Solid body: No contribution of c.m. and Rotation

but Vibration

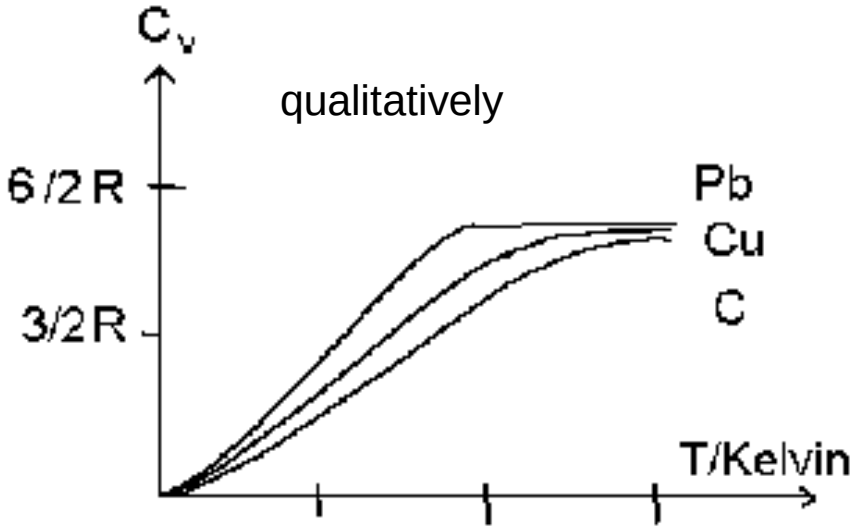
3 directions ->3 degrees of freedom kinetic

->3 degrees of freedom potential

6 degrees of freedom with $c_{Mol}=3R$

Law of Dulong-Petit

But here again, dependence on temperature



Microscopically:

Up until now we used an atomistic view! Now view the phenomena

Quantity of heat: $\Delta Q = C \cdot M \cdot \Delta T$

M:Mass of solid body

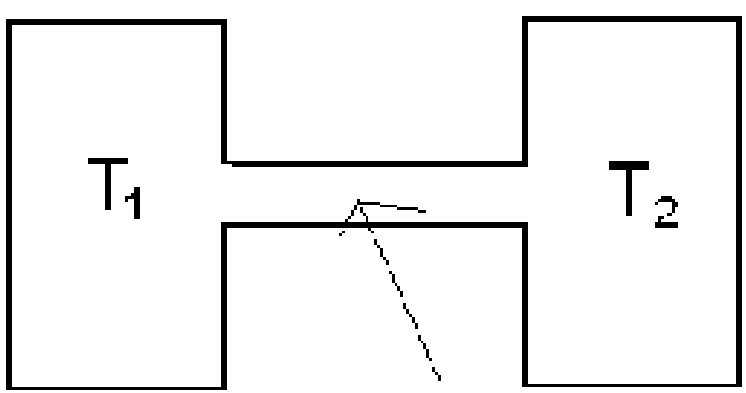
C: Capacity of heat,

$$[Q] = J, [C] = \frac{J}{kg \cdot K}$$

Temperature increase: C=4186 J/K per liter water under following conditions:

$\boxed{\Delta T = 1K}$ at $T = 15^0 Celsius \Rightarrow Q = 4186J$

Further conclusions from chapter. 5.1-5.3.



