Fizika

Literatura: Halliday - Resnick: Fundamentals of Physics

Pomembno v fiziki:

Merjenje (meritve) - primerjanje količine z standardnimi enotami

- stare enote (palec, seženj, yard, čevlji)
  (pinta, galona, ...)
  (unča, funt, ...) količina snovi
  sila v gravitacijskem polju
- količine
  osnovne enote: (dolžina, masa, (teža), čas)
- izvedene količine: (hitros, pospešek, pretok

⇓

standardni sistem enot: systeme international

Mednarodni sistem enot (SI, KMS sistem)

- dolžina: meter [m] (1791): 1/10000000 razdalje od ekvatorja do severnega pola
  (milja navtična) ekvivalent 1' na ekvatorju minuta

Leta 1960: 1.650.763,73 × valovna dolžina oranžno rdeče svetlobe
Leta 1983: 1 meter svetloba prepotuje v 1/299,792.458 sekunde

- Čas: sekunda [s] 1/2 nihajnega časa matematičnega nihala (1m)
  do 1960: 1s = 1/24·60·60 povprečnega solarnega dneva
  Leta 1967: 1s = 9.192.631.770 nihajnih časov mikrovalov iz razcepljenega osnovnega stanja Cezija

- masa: [kg] kilogram (valj iz zlitine Iridija in platiene
  gram [g] enakostraničen 39 cm)

<u>Predpone:</u>

hekto - h	10^2				
kilo - k	10^3	deci -	d	-	10^{-1}
mega - M	10^6	centi -	c		10^{-2}
Giga - G	10^9	mili -	m		10^{-3}
Tera - T	10^{12}	mikro -	μ		10^{-6}
Penta - P	10^{15}	nano -	n		10^{-9}
Eksa - E	10^{18}	piko -	p		10^{-12}
		femto -	f		10^{-15}
		oto -	a		10^{-18}

<u>Pretvarjanje:</u>

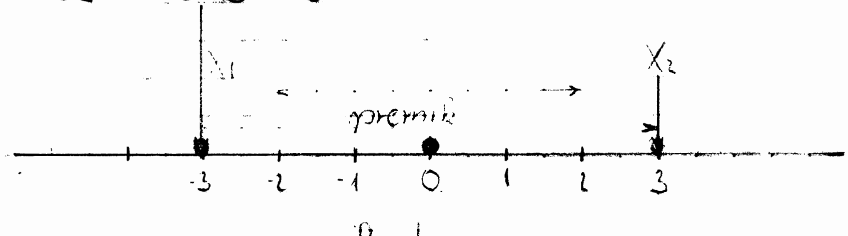
1 minuta = 1·(60 s) = 60 sekund

$100\,km/h = 100 \cdot \frac{1000\,m}{60 \cdot 60\,s} = 100 \cdot \frac{\cancel{1000}\,m}{\cancel{3600}\,s} = 100 \cdot \frac{1\,m}{3{,}6\,s} = \underline{27{,}8\,m/s}$

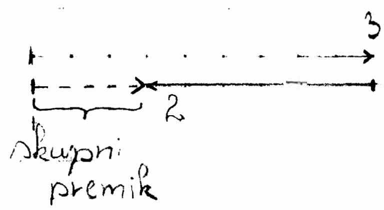
$x = v \cdot t \quad [m] = \left[\frac{m}{\cancel{s}}\right] \cdot [\cancel{s}] = [m]$

<u>Gibanje v eni dimenziji</u>

- Točkasto telo = brez razsežnosti
- brez mase
- gibanje v ravnini

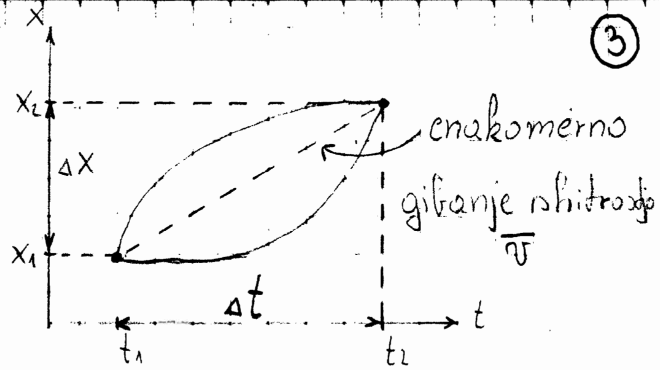


premik: $\Delta x = x_2 - x_1$
 ||
velikost + smer



Povprečna hitrost:

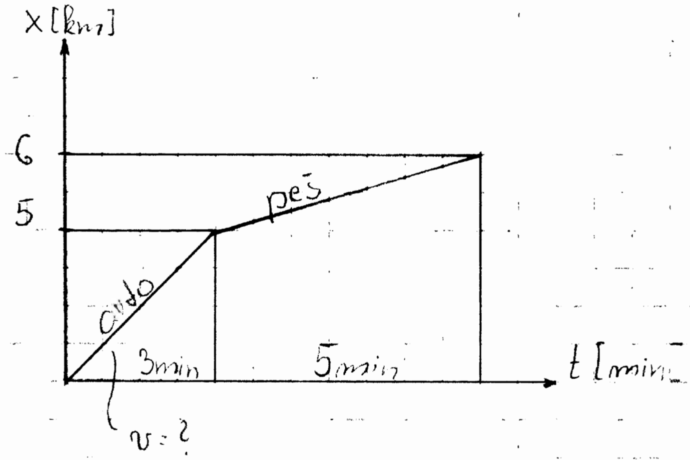
$$\overline{v} = \frac{\Delta x}{\Delta t} \qquad \Delta t = t_2 - t_1$$



$$x(t) = x_1 + \overline{v}\cdot(t - t_1)$$
$$= x_1 + \frac{\Delta x}{\Delta t}(t - t_1) = x_1 + \frac{(x_2 - x_1)}{(t_2 - t_1)}(t - t_1)$$

$$x(t_1) = \underline{\underline{x_1}}$$
$$x_{t_2} = x_1 + \frac{x_2 - x_1}{t_2 - t_1}(t_2 - t_1) = x_1 + x_2 - x_1 = \underline{\underline{x_2}}$$

Primer: Okvara avtomobila



$$\overline{v}_A = \frac{\Delta x}{\Delta t} = \frac{5\,km}{3\left(\frac{1}{60}h\right)} = \frac{5\cdot 60\,km}{3h} =$$

$$\underline{\underline{\overline{v}_A = 100\,km/h}}$$

$$\overline{v}_P = \frac{\Delta x}{\Delta t} = \frac{1km\cdot 60}{10h} = \underline{\underline{6\,km/h}}$$

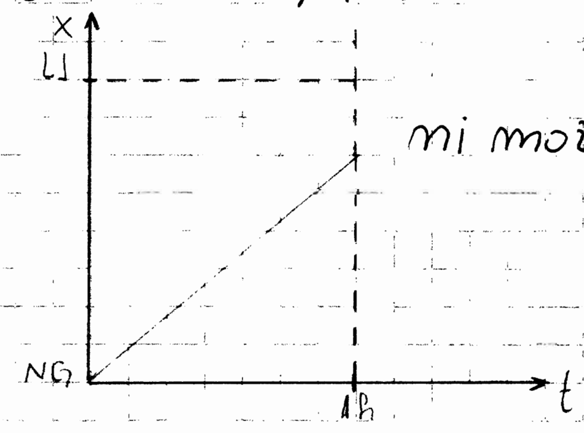
celotna: $\overline{v} = \frac{\Delta x}{\Delta t} = \frac{6\cdot 60\,km}{13h} = \underline{\underline{27{,}8\,km/h}}$

