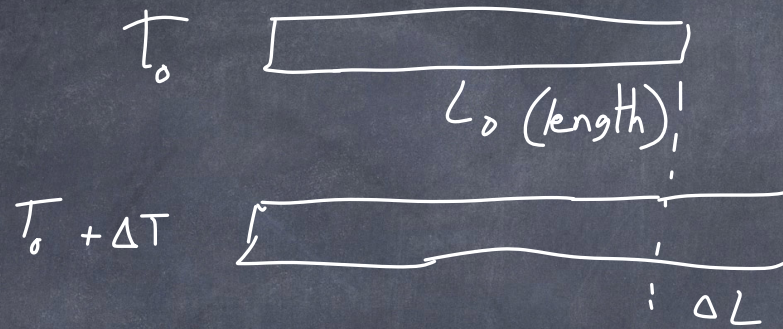


$$\frac{1}{R_{\text{eq}}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \dots$$

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

R_{eq} will decrease \rightarrow
 I increase

Thermal expansion of solids



T_0 : initial temp.

L_0 : initial length

ΔT : change in temp.

ΔL : change in length

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

α : coefficient of linear expansion

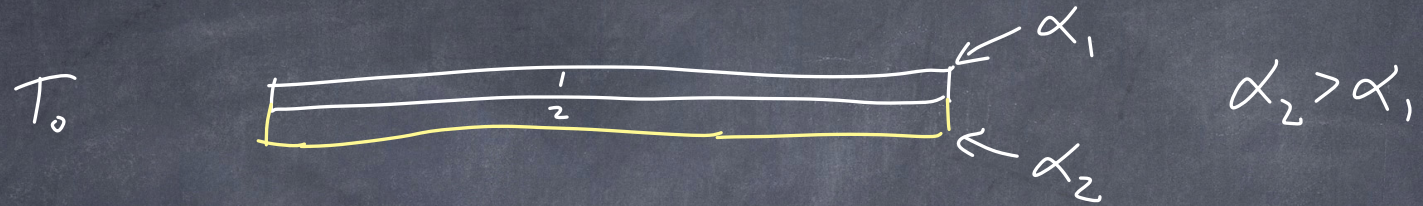
units: $\left[\frac{1}{K} \right]$ or $\left[\frac{1}{^\circ C} \right]$

Material

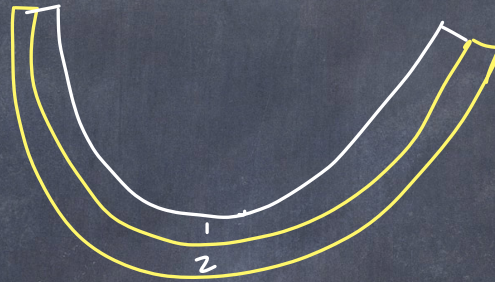
$\alpha \left[\frac{1}{K} \right]$

Aluminium	24 E-6
Steel	11 E-6
copper	17 E-6
brass	19 E-6
ice	51 E-6
water (20°C)	0.207 E-3
alcohol	1.1 E-3

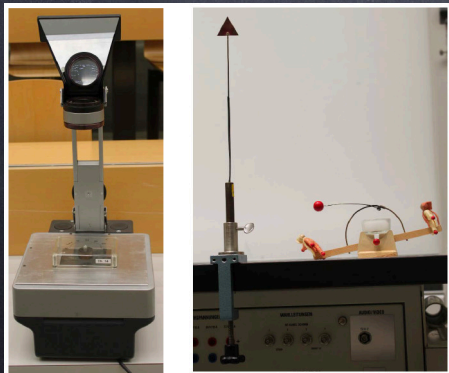
we can turn this into a ^{bimetal} thermometer,