contact

a) Are two bodies in contact

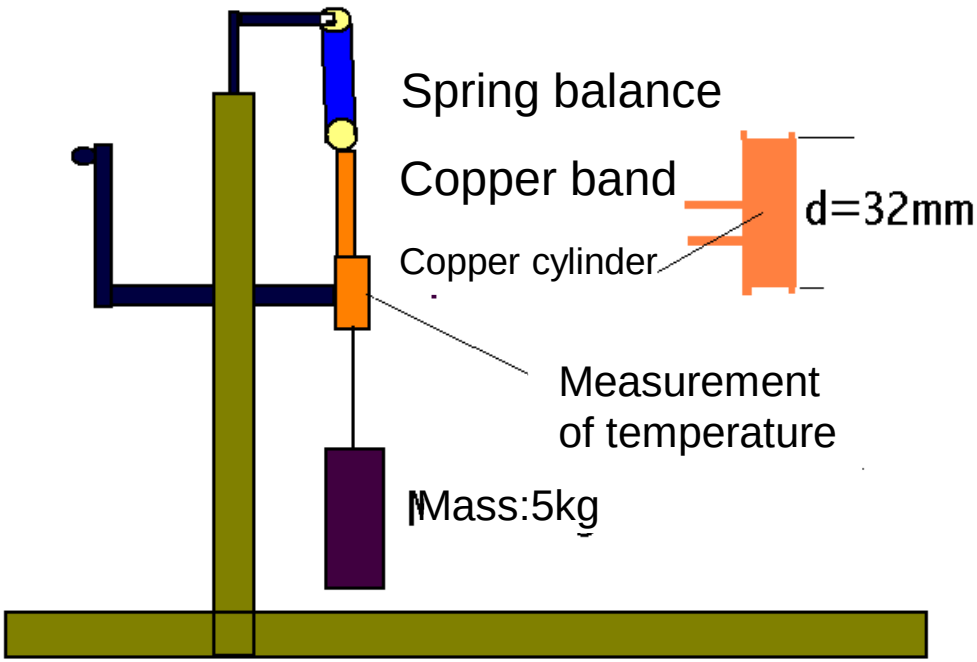
$\boxed{\Rightarrow T_1 \Leftrightarrow T_2}$

settle onT !

b) T($T_1, T_2, M_1, M_2, C_1, C_2$)

c) Independent of kind of contact

Measurement: Mechanical equivalent of heat



10 turns
≈1m
Mass copper-cylinder=119.67g
Mass copper band=5.85g
∑=125.52g

Thermic capacity
Cu:C_{CU}=0.092cal/gK

1. E_{pot}=mgh=5*9.81*1kg*m²*s^{-2}
≈ 50N*m=50J=50Ws
2. M_{Cu}*C_{Cu}*Δt=125.52*0.092*1*g*cal*K/g*K
=11.5cal

11.5·4.184= 48. 116

Calories → Joule or Ws

Temperature

Defined by fixed points

Temperature, in case of water changes its state of matter!

Melt	solid -> liquid	0^0 Celsius
Boil	liquid -> gaseous	100^0 Celsius

Celsius-Scale C

Melt	solid -> liquid	32^0 Fahrenheit
Boil	liquid -> gaseous	212^0 Fahrenheit

Fahrenheit-Scale 1714 F

At normal air pressure

Absolute thermodynamic scale of temperature

Point of sero:-273.15 ^{0} Celsius

Unit:1 Kelvin=1K

Movement of molecules beeing at rest

e.g.:T(C) =T(K)-$T_0(K); T_0 = 273.15$

Change of volume: Cube with length of the edge l_0

$$V(T) = [l(T)]^3 = l_0^3(1 + \alpha \cdot \Delta T)^3 \approx l_0^3(1 + 3 \cdot \alpha \cdot \Delta T)$$

$$l_0^3 = V_0; 3 \cdot \alpha = \gamma$$ cubic coefficient of expansion

Water at 18^0 C	$\gamma = 0.18 \cdot 10^{-3}/K$
Ethanol	$\gamma = 1.1 \cdot 10^{-3}/K$
Mercury	$\gamma = 0.18 \cdot 10^{-3}/K$

Dependence of density on temperature

$$\rho = \frac{M\ (independent\ of\ T}{V} \approx \frac{M}{V_0(1+\gamma \cdot \Delta T)} = \frac{\rho_0}{1+\gamma \cdot \Delta T} \approx \rho_0 \cdot (1 - \gamma \cdot \Delta T)$$

There are Anomalies e.g.: H_2O : Largest density at 4^0

5.5. State variables of ideal gases

Volume V, Pressure P, Temperature T
In each case one quantity stays constant!

a) T =constant.
"isotherme " change of state

PV= constant Law: Boyle-Mariotte

b) P= constant **"isobare"** change of state

$$V=V_0 \cdot [1+\gamma \cdot t]$$ t=T-T0 Law:Gay-Lussac

$$V=V_0 \cdot \left[1+\frac{1}{T_0}(T-T_0\right] = V_0 \frac{T}{T_0} \Rightarrow$$

γ equal for all gases with

$$\gamma = \frac{1}{273.2} = \frac{1}{T_0}$$

$$V= \frac{V_0}{T_0} \cdot T \Rightarrow \frac{V}{T} = \text{constant}$$

c) V=constant
"isochore" change of state

$$P=P_0 \cdot (1+\beta \cdot t)$$

P_0:Pressure at 0^0C

β: coefficient of pressure,

Measurement of Temperature

Physical phenomena areT-dependent → Thermometer

Liquid thermometer: Change of volume $\Delta V = \Delta V(T)$

Bimetal thermometer: Different extensions of metal band

Heat: $\Delta Q = C \cdot M \cdot \Delta T$

Temperature T a measure for energy within the body,

called heat !