Primer: Nova Gorica - Ljubljana

$\Delta x = 100\,km$

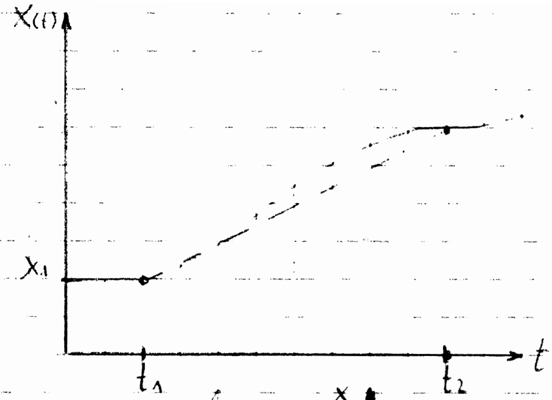
Prvo polovico poti vozimo z $50\,km/h$

S kakšno hitrostjo moramo voziti naslednjo polovico, da bo $\overline{v} = 100\,km/h$?



ni možno priti, ker v eni uri prevozimo 50km

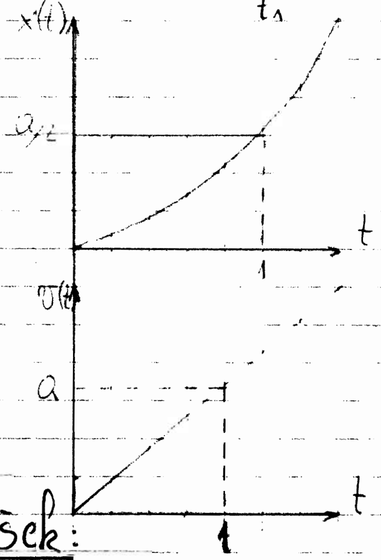
④ Trenutna hitrost:

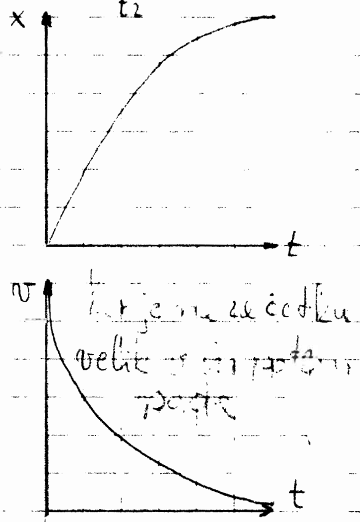


$$v = \lim_{\Delta t \to 0} \frac{\Delta x}{\Delta t} = \frac{dx(t)}{dt}$$

$$x(t) = \frac{a}{2} \cdot t^2$$

$$v(t) = \frac{dx}{dt} = \frac{a}{\cancel{2}} \cdot \cancel{2}t = a \cdot t$$

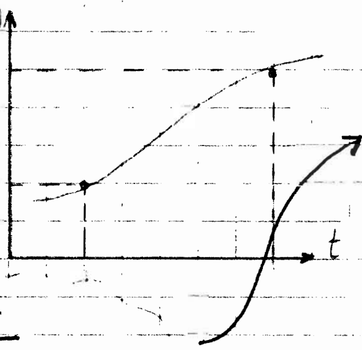




Pospešeno gibanje in pospešek:

po analogiji povprečno hitrost $\bar{v}$ definiramo

$$\bar{a} = \frac{\Delta v}{\Delta t}$$



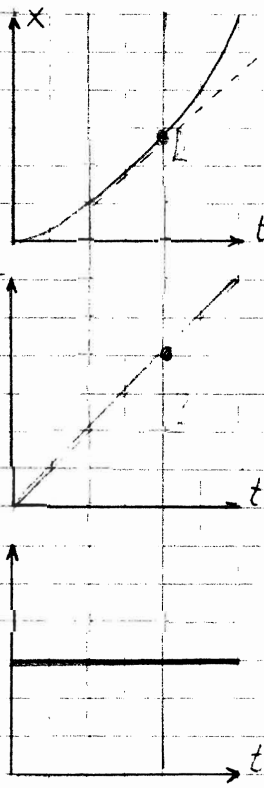
trenutni pospešek

$$a = \lim_{\Delta t \to 0} \frac{\Delta v}{\Delta t} = \frac{dv}{dt}$$

def.

$$a = \frac{dv}{dt} = \frac{d}{dt}\left(\frac{dx}{dt}\right) = \frac{d^2x}{dt^2}$$

drugi odvod po času



pot

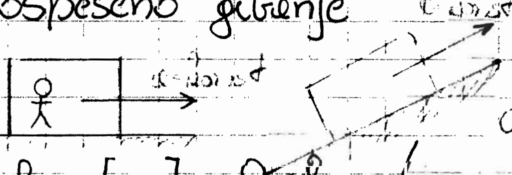
$\frac{d}{dt}$ odvajamo

hitrost

$\frac{d}{dt}$ odvajamo

pospešek

- enakomernega gibanja ne zaznavamo
- zaznavamo pospešeno gibanje
- gravitacija



- enota pospeška $[g] = 9{,}8\ m/s$

Primer: Avto v 5 s za 0 - 100 km/h

$$\Delta v = v_2 - v_1 = 100\,km/h - 0\,km/h = \underline{\underline{100\,km/h}}$$

$$\underline{\underline{\Delta t = 5\,s}} \qquad \bar{a} = \frac{\Delta v}{\Delta t} = \frac{100\,km}{5\,s \cdot h} = \frac{100 \cdot 1000\,m}{5\,s \cdot \underbrace{60 \cdot 60\,s}_{3600}} = \frac{200\,m}{36\,s^2} \approx \underline{\underline{5\,m/s^2}}$$

Natančnost meritev in izračunov:

obseg kroga: $o = 2\pi r$ $\qquad r = 1\,m \quad , \; r = 1016{,}5\,mm$

$o = 6{,}2\,m$

natančnosti:

$1\,m \pm 1\,mm$

$42\,\Omega \pm 10\,\% \Rightarrow \pm 4\,\Omega$

ppm = del na milijon (part per milion)

hitrost svetlobe: $c = 3 \cdot 10^8\,m/s = 300\,000\,km/s$

svetlobno leto: $x = c \cdot t = 3 \cdot 10^8\,m/s \cdot (\underbrace{365 \cdot 24 \cdot 60 \cdot 60}_{3{,}15 \cdot 10^7\,s}) =$

$= \underline{\underline{9{,}46 \cdot 10^{15}\,m}}$

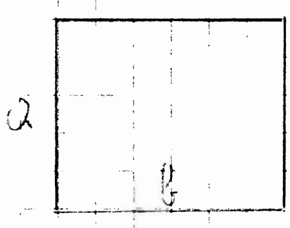
Velikostni razred:

Koliko tehta 1 M\$ zlata?