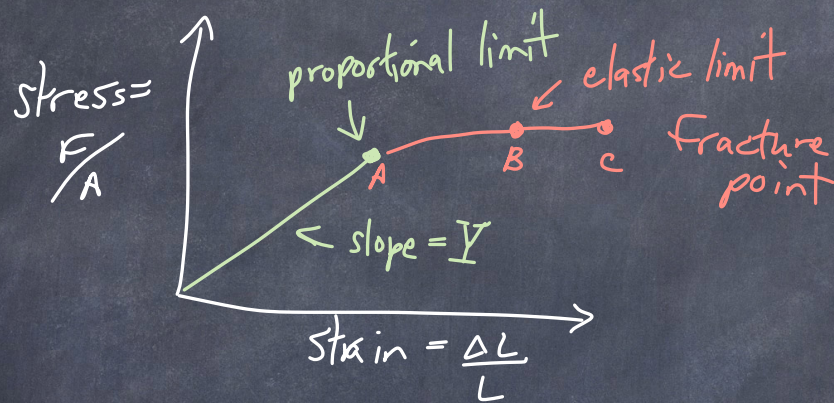
$T_0 + \Delta T$



$$L_2 > L_1$$
$$\Delta L_2 > \Delta L_1$$



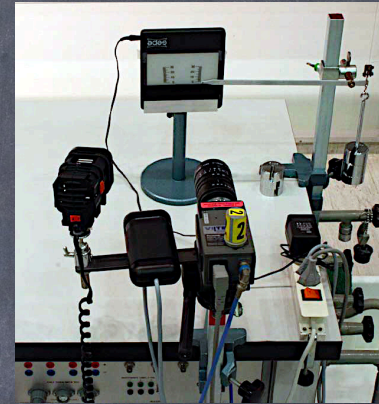
When there is a change in length $\frac{\Delta L}{L}$, called a "strain", exerts a force per area, $\frac{F}{A}$, called a "stress" on a material. The reverse is also true.



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

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

→ but then
it deforms
& breaks.



<u>material</u>	<u>γ</u> $\left[\frac{GN}{m^2} \right]$
steel	200
lead	16
gold	8

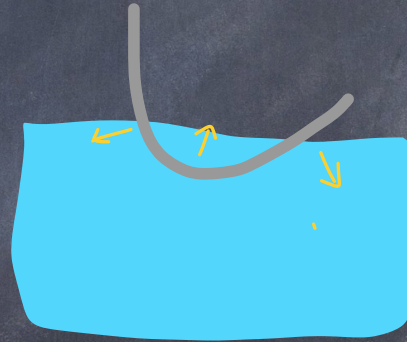
we can generate a strain, for instance, with a thermal expansion, + this will generate a stress according to γ



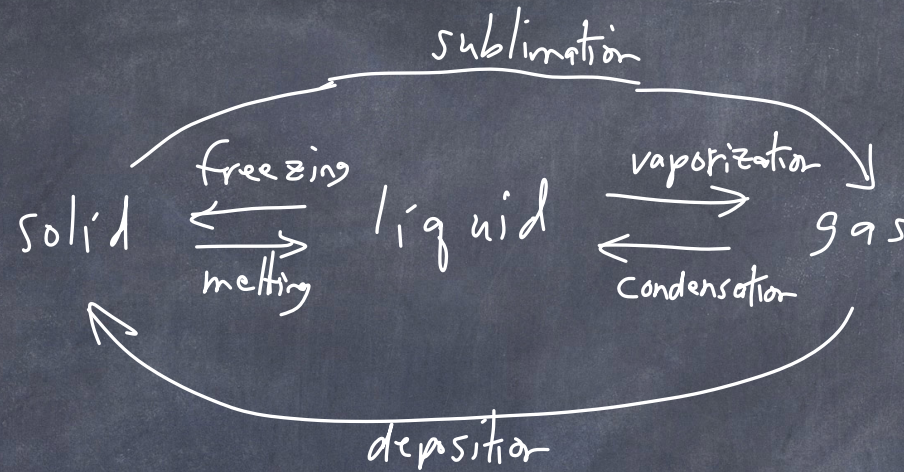
work can be done by heat



shape-memory alloy
remembers its original
molecular configuration at
high temperatures



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



Freezing or melting

$$Q = m L_F$$

↑ heat required for a phase change (+) or (-)

↑ mass of material

↑ latent heat of fusion of material

condensation or vaporization

$$Q = m L_V$$

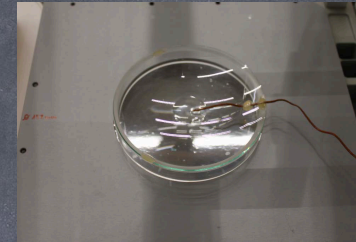
↑ latent heat of vaporization

	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

water for good storing heat without vaporizing
lead is good for making bullets

During evaporation, a liquid loses heat and decreases in temperature.

Experiment.