5.4. Extension due to heat of solid and liquid bodies

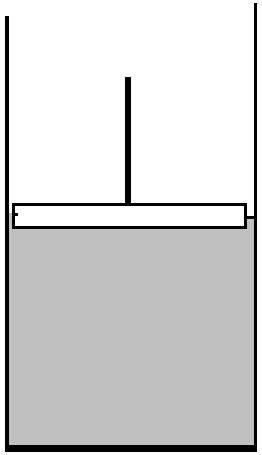
Bar: Linear coefficient of extension α

$$l(T) = l(T_0) + \Delta l(T - T_0) = l_0 + \alpha \cdot l_0 \cdot \Delta T = l_0 \cdot (1 + \alpha \cdot \Delta T)$$

Examples: Al: $\alpha = 23.8 \cdot 10^{-6}/K,$ Quartzglass: $\alpha = 0.5 \cdot 10^{-6}/K$

Conection between β and γ

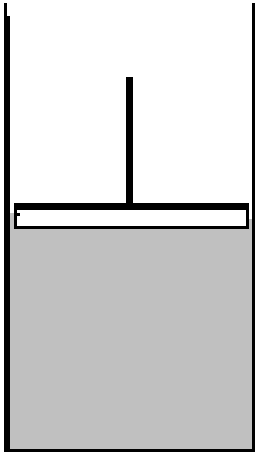
1



$P_0 \quad V_0 \quad T_0$

Heating at
P=constant

2



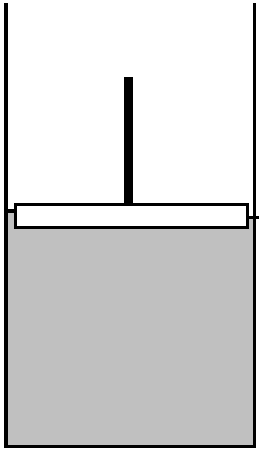
T_1

$P_1 = P_0$

Compression
at T=constant

n

3



$T_2 = T_1$

Heating at
V=constant

$V_2 = V_0$

$$\boxed{V_1 = V_0(1+\gamma t)}$$

$$P_2 \cdot V_2 = P_1 \cdot V_1 =$$

$$P_0 \cdot V_0(1+\gamma t)$$

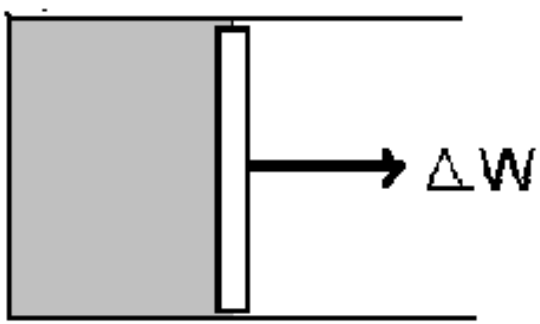
$$P_2 = P_0(1+\beta t) \Rightarrow V_2 P_2 = V_0 P_0(1+\beta t) \Rightarrow$$

