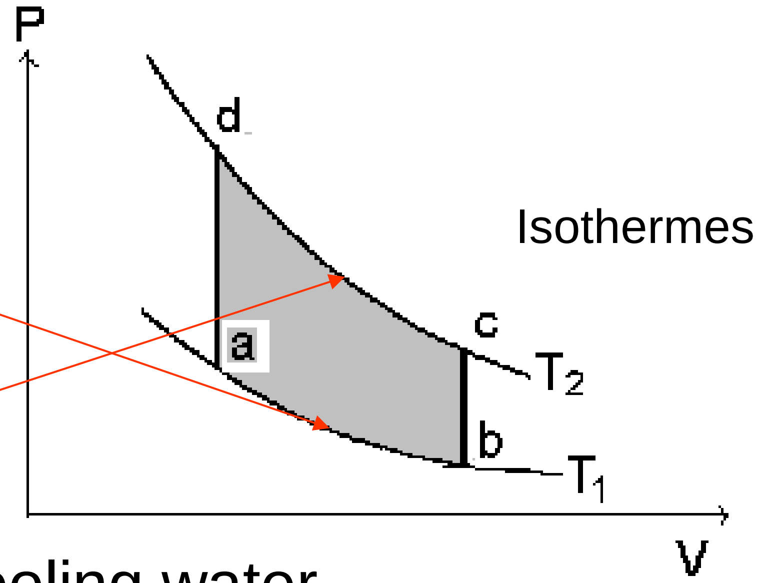
Hot air motor as cryocooler

Upper room :Heat will be extracted → Cooling water is needed

Processgas above

a-b:Expansion: Processgas detract heat from environment

Heat will be extracted out of copper wool



b-c: Displacing piston up T_2

c-d: Compression → heat goes into cooling water

d-a: Displacing piston down to T_1

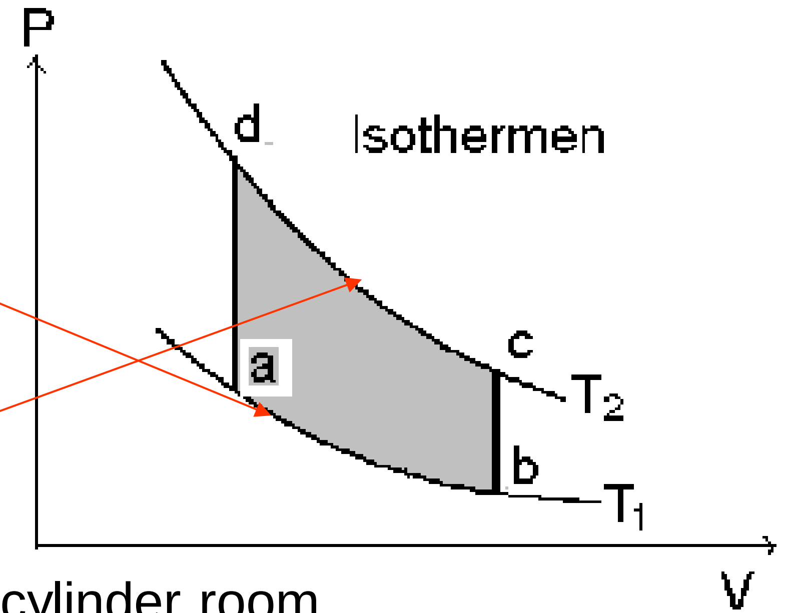
Copper wool takes up heat: Gas cools

Hot air motor as heat pump

Lower room: Heat will be detracted and added to upper room

Process gas below:
a-b: Expansion: Heat from cooling water

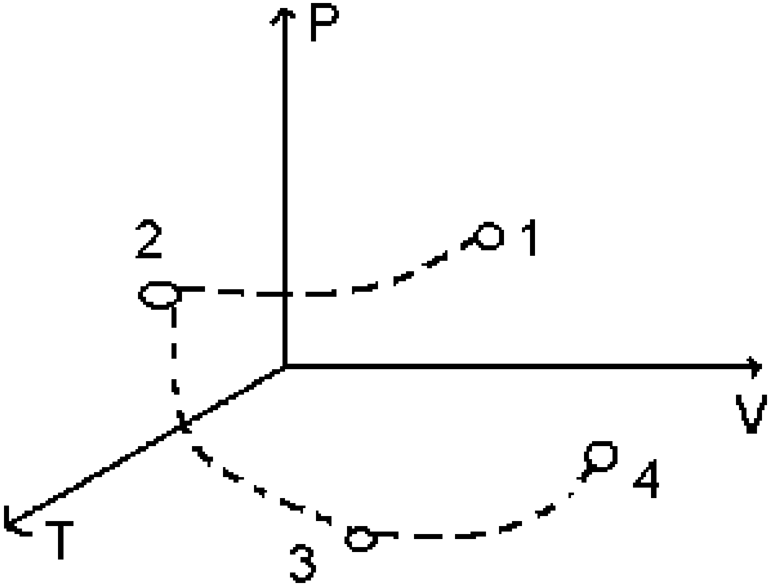
b-c: Displacing piston down
T_2 copper wool looses heat