Macroscopic: we put liquid alcohol in a dish, + measure the liquid temperature as the alcohol evaporates -
The temp. decreases from $20^{\circ}\text{C} \rightarrow -3^{\circ}\text{C}$

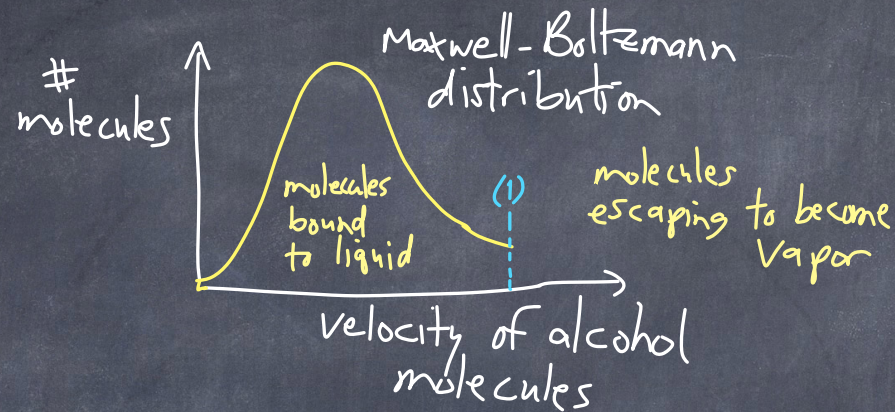
$$\Delta Q_{\text{liquid}} = -\Delta m L_v$$

heat loss depends on how much mass Δm evaporates.

This change the temp. of the remaining liquid according to

$$\Delta Q_{\text{liquid}} = m_{\text{remaining liquid}} c \Delta T$$

Microscopic scale:

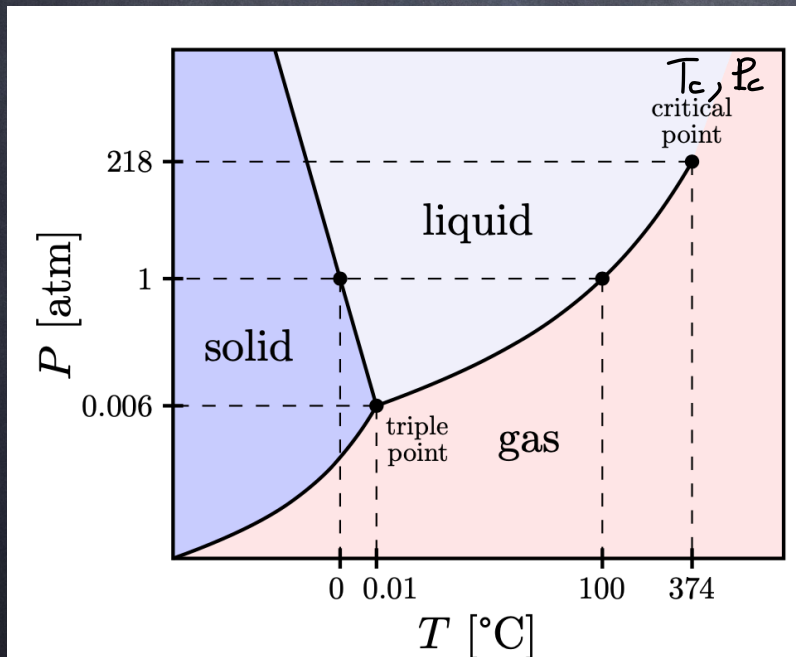


The alcohol is composed of molecules, with a velocity distribution like the one above. Molecules are bound to the liquid by a potential energy barrier. Above a certain velocity (1), molecules have enough energy to overcome the barrier & escape. Since the fastest molecules are the hottest ones, the remaining liquid gets cooler.

This is why sweating cools your body.

Phase diagram for a material, here P vs. T .
one can determine the phase/state of a material.

for water

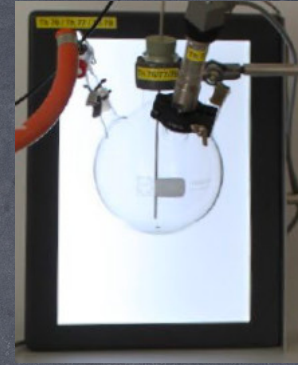
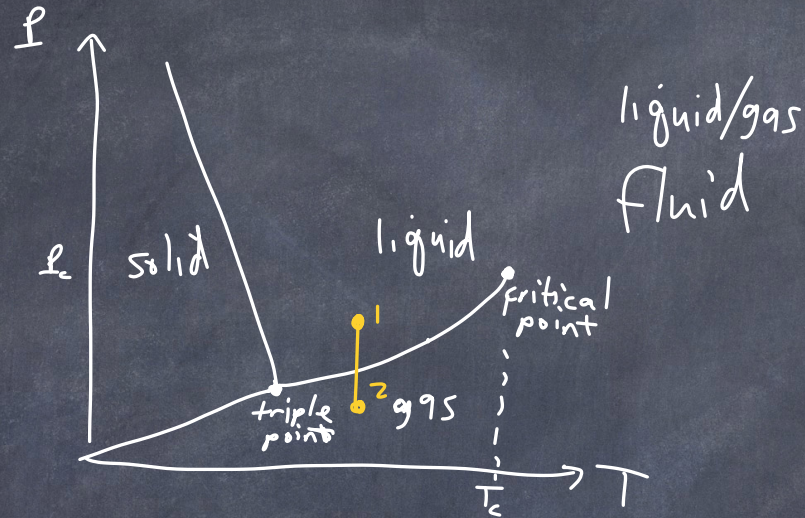