↳ unča zlata stane 300 \$, unča ≈ 28 g ⇒ 1 g stane 10 \$

$\underline{\underline{1\,M\$ \text{ zlata} \approx 100\,kg}}$

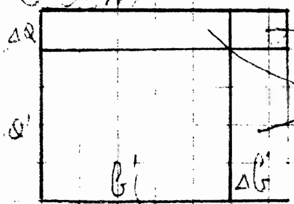
Ocena in Propagacija napak:



$a = 3\,m \pm 2\,mm$ (a')

$b = 5\,m \pm 0{,}5\,mm$ (b')

$P = a \cdot b = (a' + \Delta a) \cdot (b' + \Delta b) = a'b' + \Delta a\, b' +$
$+ a' \Delta b + \Delta a \Delta b =$



$= 15\,m^2 \pm 25/1000\,m^2$

relativna napaka: $\frac{25}{15000} \approx \underline{\underline{2\,‰}}$

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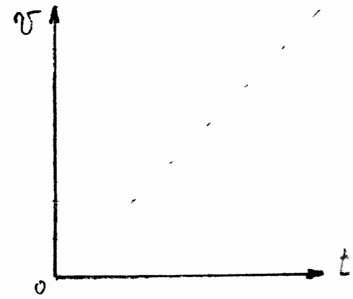
Enakomerno pospešeno gibanje:



- konstanten pospešek

$$a = \bar{a} \quad (\text{povprečen} = \text{trenutni})$$

$$\bar{a} = \frac{\Delta v}{\Delta t} = a$$

$v_0 = 0$ »

$$t_1 = 0 \Rightarrow a = \frac{v - v_0}{t - 0} = \frac{v - v_0}{t} \Rightarrow \boxed{v_{(t)} = v_0 + a \cdot t} \quad \boxed{v = a \cdot t}$$

- Opravljena pot v času t $\quad \boxed{x_{(t)} = x_0 + v_0 \cdot t + \frac{a}{2} \cdot t^2}$

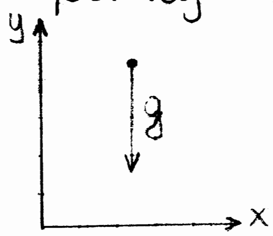
- Odvisnost hitrosti od poti:

$$\left.\begin{array}{l} v_0 = 0 \;;\; x_0 = 0 \text{ ob času } t = 0 \\ x = \frac{a \cdot t^2}{2} \Rightarrow t^2 = \frac{2x}{a} \Rightarrow t = \sqrt{\frac{2x}{a}} \end{array}\right\} v = a \cdot \sqrt{\frac{2x}{a}} = \boxed{v = \sqrt{2a \cdot x}}$$

Prosti pad

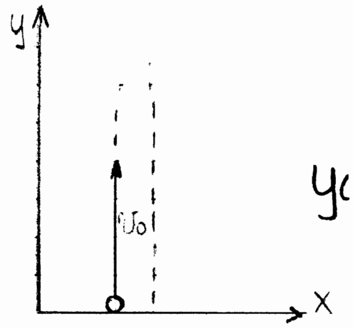
- Telesa prosto padajo univerzalno, neodvisno od njihovih lastnosti: masa, oblika, gostota ... (velja v vakuumu)

- padajo navzdol, velikost pospeška $g = 9{,}81\,m/s^2$



primer: Navpični met navzgor z v_0.

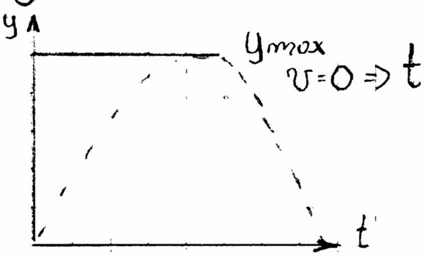
Največja višina



$y = h$ = višina

$y_{(t)} = y_0 + v_0 \cdot t + \frac{a}{2} t^2$: $a = -g$

$y = v_0 \cdot t - \frac{g}{2} \cdot t^2$



$\boxed{v_{(t)} = v_0 - g \cdot t}$

V točki maksimalne višine $v = 0$

$v - g \cdot t_{max} = 0 \Rightarrow t_{max} = \frac{v_0}{g}$ mak. višina

$y(t_{max}) = v_0 \cdot t_{max} - \frac{g}{2} t_{max}^2 = \frac{v_0^2}{g} - \frac{g}{2} \cdot \frac{v_0^2}{g^2} = \boxed{\frac{v_0^2}{2g} = y(t_{max})}$

čas leta: $t_{let} = 2 \cdot t_{max} = \frac{2 \cdot v_0}{g}$

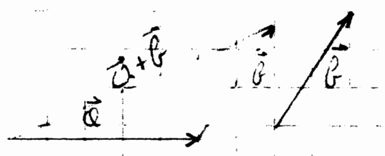
$y(t_{let}) = 0$ $\quad v_0 \cdot t_{let} - \frac{g}{2} t_{let}^2 = 0$ $\quad \boxed{t_{let} = \frac{2 \cdot v_0}{g}}$

Skalarne in vektorske količine

- Skalarji so količine, ki imajo samo velikost (masa, temperatura, svetlost, gostota ...)
- Vektorji: velikost + smer (odmik, hitrost, pospešek, električno polje, ...)

Vektorji

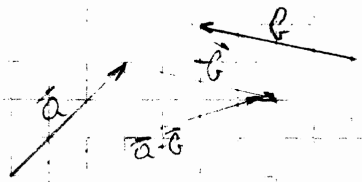
- Lahko jih seštevamo $\vec{s} = \vec{a} + \vec{b}$



$\vec{a} + (\vec{b} + \vec{c}) = (\vec{a} + \vec{b}) + \vec{c}$ → asociativnost

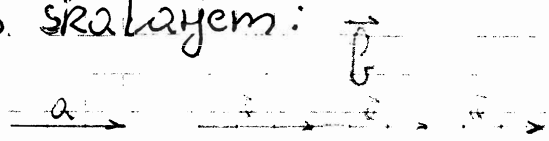
$\vec{a} + \vec{b} = \vec{b} + \vec{a}$ → komutativnost

- Odštevanje: $\vec{a} - \vec{b} = a + (-\vec{b})$



- množenje vektorja s skalarjem:

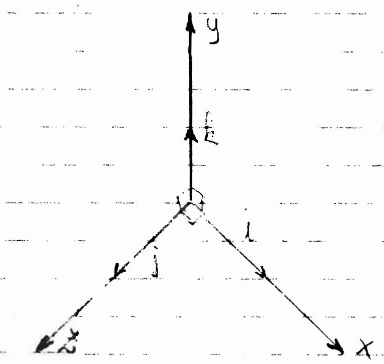
$\vec{b} = s \cdot \vec{a} \qquad s = 3$

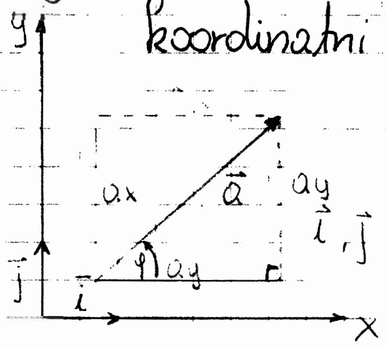


Reprezentacija vektorjev v koordinatnem sistemu

- Kartezični koordinatni sistem:

$\vec{i}, \vec{j}, \vec{k}$ so bazni vektorji, ki razpenjajo koordinatni sistem





$\vec{i}, \vec{j}$ enotni bazni vektorji

$|\vec{i}| = 1 = i$

$|\vec{j}| = 1 = j$

$|\vec{a}| = a$ - dolžina

$a_x = a \cdot \cos\varphi$

$a_y = a \cdot \sin\varphi$

Dva ekvivalentna zapisa za vektor:

- naravni: a - velikost, φ - smer
- po komponentah: a_x, a_y

Dolžina vektorja, če imamo na voljo komponente a_x in a_y:

$$a = \sqrt{a_x^2 + a_y^2}$$

preverimo: $a = \sqrt{(a \cdot \cos\varphi)^2 + (a \cdot \sin\varphi)^2} = \sqrt{a^2 \cdot (\sin^2\varphi + \cos^2\varphi)} = a$

Kot φ če imamo a_x, a_y:

$$\operatorname{tg}\varphi = \frac{a_y}{a_x}$$

Zapis po komponentah: $\vec{a} = \begin{vmatrix} a_x \\ a_y \end{vmatrix} = (a_x, a_y)$

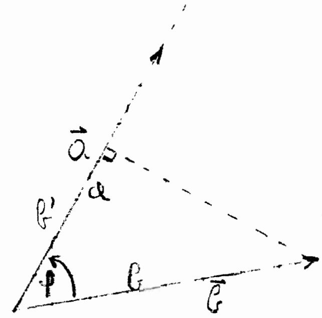
Seštevanje: $\vec{c} = \vec{a} + \vec{b}$ ⇒ po komponentah: $\vec{a} = (a_x, a_y)$

$\vec{b} = (b_x, b_y)$

$$\vec{c} = \vec{a} + \vec{b} = (a_x, a_y) + (b_x, b_y) = (a_x + b_x, a_y + b_y) = (c_x, c_y)$$

Skalarni produkt:

$$\underbrace{\vec{a}\cdot\vec{b}}_{\text{skalarna količina}} = a \cdot b \cdot \cos\varphi$$
$$= a \cdot b'$$
$$= a' \cdot b$$



$b' = b \cdot \cos\varphi$

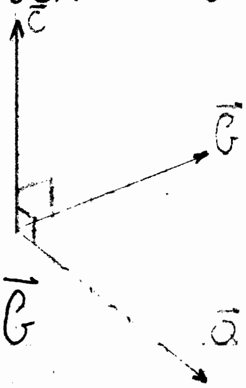
$a' = a \cdot \cos\varphi$

- Skalarni produkt je komutativen: $\vec{a}\cdot\vec{b} = \vec{b}\cdot\vec{a}$

Skalarni produkt je 0, kadar sta vektorja pravokotna.

Vektorski produkt:

$$\vec{a} \times \vec{b} = \vec{c}$$



- $\vec{c}$ je pravokoten na oba $\vec{a}$ in $\vec{b}$

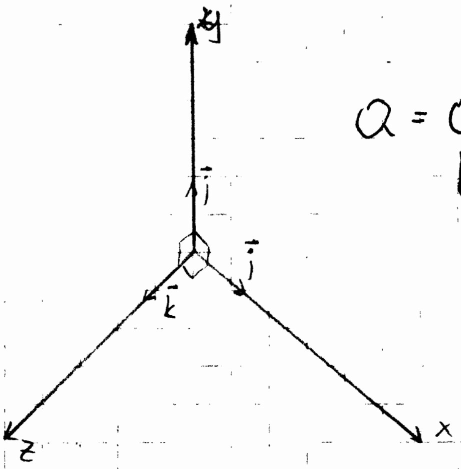
$\vec{c} \perp \vec{a}$, $\vec{c} \perp \vec{b}$

Iz obeh smeri izberemo tisto, ki ustreza pravilu desne roke (3 prsti)

$|\vec{c}| = a \cdot b \cdot \sin\varphi$ (ploščina paralelograma $\vec{a}$ in $\vec{b}$)

Vektorski produkt je enak 0, kadar sta vektorja vzporedna

Komponentni zapis:



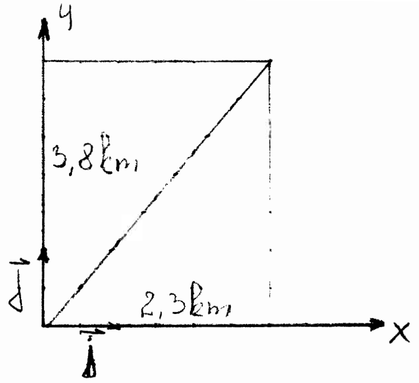
$$a = a_x \cdot \vec{i} + a_y \cdot \vec{j} + a_z \cdot \vec{k} = (a_x, a_y, a_z)$$

↳ komponente

$$a_x = a \cdot \vec{i}$$
$$a_y = a \cdot \vec{j}$$
$$a_z = a \cdot \vec{k}$$

$$\vec{a} + \vec{b} = (a_x + b_x)\, i + \ldots = (a_x + b_x, \ldots)$$

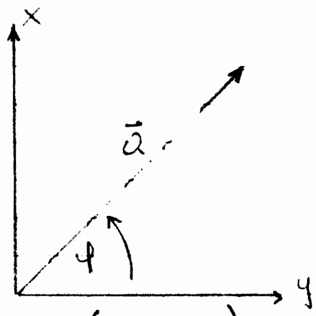
Primer:



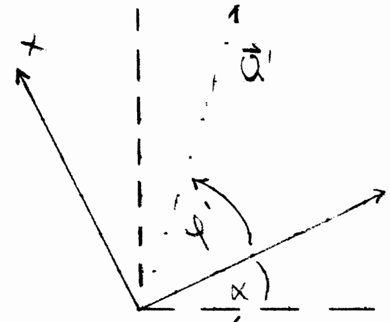
premik:

$$\vec{a} = 2{,}3 \cdot \vec{i} + 3{,}8\,km \cdot \vec{j}$$

Rotacija koordinatnega sistema



$\vec{a} = (a_x, a_y)$



$\vec{a}' = (a_x', a_y')$

Dolžina v obeh KS enaka

$$a = \sqrt{a_x^2 + a_y^2} = \sqrt{a_x'^2 + a_y'^2}$$

$$\varphi = \varphi' + \alpha$$ smer ista

Gibanje v več dimenzijah

$$r = x \cdot \vec{i} + y \cdot \vec{j} + z \cdot \vec{k} = (x, y, z) \qquad \Delta r = \vec{r}_2 - \vec{r}_1$$

začetni končni položaj

Povprečna hitrost (po analogiji z 1D)

$$\overline{\vec{v}} = \frac{\Delta \vec{r}}{\Delta t} = \frac{\vec{r}_2 - \vec{r}_1}{\Delta t} = \frac{(x_2 \cdot \vec{i} + y_2 \cdot \vec{j} + z_2 \cdot \vec{k}) - (x_1 \cdot \vec{i} + y_1 \cdot \vec{j} + z_1 \cdot \vec{k})}{\Delta t} =$$

$$= \frac{(x_2 - x_1) \cdot \vec{i} + (y_2 - y_1) \cdot \vec{j} + (z_2 - z_1) \cdot \vec{k}}{\Delta t} = \frac{\Delta x \cdot \vec{i} + \Delta y \cdot \vec{j} + \Delta z \cdot \vec{k}}{\Delta t} =$$