c-d: Compression →Heat towards upper cylinder room

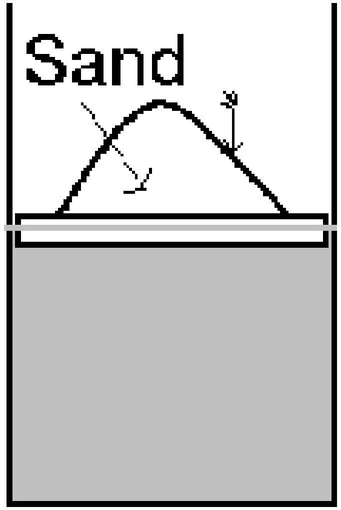
5.8.Thermodynamic Work

Gas (P,V,T),(P,V,T) are state variables
1,2,3,4 are equilibrium states
Considered are quasistatic processes:



Change of P,T,V ',very
slow, very small"
Prozess is reversibel!

e.g: Sand: + grain of sand



Piston down

- Sandkörnchen

Piston back

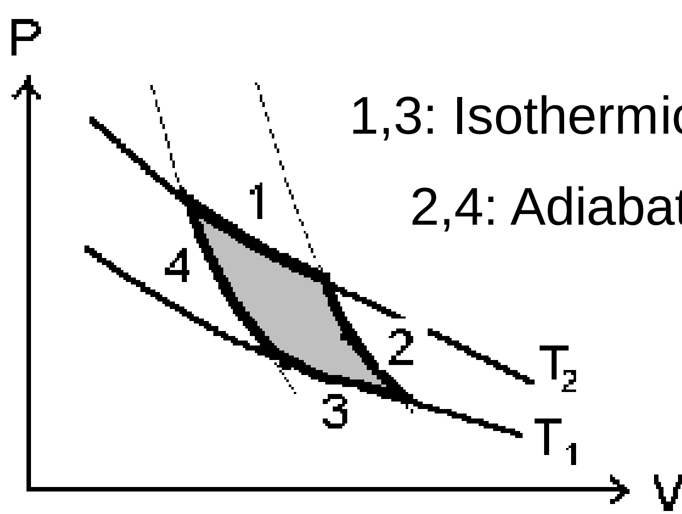
Irreversible processes: e.g: Chemicel reaktions, perfume → air

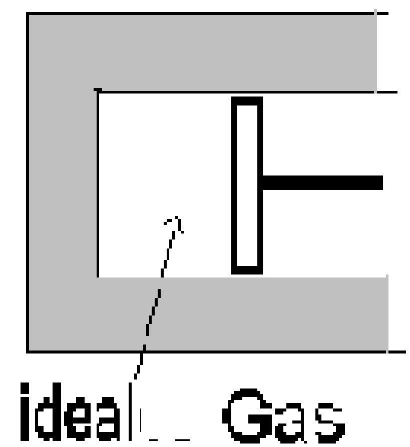
Work performed: $W = W(\underline{P, V, T})$

5.9.Carnot -cycle

(The most efficient heat cycle)

Exchange of heat possible or interrupted!

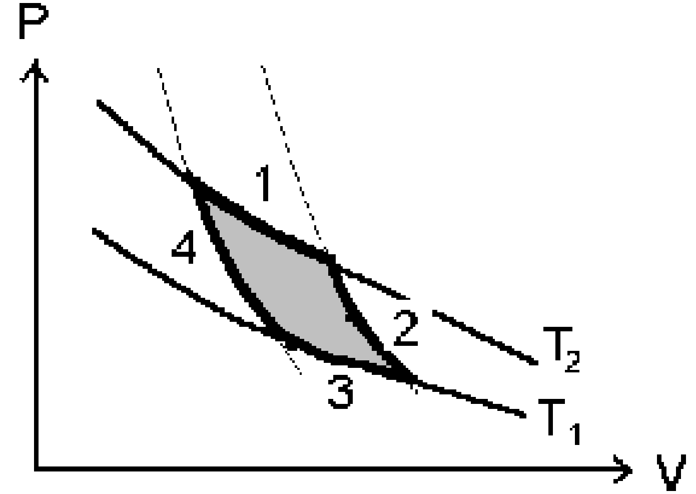




$P \cdot V = R \cdot T$	$T \cdot V^{\gamma-1}$ = constant
$U = c_V \cdot T$	$\Delta Q = \Delta U + \Delta W$

