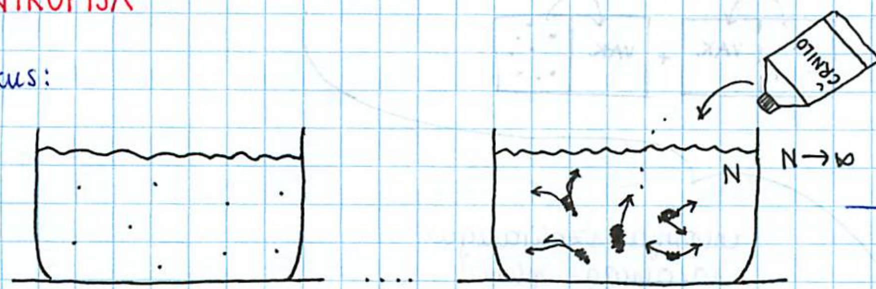
1. zakon termodinamike = energijski zakon
(= ohranjal Joule) $\Delta W_n = Q + A$

Če je posoda izolirana, ne „deluje" notranje delo → ne obstaja **PERPETUM MOBILE I. stopnje**, torej energija se ohranja (superprevodniki, vrtavka bi se večno ⟺ ni trenja).

2. zakon termodinamike = entropijski zakon
(= za izoliran sistem) $\Delta S \geq 0$

ENTROPIJA

poskus:

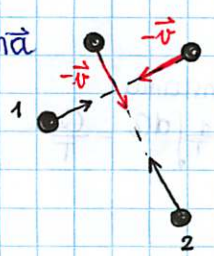


$N \to \infty$ → MP4 (posnetek)

$t=0$ molekule vode

$t>0$ molekule vode in črnila se pomešajo

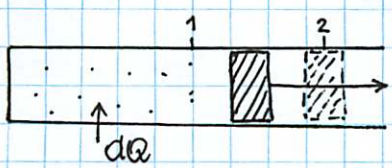
$\vec{F} = m\vec{a}$



$$\vec{F} = m\ddot{\vec{r}} = m\frac{d^2\vec{r}}{dt^2} = \frac{m\, d^2\vec{r}}{d(-t)^2} \Longrightarrow \quad ; t \to -t \qquad \vec{v} = \dot{\vec{r}} = \frac{d\vec{r}}{dt}$$

$$\frac{d\vec{r}}{d(-t)} = -\vec{v}$$

$\Longrightarrow \vec{a}(t) = \vec{a}(-t)$
(= prav tako so sile enake, ne glede ali čas teče naprej ali nazaj)
Newtonovi zakoni omogočajo, da ne glede na smer časa, „dogodki" potekajo enako.



premaknemo bat!

$$dW = dA + dQ$$

$$mc_v\,dT = -p\,dV + dQ \quad / \frac{1}{T}$$

$$\frac{dQ}{T} = \frac{p\,dV}{T} + mc_v\frac{dT}{T}$$

$$pV = \frac{m}{M}RT \qquad \frac{p}{T} = \frac{m}{M}R\frac{1}{V} \qquad c_v = \frac{R}{M}\frac{1}{\kappa-1}$$

$$dS = \frac{dQ}{T} = m\frac{R}{M}\cdot\frac{1}{\kappa-1}\frac{dT}{T} + \frac{m}{M}R\frac{dV}{V}$$

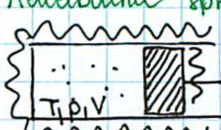
$$\Delta S = \int_{S_1}^{S_2} dS = m\frac{R}{M}\frac{1}{\kappa-1}\ln\frac{T_2}{T_1} + \frac{m}{M}R\ln\frac{V_2}{V_1} = S_2 - S_1$$

> Definicija:
> $$S = S_0 + \frac{mR}{M}\frac{1}{\kappa-1}\ln T + \frac{m}{M}R\ln V$$
> Entropija idealnega plina ↗
> $W_n = \frac{m}{M}R\frac{1}{\kappa-1}$

ΔS nam pove, koliko joulov toplote je bilo dovedeno pri neki T (= kelvini).

