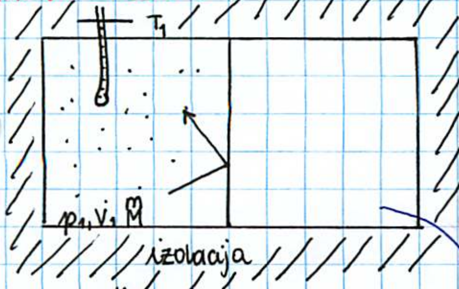
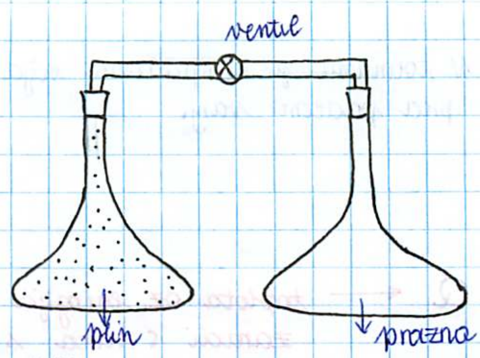
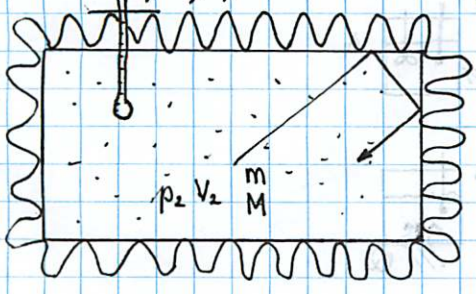
HIRNOV POSKUS





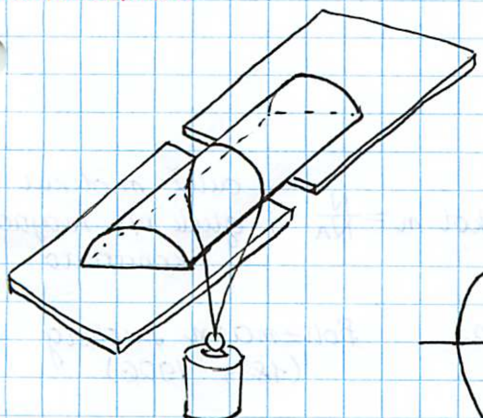
razbijemo steklo



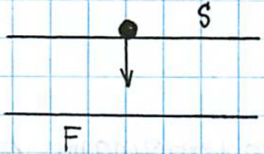
$T_2 = ?$
temperatura je enaka $T_1 = T_2$

pV sta sorazmerna z $\propto W_k \propto T$.
Temperatura ostane enaka, saj se notranja energija plina ni spremenila. Sledi, da je energija odvisna le od hitrosti molekule (temperature) $\Longrightarrow W_n(T)$

RELEGACIJA

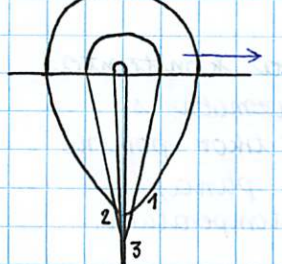


S strani:



$T \sim -5°C$

$p = \frac{F}{S}$ velik, saj je S zelo majhen (nekaj milimetrov debela žica), sila pa zelo velika.



led se topi zaradi pritiska, ne pa zaradi žice (ta ima $T \cong -5°C$)

$\sim -8°C$

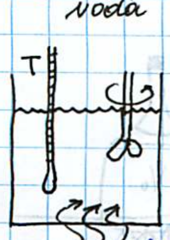
ENERGIJSKI ZAKON IN TOPLOTA

$m_0, N \to \infty$

$pV = \frac{m}{M} RT$
$W_n \propto T$
$W_n = m c_v T$
$\left(\sum_{i=1}^{N} \frac{1}{2} m_0 v_i^2 \longleftrightarrow\right) W_n = m c_v T$

Zgodovina: James Prescott Joule (1818 – 1889)
- žaganje → segrevanje
- vrtanje cevi (top)

vrtanje + hlajenje z vodo → segrevanje (lahko bi se stalili)



2. propeler (grejemo z mešanjem)
↓
"voda se ne spomni", kako se je segrela
1. toplota (npr. štedilnik

Joule je določil toplotni ekvivalent vode oz. kakšno delo moramo opraviti, da se energija spremeni.