T_c : critical temp.
 P_c : critical pressure

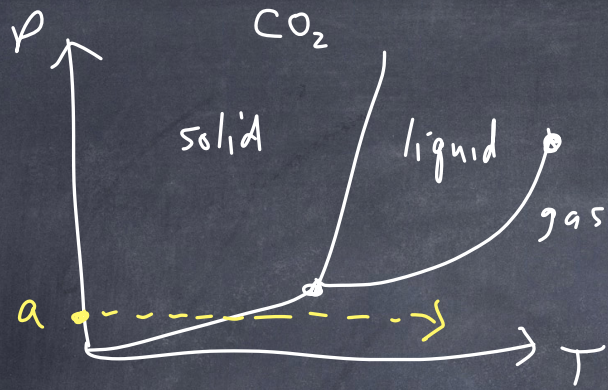
- 1) Along solid black lines, 2 phases can exist.
Away from the lines, only 1 phase exists.
- 2) At the triple point, all 3 phases can exist.
- 3) At T_c, P_c , density of liquid & gas phases are the same.
For $T > T_c, P > P_c$, there is no difference between liquid & gas.

Expt: Boiling by vacuum.

phase diagram for water.



In this experiment, we move along the phase diagram for water from 1 to 2.
(20°C, 1000 hPa) → (20°C, 30 hPa)
we see the water boil.

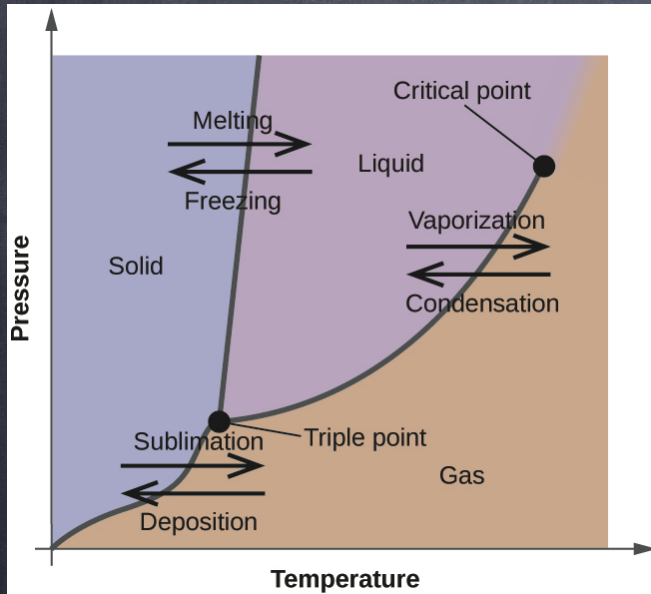


If we move along line (a), we heat at constant pressure. Below the triple point pressure, we go from solid \rightarrow gas.

CO₂ sublimates solid to gas at 1 atm because the triple point is at 5.1 atm

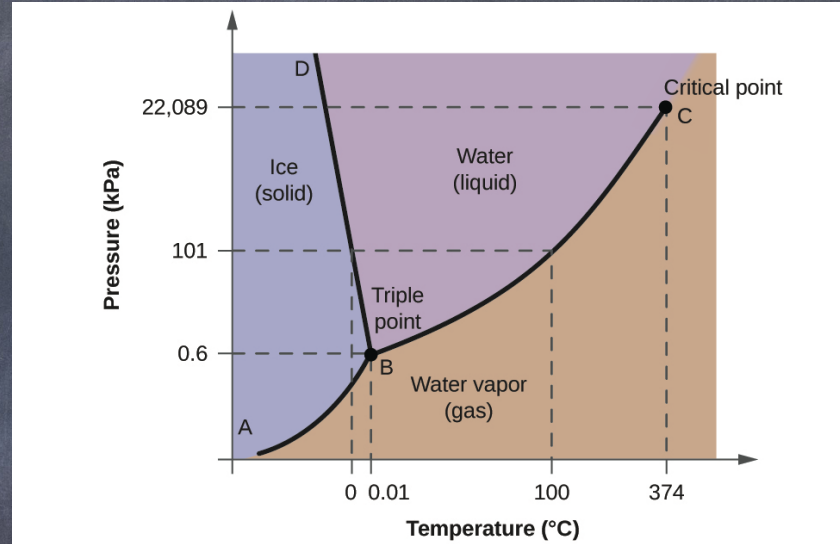
Note:

Typical material



increase in melting point at higher pressures

water is unique



decrease in melting point at higher pressures because liquid state is denser than solid state

Back to ideal gases. We can add heat while keeping the pressure constant or volume constant. The heat will change the internal energy differently.