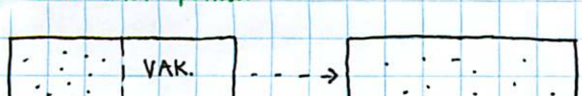
Entropija idealnega plina:
$$S = S_0 + a\ln V + b\ln T$$

(a) Adiabatna sprememba (izentropna sprememba)



konstantna izentropija
$\Delta S = 0$
pV^{κ} = konstanta
$TV^{\kappa-1}$ = konstanta

(b) Hirnov poskus

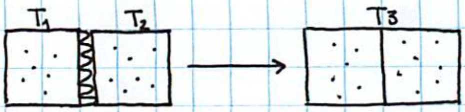


$t=0$ $\qquad$ $t>0$

$$\Delta S = \frac{m}{M}R\ln\frac{2V}{V} = \frac{m}{M}R\ln 2 > 0$$

ireverzibilna razširitev

(c)

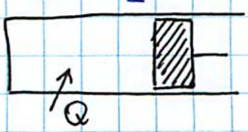


$$\Delta S = 2b\ln T_3 - (b\ln T_1 - b\ln T_2) = b\ln\frac{T_3^2}{T_1T_2} = b\ln\frac{T_1^2+T_2^2+2T_1T_2}{4T_1T_2} =$$

$$T_3 = \frac{T_1+T_2}{2} \qquad = b\ln\frac{(T_1-T_2)^2+4T_1T_2}{4T_1T_2} \geq 0$$

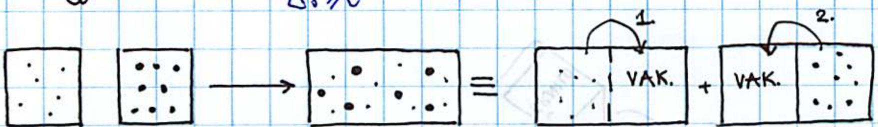
(enačaj je le takrat, ko sta $T_1 = T_2$)

(d)



T = konstantna
$\Delta S \geq 0$

(e)



vsi pogoji so enaki, le molekulama masa je različna

$\Delta S = a_1 \ln 2 + a_2 \ln 2 \geq 0$

ustrezni konstanti za 1. in 2. posodo

entropija izoliranega idealnega plina
$S: \Delta S \geq 0$

Sklep – 2. zakon (aksiom) termodinamike (SƎ)

$$\frac{dW}{T} = \frac{dA}{T} + \frac{dQ}{T}$$

$$dS = \frac{dQ}{T} = \frac{-p\,dV}{T} + \frac{mc_v\,dT}{T}$$

$$\Delta S \geq \int\frac{dQ}{T} = \int\sum_{i=1}^{n}\frac{\Delta Q_i}{T_i}$$

↳ pogledaš limito $N \to \infty$

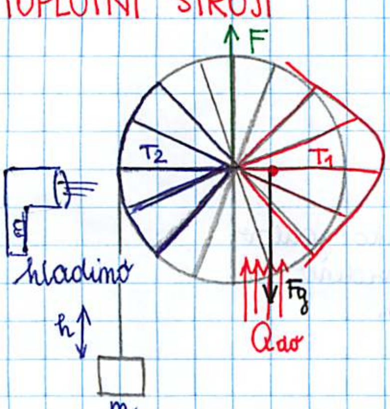
Če je T konstanta:
$$\frac{1}{T}\int dQ = \frac{Q}{T}$$

$W_n = mc_vT = \frac{m}{M}R\frac{1}{\varkappa-1}T$

$W_n(T)$!

$\varkappa = 1{,}6$ za enoatomne molekule
$\varkappa = 1{,}4$ za dvoatomne molekule
$\varkappa = 1{,}3$ za troatomne molekule

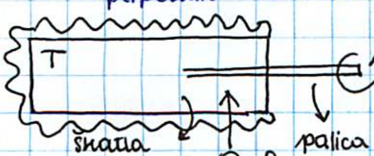
TOPLOTNI STROJI

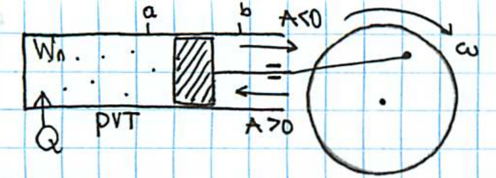


× težišče se premakne
× $T_1 > T_2$
× na kolo je navita vrv
× $mgh = A$
× izkoristek toplotnega stroja (=vedno manjši od 1)
$\eta = \frac{A_{kr}}{Q_{do}} < 1$
× ciklične spremembe

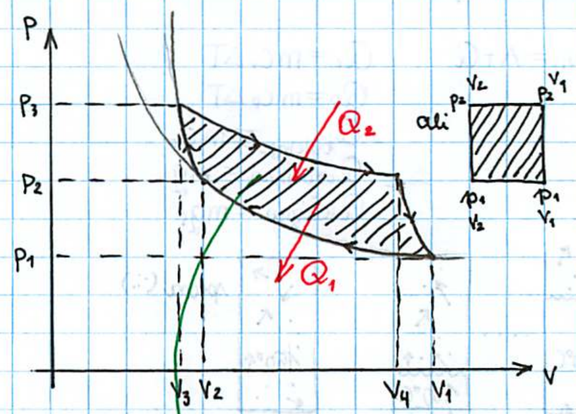
$\eta = \frac{A_{kr}}{Q_{do}}$ $\left[\frac{\text{koliko dela v enem ciklu}}{\text{dovedena toplota v enem ciklu}}\right]$

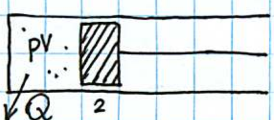
Poznamo: perpetum mobile 1. vrste (stroj se bi večno vrtel)
perpetum mobile 2. vrste (ne obstaja – stroj bi sam opravljal neko delo?)