Prozesses reversible

1: W_1 positive, $\Delta U = 0 \Rightarrow \Delta Q_{T_2} = W_1$



2: $\Delta Q = 0, W_2$ positive,

$$\Rightarrow \Delta U = W_2 = c_V \bullet (T_2 - T_1)$$

3: $\Delta U = 0 \Rightarrow W_3 = \Delta Q_{T_1} \prec 0$

4: $\Delta Q = 0 \Rightarrow W_4 = \Delta U = c_V \quad (T_1 - T_2)$

Overall: $W = \Delta Q_{T_2}(\succ 0) + \Delta Q_{T_1}(\prec 0)$

Efficiency of CARNOT- machine

$W_1 = \int^1 P \bullet dV$ with $P = \frac{N \bullet k \bullet T}{V}$

$$= N \bullet k \bullet T_2 \bullet \int^1 \frac{dV}{V} = N \bullet k \bullet T_2 \bullet \ln \frac{V_2}{V_1};$$

V_2(Volume after cycle from 1 etc.)

analogical: $W_3 = N \bullet k \bullet T_1 \bullet \ln \frac{V_4}{V_3};$

For adiabatical prozesses applies:

$$T_2 \bullet V_2^{\gamma-1} = T_1 \bullet V_3^{\gamma-1}$$

$$T_1 \bullet V_4^{\gamma-1} = T_2 \bullet V_1^{\gamma-1}$$

$$\Rightarrow \frac{V_3}{V_4} = \frac{V_2}{V_1} \Rightarrow$$

$$\frac{W_1}{W_3} = \frac{\Delta Q_{T_2}}{\Delta Q_{T_1}} = -\frac{T_2}{T_1}$$

$$\boxed{\frac{\Delta Q_{T_2}}{T_2} = -\frac{\Delta Q_{T_1}}{T_1} \Rightarrow}$$

$$\frac{\Delta Q_{T_2}}{T_2} = -\frac{\Delta Q_{T_1}}{T_1} \Longrightarrow \qquad \boxed{W = \Delta Q_{T_2}(1 - \frac{T_1}{T_2})}$$

$$(1 - \frac{T_1}{T_2}) = \eta \Longrightarrow \eta = \frac{\Delta T}{T}$$

Result: Only a part of Q_{T_2}

can be inverted to work!

Kelvin(1824-1907)

5.10. Second fundamental law of thermodynamics

R. Clausius (1822-1888) :

Not all energy conserving prozesses are possible

Heat, without work performed, flows always from higher to lower temperature!

Clausius introduced the term entropy S.

with $dQ = T \cdot dS$ or $dS = \frac{dQ}{T}$

$\Delta S = S_{end} - S_{beginning} = \int_{beginning}^{end} \frac{dQ}{T}$ $\Delta S_{CARNOT} = 0$: Reversible!

because (s.above): $\frac{\Delta Q_{T_2}}{T_2} = -\frac{\Delta Q_{T_1}}{T_1}$ Irreversible prozesses lead to $\Delta S \succ 0$

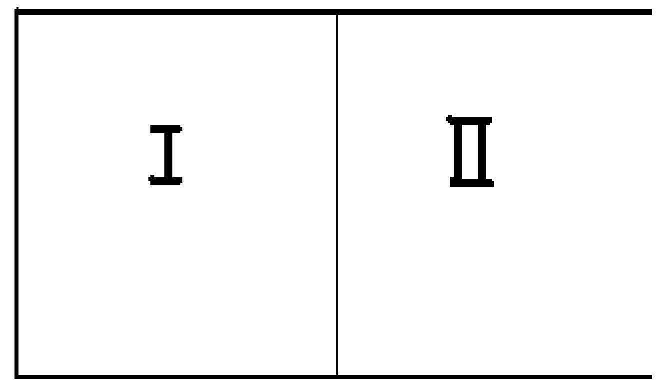
Clausius: 1. Energy of the world is constant

2. The entropy of the world pursuit to a maximum !'

5.11. Entropy and probability (Boltzmann)

N= $N_1 + N_2$

Example:



N particles in I and II

Probability

N_1 in I and N_2 II

e.g.: N=8

One possibility 8 in I
8 posibilties 1 in I, 7 in II

Uniform distribution:

i.e: 4 in I 4 in II $\boxed{\frac{8!}{4!\cdot 4!} = 70}$

The more P, the smaller $N_1 - N_2$

Possibilities for realisation P in general:

$$\boxed{P = \frac{N!}{N_1! \cdot N_2!}}$$

P at most: $N_1 = N_2 = \frac{N}{2}$

At $N = 10^{23}$

All other states are improbable!

Irreversible growth of S leads to growing molecular disorder.

Connection between P and S

$$\boxed{S = k^* \ln P}$$

$N_1 = N_2$ in the example above, forms the endpoint of an irreversible development!

Entropy grows into direction of future, not past,

arrow of time!

5.12. Third fundamental law of thermodynamics

The thermodynamical state of equilibrium at absolute point sero is a state of maximal order, which only one realisation process $P=1$!