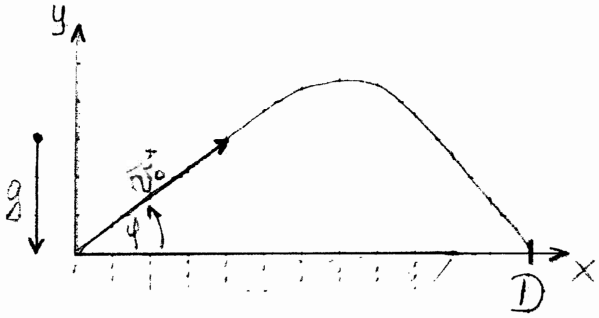
$$= \overline{v_x} \cdot \vec{i} + \overline{v_y} \cdot \vec{j} + \overline{v_z} \cdot \vec{k} = (\overline{v_x}, \overline{v_y}, \overline{v_z})$$

Trenutna hitrost: $\vec{v} = \frac{d\vec{r}}{dt} = \frac{d}{dt}(x, y, z) = \left(\frac{dx}{dt}, \frac{dy}{dt}, \frac{dz}{dt}\right)$

Pospešek: $\vec{a} = \frac{dv}{dt} = \left(\frac{dv_x}{dt}, \frac{dv_y}{dt}, \frac{dv_z}{dt}\right)$

$$a = \frac{d^2\vec{r}}{dt^2} = \left(\frac{d^2x}{dt}, \frac{d^2y}{dt}, \frac{d^2z}{dt}\right)$$

Poševni met



- gibanje v smeri osi X je nepospešeno, ker gravitacijski pospešek nima komponente x $\Rightarrow$ gibanje je enakomerno ($v = \text{konst.}$)

- Gibanje v smeri y je navpični met

- Vodoravni del gibanja (x):
$$x = v_{0x} \cdot t = v_0 \cdot \cos\varphi \cdot t$$

- Navpični del: $y = v_{0y} t - \frac{g}{2} t^2 = v_0 \cdot \sin\varphi \cdot t - \frac{g}{2} t^2$

$$\vec{r} = (x_{(t)}, y_{(t)}) = r_{(t)}$$ -> časovna odvisnost poti

$$\vec{v} = \frac{dr}{dt} = \left(\frac{dx}{dt}, \frac{dy}{dt}\right) = (v_0 \cdot \cos\varphi, v \cdot \sin\varphi - gt) = \vec{v}_{(t)}$$

$$a = \frac{d\vec{v}}{dt} = (0, -g)$$

- Krivulja poti $y(x) \Leftarrow \begin{matrix} x_{(t)} \\ y_{(t)} \end{matrix}$

Izrazimo t iz prve enačbe: $t = \frac{x}{v_0 \cdot \cos\varphi}$

Vstavimo v drugo enačbo: $y = v_0 \cdot \sin\varphi \cdot \frac{x}{v_0 \cdot \cos\varphi} - \frac{g}{2}\left(\frac{x}{v_0 \cdot \cos\varphi}\right)^2 =$

$$y = x \cdot \operatorname{tg}\varphi - \frac{g x^2}{2 \cdot v_0^2 \cos^2\varphi}$$ => kvadratna enačba,

in to nam pove da je krivulja poti parabola

(12)

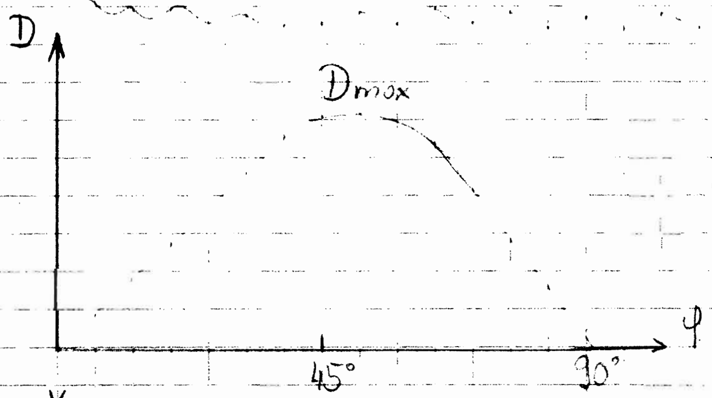
Domet (D):

ko je $x = D \Rightarrow y(x=D) = 0$

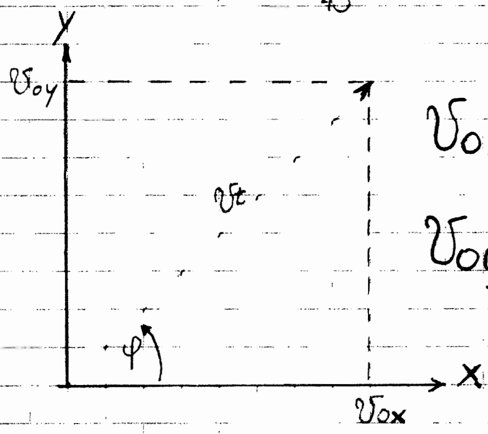
$$D\cdot \tan\varphi - \frac{g\cdot D^2}{2\cdot v_0^2 \cos^2\varphi} = 0 \;/ : D$$

$$\tan\varphi - \frac{g\cdot D^2}{2 v_0^2 \cos^2\varphi} = 0 \Rightarrow \frac{D - 2v_0^2\cdot\cos^2\varphi\cdot tg\,\varphi}{g}$$

$$D = \frac{2\cdot v_0^2 \sin\varphi\cdot\cos\varphi}{g} = \frac{v_0^2}{g}\cdot\sin 2\varphi$$



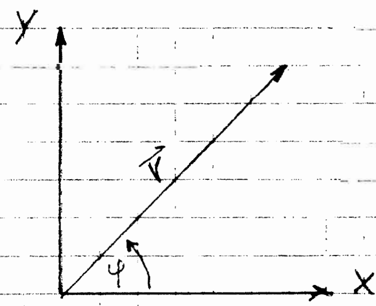
Največji domet je pod kotom 45°



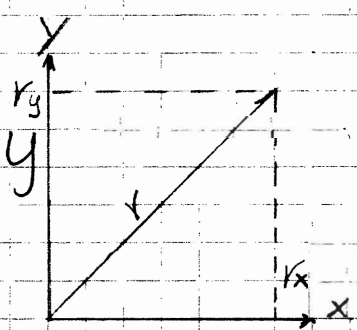
$v_{ox} = v_0 \cos\varphi \rightarrow$ enakomerno gibanje

$v_{oy} = v_0 \cdot \sin\varphi \rightarrow$ navpični met

2D vektorji:



- Polarni koordinatni sistem: $\vec{r} \ldots r, \varphi$



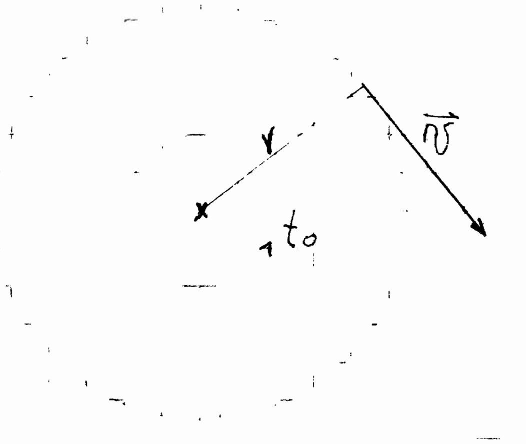
- Kartezični koordinatni sistem: $r_x = x$, $r_y = y$