C_v : heat capacity at constant volume

C_p : heat capacity at constant pressure.

There is a relationship between these two.

At constant volume, we add heat to a gas.

$$Q = \Delta U + W \quad (\text{no work if } V \text{ is constant})$$

$$\Delta U = Q = C_v \Delta T$$

$$\text{As } \Delta T \rightarrow 0, \quad dU = C_v dT \quad \textcircled{1}$$

$$C_v = \frac{dU}{dT}$$

At constant pressure, we add heat to a gas.
The gas expands.

$$Q = \Delta U + W$$

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

for small changes, $C_p dT = dU + P dV$ (2)

rewrite $PV = nRT \rightarrow P dV = nR dT$ (3)

put (1) + (3) \rightarrow into (2)

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

$$C_p = C_v + nR$$

for an ideal gas

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

The ratio of the heat capacities

$$\frac{C_p}{C_v} = \gamma \quad \& \quad \text{is dimensionless.}$$

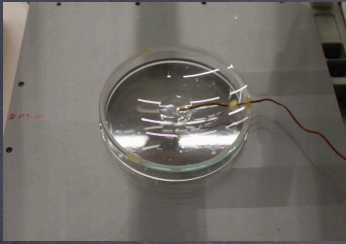
For an ideal monatomic gas, $C_v = \frac{3}{2}nR$

$$\text{so } \gamma = \frac{5}{3} \qquad C_p = \frac{5}{2}nR$$

For an ideal diatomic gas,

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

$$\gamma = \frac{7}{5}$$



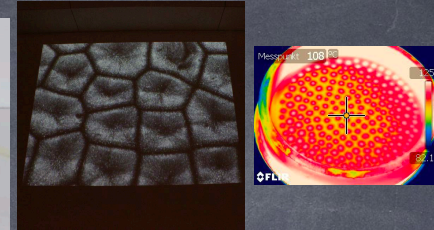
Th81



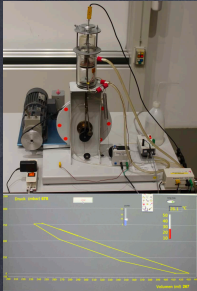
Th34



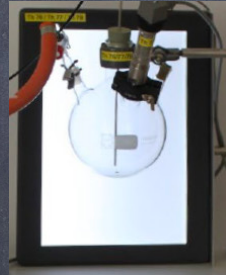
Th55



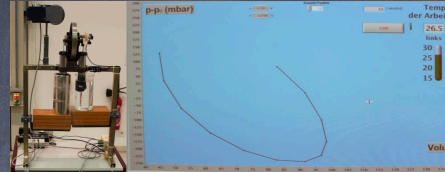
Th35



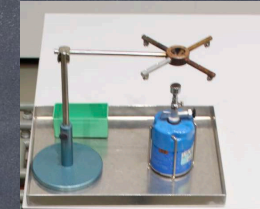
Th70



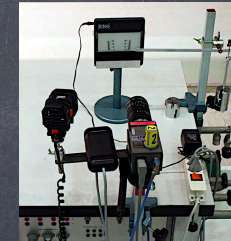
Th77



Th68



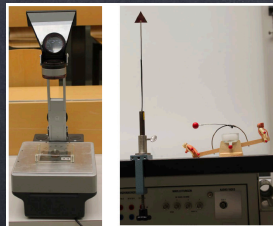
Th20



E12



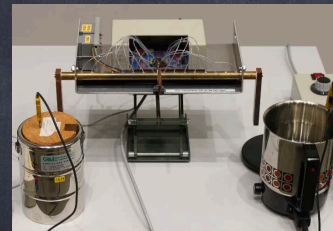
Th19



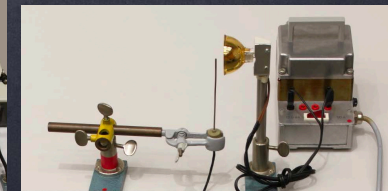
Th14



Th2



Th22



Th48