$$\boxed{\beta = \gamma}$$

5.6. 1. Main law of thermodynamics

Conservation of energy

Total energy of a closed system remains always constant



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

added thermal energy =inner energy+ work done

$$\Delta U \sim \Delta T$$

$$\Delta W = F \cdot ds = \frac{F}{A} \cdot A \cdot ds = P \cdot dV$$

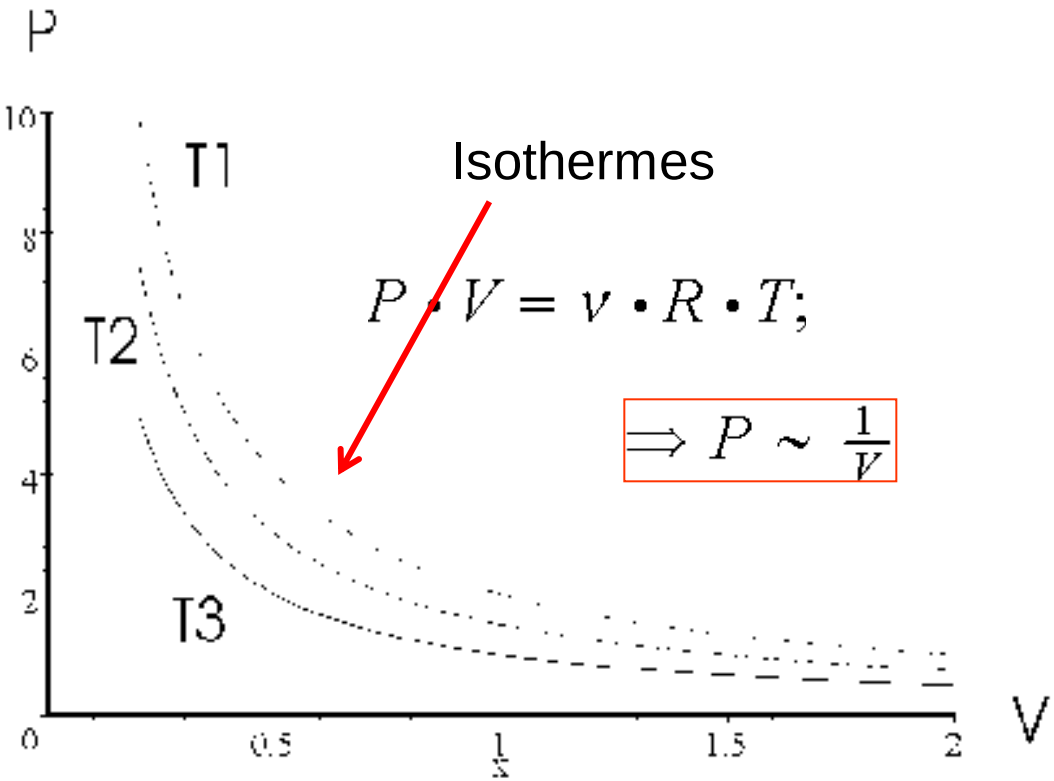
$$dQ = dU + dW$$

$$dQ = c_V dT + PdV$$

It is important to realize that in physics today we have no knowledge of what energy is…it is an abstract thing.

R. Feynman

Isothermic changes of states



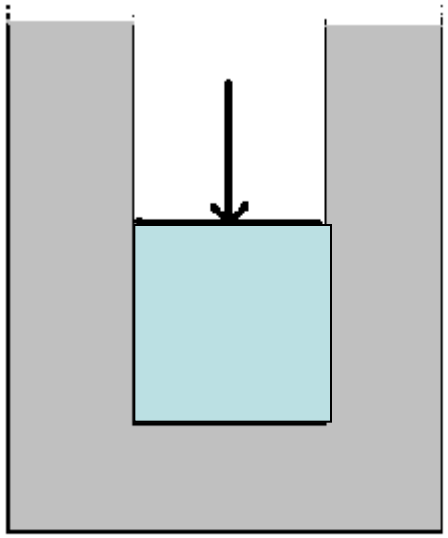
Isothermes

$$P \cdot V = \nu \cdot R \cdot T;$$

$$\boxed{\Rightarrow P \sim \frac{1}{V}}$$

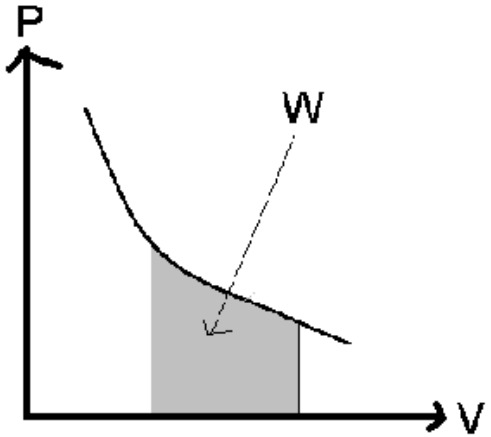
Experiment:

Bath of heat: T=constant



dU=0

from first law: dQ=dW=PdV or



W= $$\boxed{\int_{V_1}^{V_2} PdV = \nu \cdot R \cdot T \int_{V_1}^{V_2} \frac{dV}{V} = \nu \cdot R \cdot T \cdot \ln \frac{V_2}{V_1}}$$