Enakomerno kroženje

- **Perioda kroženja** (obhodni čas): je čas potreben za en obrat. $[t_0]$

- **frekvenca kroženja**: $f = \nu = \frac{N}{t}$ $\quad \nu = \frac{1}{t_0} \quad [s^{-1}, \frac{1}{s}, Hz]$

- **Obodna hitrost**:



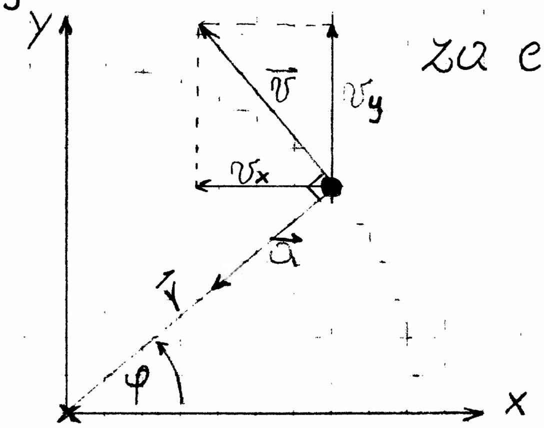
obseg kroga: $o = 2\pi r$

obodna hitrost $\quad v = \frac{2\pi r}{t_0}$

$$\Downarrow$$

$$t_0 = \frac{2\pi r}{v}$$

kroženje delca:



za enakomerno kroženje: $\varphi = \omega \cdot t$

kot $\quad$ kotna hitrost

$$\vec{r} = (x, y) = (r \cdot \cos\varphi, r \cdot \sin\varphi) = (r \cdot \cos\omega \cdot t, r \cdot \sin\omega t)$$

$$\vec{v} = \frac{dr}{dt} = \left(\frac{dx}{dt}, \frac{dy}{dt}\right) = \left(\frac{d}{dt}(r \cdot \cos\omega t), \frac{d}{dt}(r \cdot \sin\omega t)\right) =$$

$$= \left(r \cdot \frac{d \cos\omega t}{dt}, r \cdot \frac{d \sin\omega t}{dt}\right) = (\underbrace{-r\omega}_{v_0} \sin\omega t, r\omega \cos\omega t)$$

odvod

$$\boxed{v_0 = \omega \cdot r} \Leftarrow \text{obodna hitrost}$$

$$\vec{v} = (-v_0 \sin\omega t, v_0 \cos\omega t) \Leftarrow \text{hitrost}$$

14

skalarno pomnožimo: $\vec{r} \cdot \vec{v} = 0 \Rightarrow \perp$

$$(x, y) \cdot (v_x, v_y) = x v_x + y v_y = 0$$

Pospešek kroženja:

- centripetalni pospešek (proti središču)
- centrifugalni pospešek (iz središča)

$$\vec{a} = \frac{d\vec{v}}{dt} = \left(-v_0 \frac{d \sin\omega t}{dt}, v_0 \frac{d \cos\omega t}{dt}\right) = (\underbrace{-v_0 \cdot \omega}_{a_0} \cos\omega t, -v_0 \cdot \omega \cdot \sin\omega t)$$

Pospešek kaže proti središču kroženja

$$|\vec{v}| = v_0 = \text{konst.} = \omega \cdot r$$

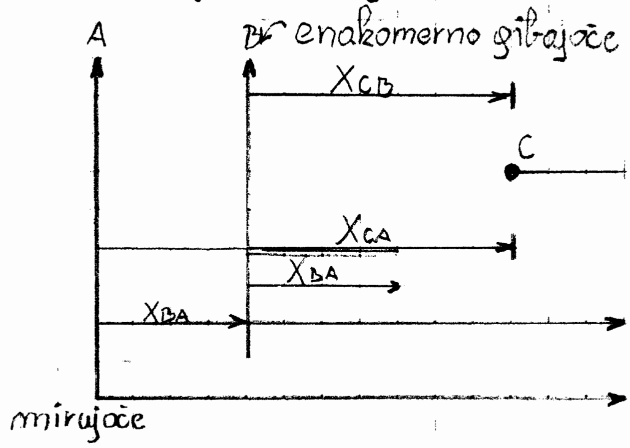
$a_0 = v_0 \cdot \omega$ -> velikost centripetalnega pospeška

$$a_0 = \omega^2 \cdot r \qquad a_0 = \frac{v_0^2}{r}$$

Primer: Avtomobil skozi ovinek $r = 25\,m$, vozi s hitrostjo $v_0 = 100\,km/h = 27{,}7\,m/s$

$$a_0 = \frac{v_0^2}{r} = \frac{27.7^2\,m^2}{s^2\,25\,m} = \underline{\underline{30{,}7\,m/s^2}} = 3{,}13\,g$$ mi ~~možno~~

RELATIVNO GIBANJE
(Galilejeva transformacija)



obe strani odvajamo

$$X_{CA} = X_{BA} + X_{CB} = X_{CB} + X_{BA} \quad \Big/ \frac{d}{dt}$$

$$\frac{dX_{CA}}{dt} = \frac{dX_{CB}}{dt} + \frac{dX_{BA}}{dt}$$

$$\Downarrow$$

$$\boxed{v_a = v_B + v_{BA}}$$

v_a – hitrost predmeta, kot jo izmerimo v sistemu A
v_B – hitrost v sistemu B
v_{BA} – hitrost gibajočega se sistema B (enakomerno gibanje

Galilejeva transformacija (gibanje je relativno)

V več dimenzijah:

$$\boxed{\vec{v}_A = \vec{v}_B + \vec{v}_{BA}}$$

Transformacija pospeško:

$$v_A = v_B + v_{BA} \quad \Big/ \frac{d}{dt}$$

$$\frac{dv_A}{dt} = \frac{dv_B}{dt} + \frac{dv_{BA}}{dt} \leftarrow \text{enakomerno gibanje (konst. odvod je 0)}$$

$$\Downarrow \qquad \Downarrow \qquad \Downarrow$$

$$a_A = a_B + 0$$

Sistemi, ki mirujejo oziroma se enakomerno (nepospešeno) gibljejo so inercialni sistemi

Zakoni gibanja

Spremembe v gibanju → interakcija (medsebojno delovanje)
→ sile , F - sila

1. Newtonov zakon:

- Mirujoče telo ostane mirujoče, če nanj ne deluje nobena sila
- Enakomerno gibajoče telo ostane enakomerno gibajoče telo z isto hitrostjo kot prej, če nanj ne deluje nobena sila

MASA - POSPEŠEK - SILA

m_1 1kg žoga pospešuje $1\, m/s^2$
m_2 2kg žoga pospešuje $0{,}25\, m/s^2$

$$\frac{m_1}{m_2} = \frac{a_2}{a_1} \Rightarrow m_1 \cdot a_1 = m_2 \cdot a_2 = F$$

$F = m \cdot a$ Sila je produkt mase in pospeška

2. Newtonov zakon: $\sum \vec{F} = m \cdot \vec{a}$

Če vsota vseh zunanjih sil ni enako 0, je gibanje enakomerno pospešeno.