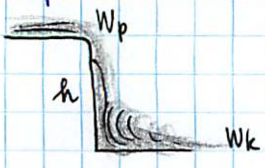
različno za različne snovi

$A = F \cdot s = -\int_{V_1}^{V_2} p\,dV$

ker je delo opravljeno na plinu

$A = \int F dx = \int F \frac{dxS}{S} = \int p\,dV$

:: slap

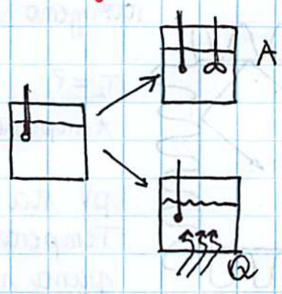


V tolmunu je temperatura višja kot pred padcem vode.

$\Delta W_k + \Delta W_p = A_{zn} + Q$ ← toplota oz. energija dovedena zaradi stika s toplejšim telesom

ΔW_n

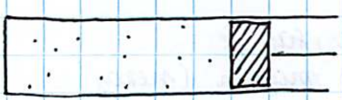
↑ dovedeno delo (notranjih in zunanjih sil)



$\boxed{\Delta W_n = A + Q}$

IDEALNI PLINI

• $pV = \frac{m}{M}RT$ (če plin preveč stisnemo, se utekočini)



$pV = nRT$

$n = \frac{m}{M}$ ... množina, ki jo lahko izračunamo tudi kot $n = \frac{N}{N_A}$ } delež molekul glede na Avogad. konstanto

$pV = NkT$ (fizikalno „najlepša oblika")

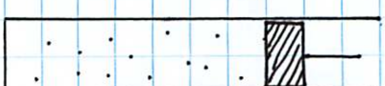
$nR = Nk$

$k = \frac{n}{N}R = \frac{R}{N_A}$ ... Boltzmannova konstanta

Boltzmann Ludwig (1834 - 1906)

Torej ta enačba nam pove, da je tlak sorazmeren s številom delcev in temperaturo. Skratka več delcev pomeni več trkov, posledično večji tlak (idealnega plina). Zaradi povečanega tlaka se poviša tudi temperatura.

•• notranja energija; W_n (E)

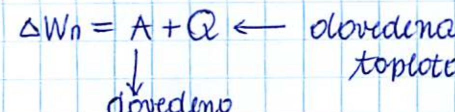


(Hirnov poskus dokaže, da je notranja energija odvisna le od temperature)

$W_n = m c_v T$
↳ konstanta

∵ $\Delta W_n = A + Q$ ← dovedena toplota

↓ dovedeno delo



$A = |A|$
$Q = |Q|$ $\Rightarrow \Delta W_n > 0$

$A = -\int_{V_1}^{V_2} p\,dV$ ← na splošno

:: specifična toplota

(a) V = konstanta

~ izohorna sprememba z idealnim plinom ~

$\Delta W_n = A + Q = Q_v$ $A = -\int_{V_1}^{V_2} p\,dV$ (ker je $V_1 = V_2$)

↓ toplota dovedena konstantni prostornini

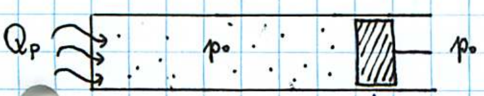
$\Delta W_n = m c_v \Delta T = Q_v$ ← sprememba temperature glede na dovedeno toploto

specifična toplota pri konstantni prostornini V_0

povezan s pojmom, koliko toplote je bilo dovedeno

(b) $p =$ konstanta (= gibljiv bat)

~ izobarna sprememba ~



bat se premika, dokler tlaka nista enaka

$$\Delta W_n = A + Q = p_0(V_1 - V_2) + Q_p = p_0(V_1 - V_2) + m c_p \Delta T$$

$$m c_v (T_2 - T_1) = -p_0(V_2 - V_1) + m c_p (T_2 - T_1)$$

$$\cancel{m} c_v \cancel{(T_2 - T_1)} = -\frac{\cancel{m}}{M} R \cancel{(T_2 - T_1)} + \cancel{m} c_p \cancel{(T_2 - T_1)}$$