Ko gre bat nazaj (A>0), se ohlaja hladen zrak, ki ga segreje in ta zrak porine bat naprej, navzgor (A<0) ... to je EN cikel.





T je konstanta, $A = -\int_{V_1}^{V_2} p\,dV > 0$

pV = konstanta

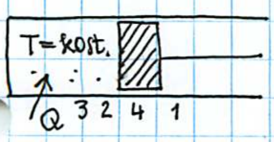
Q odvajamo (sicer T ≠ konstantna)

Temperatura raste.

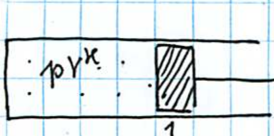
pV^{κ} (adiabatna sprememba)

$A_{kr} = \int p\,dV =$

$= (p_2 - p_1)(V_1 - V_2) > 0$

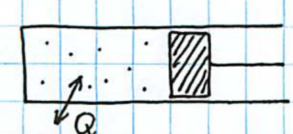


Odstranimo izolacijo in dovajamo Q (kopel z vročo vodo).



Bat na hitro raztegnemo na začetno stanje (1).

Sklep:



Pomembno: Kdaj dobimo največje delo?

$\Delta W_n = A + Q = 0$

$\Delta W_n = A + Q = 0$

$0 = -A_{kr} + Q_{do} - Q_{odv}$ (vsi členi ≥ 0)

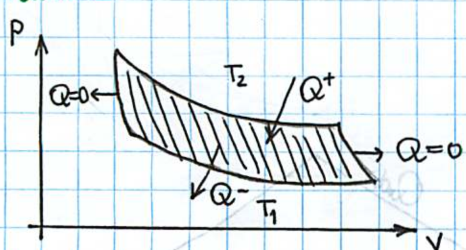
$\eta = \frac{A_{kr}}{Q_{do}} = \frac{Q_{do} - Q_{odv}}{Q_{do}} = 1 - \frac{Q_{odv}}{Q_{do}} \leq 1$

izkoristek (η) toplotnega stroja

Q_{odv} ... izgubljena toplota pri hlajenju npr. ❄

Q_{do} ... tenan, ki ga plačamo, ali pa ogenj ❄

Carnot



Q=0 ... „bat" je izoliran (na hitro premaknemo bat)

$\Delta S_{carnot} = 0 = -\frac{Q_{odv}}{T_1} + 0 + \frac{Q_{do}}{T_2} + 0$

↑ odvajanje toplote

$\Delta S \geq \int \frac{dQ}{T}$

$\frac{Q_{do}}{T_2} = \frac{Q_{odv}}{T_1}$

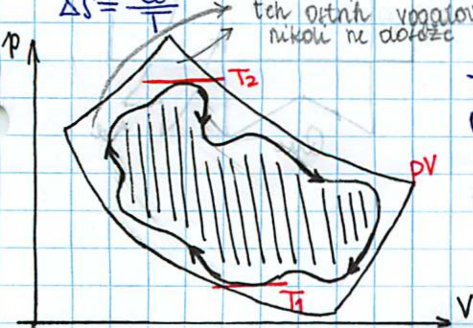
$\frac{Q_{odv}}{Q_{do}} = \frac{T_1}{T_2}$

$\eta \leq \eta_c = 1 - \frac{T_1}{T_2} < 1$ ← „druga oblika" izkoristka idealnega toplotnega stroja (Carnot)

(T_2 ... nikoli ne more biti enak 0)

$\frac{Q_{odv}}{Q_{do}} = \frac{T_1}{T_2}$

$\Delta S = \frac{Q}{T}$



$T_2 > T_1$

Q_{do} = konstantna

Cikel je maksimalen.

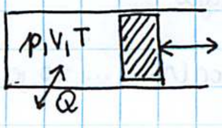
$\eta \leq \eta_c = 1 - \frac{T_1}{T_2} < 1$

$\eta = 1 - \frac{Q_{odv}}{Q_{do}}$

1. $\Delta W_n = A + Q$
2. $\Delta S \geq \int \frac{dQ}{T}$

→ Ni izoliran $= \frac{Q}{T}$

TOPLOTNI STROJ



A_{kr} je ploščina.