Za kartezični sistem:

$\sum F_x = m \cdot a_x$

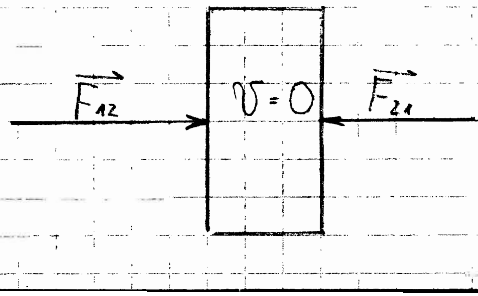
$\sum F_y = m \cdot a_y$

$\sum F_z = m \cdot a_z$

3. Newtonov zakon: AKCIJA = REAKCIJA

Zakon o vzajemnem učinku. Če prvo telo deluje na drugo z neko silo, deluje tudi drugo telo na prvo z nasprotno enako silo

$\vec{F_{12}} = -\vec{F_{21}}$



Ekvilibrij, Ravnovesje: $\sum F = 0 \Rightarrow \vec{a} = 0$

$\vec{v}$ = konstanta

$(\vec{v} = 0)$

Enota sile:

$$F = m \cdot a$$

$$\underbrace{[kg \, m/s^2]}_{[N]} = [kg] \cdot [m/s^2]$$

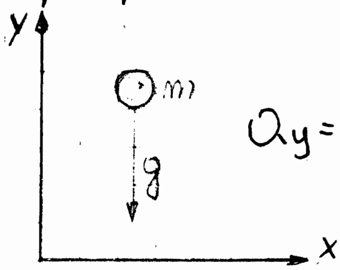
[N] - Newton

1 Newton je sila, ki pospeši 1 kg mase z pospeškom 1 m/s^2

Teža:

$F_g = m \cdot g$; $g = 9{,}81 \, m/s^2$

sila gravitacije



$a_y = -g$

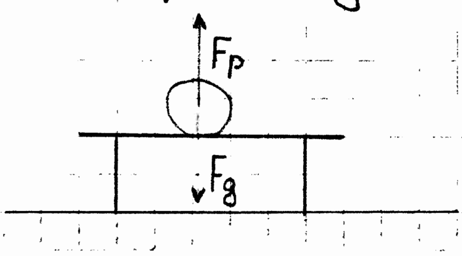
Odvisnost gravitacijske sile od nadmorske višine:

$$F = \gamma \cdot \frac{m \cdot M}{r^2}$$

$$F = \underbrace{\frac{\gamma \cdot M}{r^2}}_{g} \cdot m$$

$$F = m \cdot g$$

Sila podlage:

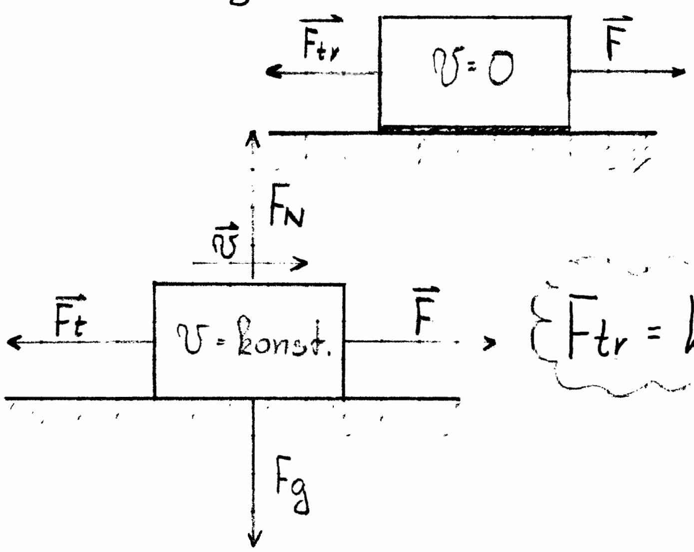


$$\sum_i F_i = 0$$

$$F_p + F_g = 0$$

$$F_p = -F_g$$

Sila trenja:



F_{tr} obstaja, ker $\sum F = 0$

$$\boxed{F_{tr} = k_{tr} \cdot F_N}$$

k_{tr} → koeficient trenja

Zračni upor:

(Mikrodinamski upor)

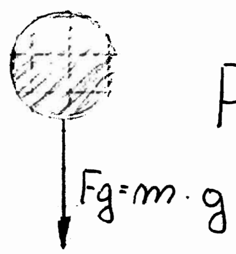
$$\boxed{F_u = \frac{1}{2} C \cdot \rho \cdot S \cdot v^2}$$

$C = 0{,}3$ do 1

S – presek telesa

C – koeficient (zračnega) upora

Končna (Terminalna) hitrost



$$F_g = m \cdot g = \frac{1}{2} C \cdot \rho \cdot S \cdot v^2 \Rightarrow \boxed{v = \sqrt{\frac{2m \cdot g}{C \cdot \rho \cdot S}}}$$

Kinetična energija

$$\boxed{K = \frac{1}{2} m \cdot v^2} \; [J] \qquad 1J = kg \frac{m^2}{s^2}$$

$\Delta K + \Delta U = 0$ → Zakon o ohranitvi energije

Velja za sistem na katerega ne deluje nobena zunanja sila (razen gravitacije)

$\Delta U = m \cdot g \cdot \Delta h$ - potencialna energija

Delo sile trenja $\Delta W_t = F_t \cdot d$ premik

delo trenja, sile trenja

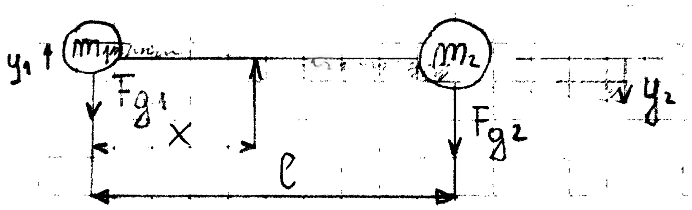
$\Delta K + \Delta U + \Delta E_n = 0$ sprememba notranje energije

Izoliran sistem ohranja energijo (energija se ne izgublja)

Točkasta telesa → sestavljena telesa

TEŽIŠČE

Točka v katero lahko prestavimo vse zunanje sile, pa se bo ta točka še vedno enako gibala



Podobni trikotniki ⇒ $\frac{y_1}{x} = \frac{y_2}{l-x}$

Delo sile teže na prvem telesu: $W_1 = F_{g1} \cdot y_1 = m_1 \cdot g \cdot h_1$

$W_2 = F_{g2} \cdot y_2 = -m_2 \cdot g \cdot h_2$

$W_1 = W_2 \Rightarrow$ ravnovesje

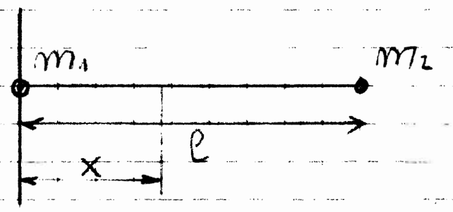
$$m_1 \cdot g \cdot y_1 = -m_2 \cdot g \cdot y_2 \quad / : g$$

$$\left.\begin{aligned} m_1 \cdot y_1 &= -m_2 \cdot y_2 \\ y_2 &= y_1 \cdot \frac{l-x}{x} \end{aligned}\right\} \begin{aligned} &m_1 \cdot y_1 + m_2 \cdot y_2 = 0 \\ &m_1 \cdot y_1 + m_2 \cdot y_1 \cdot \frac{l-x}{x} = 0 \quad / : y \cdot x \end{aligned}$$