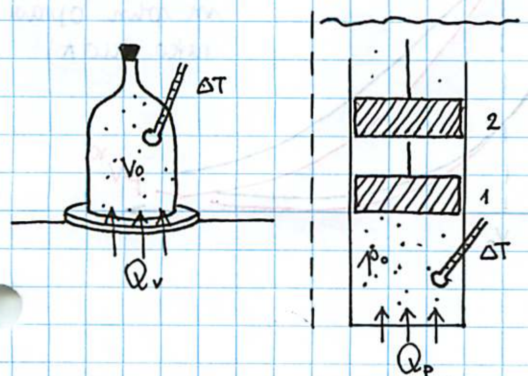
$$c_v = -\frac{R}{M} + c_p$$

$$c_p = c_v + \frac{R}{M} \geq c_v$$

$$\boxed{c_p = c_v + \frac{R}{M} \geq c_v}$$

$$A = -\int_{V_1}^{V_2} p_0 \, dV = -p_0(V_2 - V_1) = p_0(V_1 - V_2)$$

stiskanje plina $\longrightarrow$ povečanje ΔW_n



- $c_p \geq c_v$, ker tudi plin opravlja neko delo - s potiskanjem bata navzgor, potiska navzgor tudi zunanji zrak, posledično se gladina ozračja rahlo dvigne
- $c_p = c_v$, če je zunanji tlak enak 0, torej vakuum

$$\frac{c_p}{c_v} = \kappa \geq 1$$

$$c_p = \kappa c_v$$

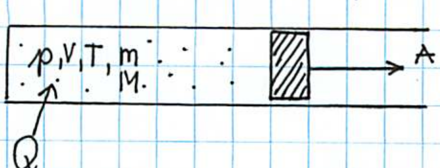
$$\kappa c_v = c_v + \frac{R}{M}$$

$$c_v = \frac{R}{(\kappa - 1) M} \implies c_p = \frac{\kappa}{\kappa - 1} \frac{R}{M}$$

(c) $T =$ konstanten

~ izotermna sprememba ~

1775 - sprejet v Franciji z zakonom "perpeto mobile"



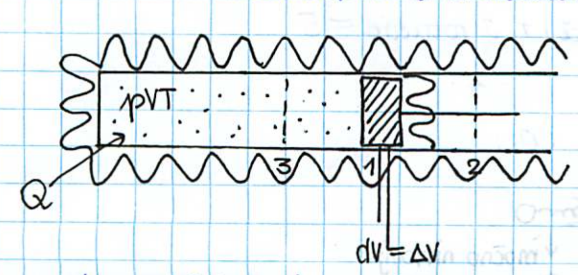
Ker prostornino povečamo, se temperatura zniža, zato moramo dovajati neko toploto, da temperatura ostane nespremenjena. Torej posodo ohlajamo ali segrevamo (glede ΔT)

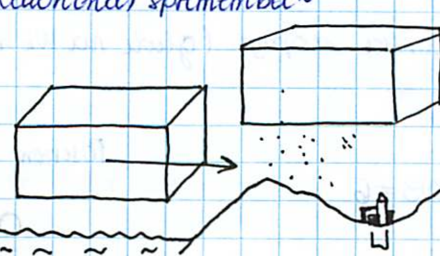
$$\Delta W_n = A + Q = 0$$

$$Q = -A = +\int_{V_1}^{V_2} p \, dV = \int_{V_1}^{V_2} \frac{m}{M} RT \frac{dV}{V} = \frac{m}{M} RT \ln \frac{V_2}{V_1}$$

(d) $Q = 0$, $\frac{pV}{T} =$ konstanta

~ izentropna (= adiabatna, izokalorična) sprememba ~





$1\,km^3$ zraka z morja

Plin se zaradi prepreke dvigne, oz. raztegne, poveča svoj V, zmanjša tlak, se ohladi - dežuje.