$\eta = \frac{A_{kr}}{Q_{do}}$ ... izkoristek

$\Delta W_n = A + Q$ ... $Q_v = m c_v \Delta T$

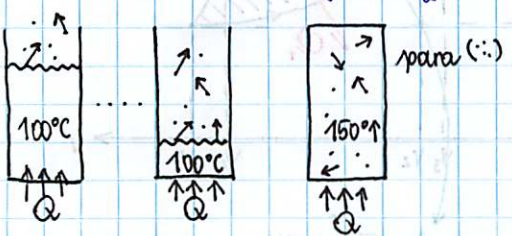
$Q_p = m c_p \Delta T$

$Q_{talilna} = m q_t$

$Q_{izparilna} = m q_i$

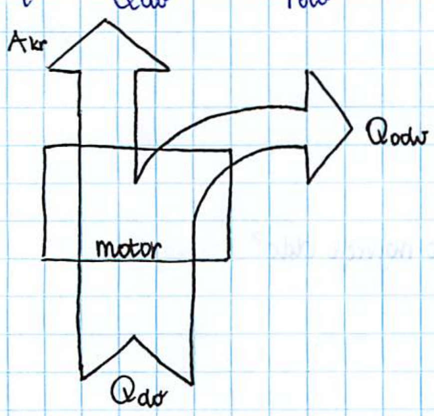
$Q_{sežigna} = m q_s$

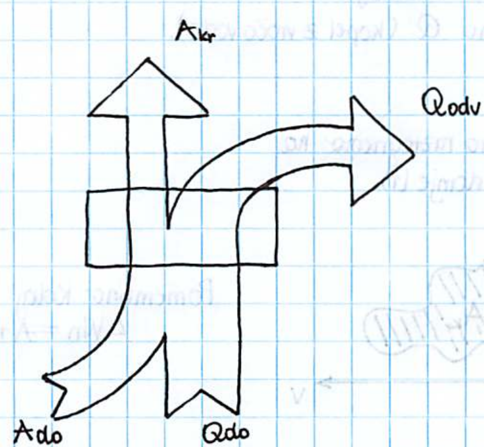
Specifična toplota snovi – koliko toplote je bilo dovedeno, da se je temperatura spremenila za toliko, kolikor se je spremenila.



$\Delta S = 0 + \frac{Q_{do}}{T_{do}} + 0 - \frac{Q_{odv}}{T_{odv}} = 0$

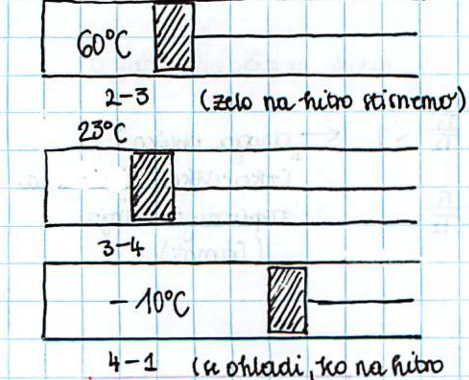
$\eta = 1 - \frac{Q_{odv}}{Q_{do}} = 1 - \frac{T_{odv}}{T_{do}} \leq 1$

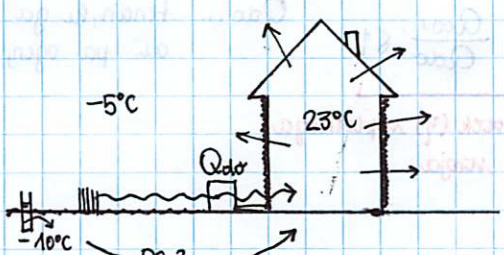




HLADILNI STROJ (KLIMATSKA NAPRAVA), HLADILNIK, TOPLOTNA ČRPALKA

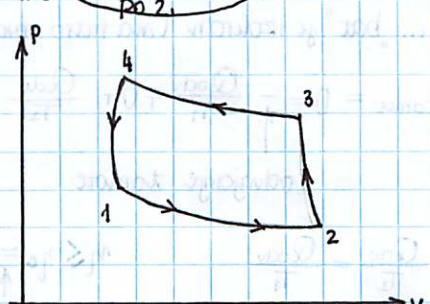
(A) Toplotna črpalka





$\eta = \frac{Q_{do}}{A_{kr}} > 1$

definicija (izkoristka) za hladilni stroj



$\eta = \frac{Q_{do}}{Q_{odv} - Q_{do}} = \frac{T_{do}}{T_{odv} - T_{do}}$

↑ ker se stroj v enem ciklu vrne nazaj v isto stanje, lahko namesto Q pišemo T.