Adiabatic changes of states

No exchange of heat within surroundigs → dQ=0

1. Law $\rightarrow dU + PdV = 0$ with $\boxed{dU = \nu \cdot C_V \cdot dT \Rightarrow}$

and from $P \cdot V = \nu \cdot R \cdot T$

$$P \cdot dV + V \cdot dP = \nu \cdot R \cdot dT \rightarrow dT = \frac{1}{\nu \cdot R}\{P \cdot dV + V \cdot dP\}$$

with main law: $\frac{C_V}{R}\{P \cdot dV + V \cdot dP\} + P \cdot dV = 0$

$$P \cdot dV(C_V + R) + C_V V \cdot dP = 0 \qquad P \cdot dV \frac{C_V + R}{C_V} + V \cdot dP = 0$$

$$\gamma \cdot P \cdot dV = -V \cdot dP \qquad (\gamma \frac{dV}{V}) + (\frac{dP}{P}) = 0$$

Integration:

$$\boxed{\gamma \ln V + \ln P = \ln C \Rightarrow}$$

$$\boxed{P \cdot V^{\gamma} = C}$$

C constant of integration

or because PV~ T

$$T \cdot V^{\gamma - 1} = \text{constant}$$

or because V~T/P

$$T^{\gamma} \cdot P^{1-\gamma} = \text{constant}$$

Example: Pneumatic lighter

$V_1 \rightarrow \frac{V_1}{10} \rightarrow$ with

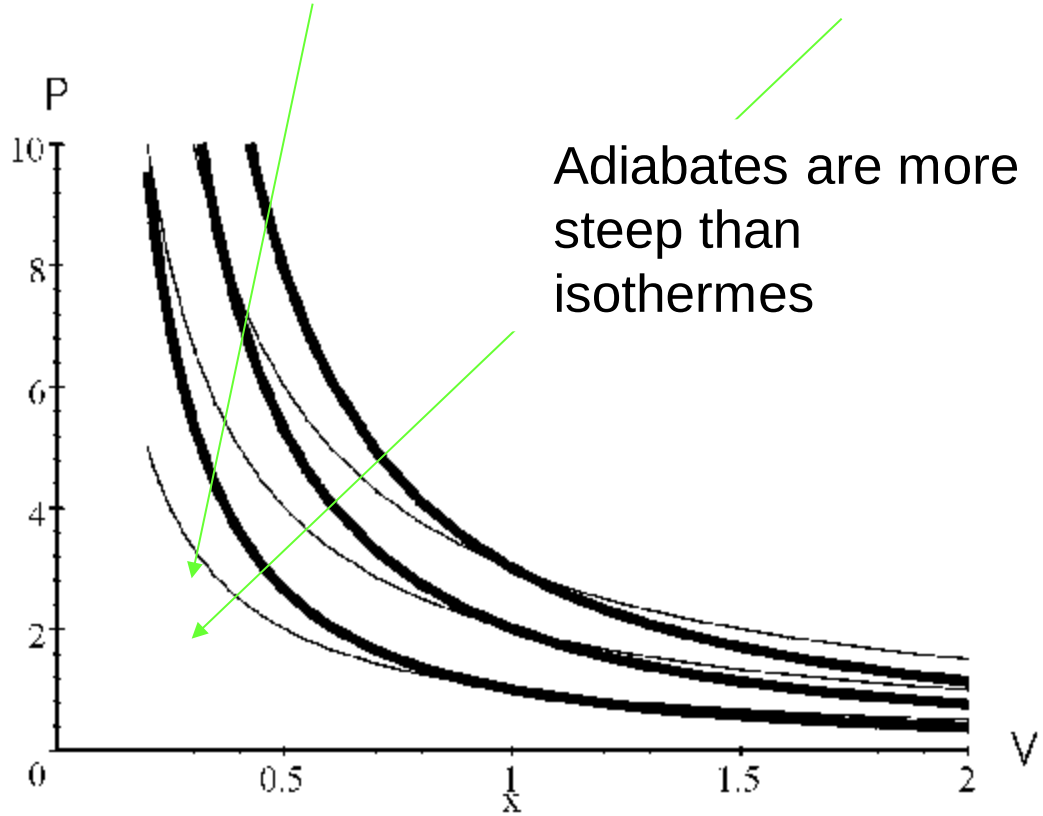
$$T_1 \cdot V_1^{\gamma-1} = T_2 \cdot V_2^{\gamma-1} \Rightarrow T_2 = T_1 (\frac{V_1}{V_2})^{\gamma-1}$$

$\gamma = 1.4$

for air

or 293K $\cdot 10^{0.4} = 293 \cdot 2.51 = 735.43K = 463^0C$

Comparison Adiabates <→ Isotermes



Adiabates are more steep than isothermes