1... začetna lega bata

$$\Delta W_n = A + Q$$

$$\Delta W_n = A$$

$$\cancel{m} c_v \Delta T = \Delta A = -p \Delta V = -\frac{\cancel{m}}{M} RT \frac{\Delta V}{V}$$

$$pV = \frac{m}{M} RT$$

$$\frac{R}{(\kappa-1)\cancel{M}}\Delta T = -\frac{\cancel{R}}{\cancel{M}}T\frac{\Delta V}{V}$$

$$\frac{1}{\kappa-1}\frac{\Delta T}{T} = -\frac{\Delta V}{V}$$

$$\frac{1}{\kappa-1}\int_{T_1}^{T_2}\frac{dT}{T} = -\int_{V_1}^{V_2}\frac{dV}{V}$$

$$\frac{1}{\kappa-1}\ln\frac{T_2}{T_1} = \ln\frac{V_1}{V_2}$$

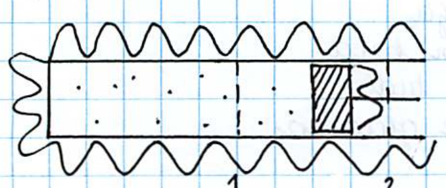
$$\ln\frac{T_2}{T_1} = (\kappa-1)\ln\frac{V_1}{V_2} = \ln\left(\frac{V_1}{V_2}\right)^{(\kappa-1)}$$

$$\frac{T_2}{T_1} = \left(\frac{V_1}{V_2}\right)^{(\kappa-1)} \Longrightarrow \boxed{T_1V_1^{\kappa-1} = T_2V_2^{\kappa-1}}$$

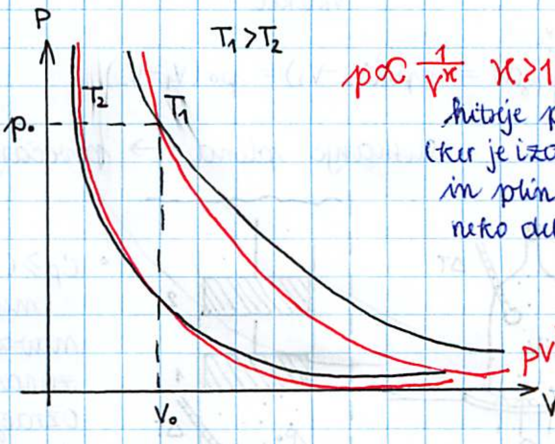
$$\frac{p_1V_1}{T_1} = \frac{p_2V_2}{T_2}$$

$$\boxed{p_1V_1^{\kappa} = p_2V_2^{\kappa}}$$

pV^{κ} = konstanta



Boylov zakon:
Č T konstanta ⇒
⇒ pV = konstanta
$p = \frac{p_1V_1}{V}$



$p \propto \frac{1}{V^{\kappa}}$ $\kappa > 1$
hitreje pada (ker je izolirana in plin opravi neko delo A)

κ (KAPPA)

$\kappa = \frac{c_v}{c_p}$; $c_v = \frac{1}{\kappa-1}\frac{R}{M}$

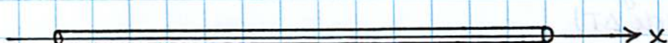
plin	κ		$\frac{1}{\kappa-1}$
He	1,66	$\frac{5}{2}$	$\frac{3}{2}$
Ar	1,66		
H_2	1,41	$\frac{5}{2}$	$\frac{5}{2}$
N_2	1,40		
O_2	1,40		
CO	1,40		
CO_2	1,28	$\frac{4}{3}$	$\frac{6}{2}$
H_2O	1,30		
CH_4	1,32		

$pV = nRT = NkT$

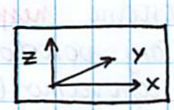
$$W_n = mc_vT = \frac{m}{\kappa-1}\frac{R}{M}T = \frac{NkT}{\kappa-1}$$

$W_n = 3n\left(\frac{1}{2}kT\right)$
$W_n = 5n\left(\frac{1}{2}kT\right)$
$W_n = 6n\left(\frac{1}{2}kT\right)$

EKVIPARTICIJSKI TEOREM



$W_n = N\frac{1}{2}kT$

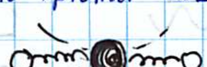


$\left.\begin{array}{l}\frac{1}{2}mv_x\\ \frac{1}{2}mv_y\\ \frac{1}{2}mv_z\end{array}\right\}$ 3 prostorske stopnje

- 1 atomni plini imajo 3 prostorske stopnje (smeri)
  $\overline{v_x^2} = \overline{v_y^2} = \overline{v_z^2}$
- dvoatomni plini:
  3 prostorski stopnje (glede na W_k in težišče) + 2 rotacije = 5

- troatomni plini: 3+3 = 6

Poseben primer CO_2:



močno nihanje

3+2+ 1 → mogoči je
mogoči pa ni