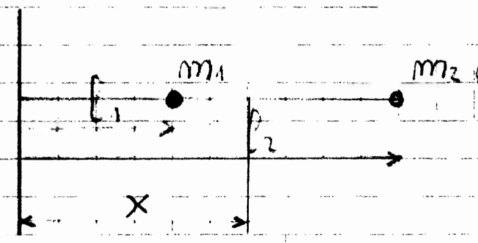
$$m_1 x + m_2 (l-x) = 0$$

$$m_1 x + m_2 l - m_2 x = 0$$

$$(m_1 + m_2)\, x = m_2 l$$



$\Longrightarrow$ težišče : $x = \dfrac{m_2 l}{m_1 + m_2}$



$$x = \frac{m_1 \cdot l_1 + m_2 \cdot l_2}{m_1 + m_2}$$

$$x = \sum_i m_i \cdot l_i \Big/ \underbrace{\sum_i m_i}_{\text{masa celotnega telesa}} \qquad M = \sum m_i$$

2. Newtonov zakon za sistem teles

$$\underbrace{\sum_i F_i}_{\text{vsota vseh zunanjih sil}} = \underbrace{M}_{\text{skupna masa}} \cdot \vec{a}_{tež}$$

pospešek težišča sistema teles

GIBALNA KOLIČINA

$$P \quad \vec{p} = m \cdot \vec{v}$$

2. Newtonov zakon: $\left(\sum F = m \cdot a = m \cdot \frac{dv}{dt}\right.$

$$\sum \vec{F} = \frac{d\vec{p}}{dt}$$

$$\sum F = \frac{d(m \cdot \vec{v})}{dt} = m \cdot \frac{d\vec{v}}{dt} = m \cdot \vec{a}$$

$$\Delta P = F_z \cdot \Delta t$$

Ohranitev gibalne količine

$$\sum_i F_i = 0 \Rightarrow \vec{p} = konst.$$

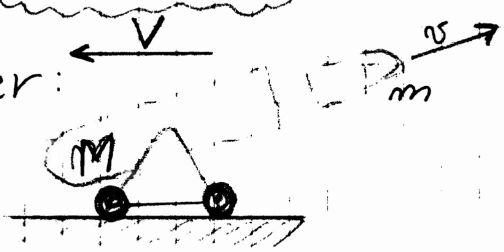
$\Delta P = 0$ => se ohrani

Posplošitev gibalne količine na sistem več delcev: $\vec{P} = \sum_i p_i$ celotna gibalna količina

$$\sum_i F_i = 0 \Rightarrow \vec{P} = konst.$$

$$\vec{P}_{zač} = \vec{P}_{konč}$$

Primer:



$v = 55\,m/s$
$m = 72\,kg$
$M = 1300\,kg$
$V = ?$

$$V_2 = \frac{72\,kg}{1300\,kg} \cdot 55\,m/s = \underline{\underline{3\,m/s}}$$

zač. stanje	končno stanje
$v_1 = 0$	$v_2 = 55\,m/s$
$V_1 = 0$	$V_2 = ?$
$\vec{P}_1 = m \cdot v_1 + M \cdot V_1$	$\vec{P}_2 = m \cdot v_2 - M \cdot V_2$
$\vec{P}_1 = 0$	

$$0 = m \cdot v_2 - M \cdot V_2 \Rightarrow M V_2 = m \cdot v_2 \Rightarrow V_2 = \frac{m}{M} \cdot v_2$$

$\vec{P} = konst \Rightarrow$

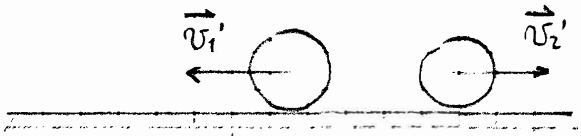
$\vec{P}_1 = \vec{P}_2 = 0$

TRK in ODBOJ

- Elastični trk: (pingpong žogica)
  - energija se ohranja $\Leftarrow$ elastična energija se popolnoma povrne

Začetek: $\vec{P} = m_1 \cdot \vec{v}_1$

konec (po trku)



$$\vec{P} = m_1 \cdot \vec{v}_1{}' + m_2 \cdot \vec{v}_2{}'$$

Iz ohranitve gibalne količine sledi:

skupna enačba

Ohranitev
$$m_1 \cdot \vec{v}_1 = m_1 \cdot \vec{v}_1{}' + m_2 \cdot \vec{v}_2{}'$$

kinetične energije:

začetek: $K = m_1 \cdot \dfrac{v_1^2}{2}$

konec: $K = m_1 \cdot \dfrac{\vec{v}_1{}'^2}{2} + m_2 \dfrac{\vec{v}_2{}'^2}{2}$

$$\Delta K = 0 \Rightarrow K = K'$$

$$m_1 \cdot \frac{v_1^2}{2} = m_1 \frac{v_1'^2}{2} + \frac{v_2'^2}{2}$$

$$v_2' = \frac{m_1 \cdot v_1 - m_1 \cdot v_1'}{m_2}$$

$$m_1 \cdot v_1^2 = m_1 \cdot v_1'^2 + m_2 \frac{(m_1 \cdot v_1 - m_1 \cdot v_1')^2}{m_2^2} = m_1 \cdot v_1'^2 + \frac{m_2}{m_2^2}\left(m_1^2 v_1^2 - 2 m_1^2 v_1 v_1' + m_1^2 \cdot v_1'^2\right)$$

$$m_1 v_1^2 = m_1 \cdot v_1'^2 + \frac{m_1^2}{m_2}\left(v_1^2 - 2 v_1 \cdot v_1' + v_1'^2\right)$$

$v_1' = ?$

$$\left(m_1 + \frac{m_1^2}{m_2}\right) v_1'^2 - 2 \frac{m_1^2}{m_2} v_1 \cdot v_1' + \left(\frac{m_1^2}{m_2} - m_1\right) v_1^2 = 0$$

Primer: $m_1 = m_2 = m \Rightarrow$

$$2 m v_1'^2 - 2m \cdot v_1 \cdot v_1' = 0 \; / :2$$

$$v_1' (m \cdot v_1' - m \cdot v_1) = 0$$

1. $v_1' = 0 \Rightarrow v_2' = v_1$
2. $v_1' = v_1$ // možna če gre ena krogla skozi drugo

Ohranitev gibalne količine: $m_1 \cdot v_1 = m_1 \cdot v_1' + m_2 \cdot v_2'$

-II- kinetične energije: $\frac{1}{2} m_1 v_1^2 = \frac{1}{2} m_1 v_1'^2 + \frac{1}{2} m_2 \cdot v_2'^2 \; / \cdot 2$

$$m_1 (v_1 - v_1') = m_2 \cdot v_2'$$

$$m_1 (v_1^2 - v_1'^2) = m_2 \cdot v_2'^2$$

zdelimo

$$m_1 (v_1 + v_1')(v_1 - v_1') = m_2 \cdot v_2'^2$$

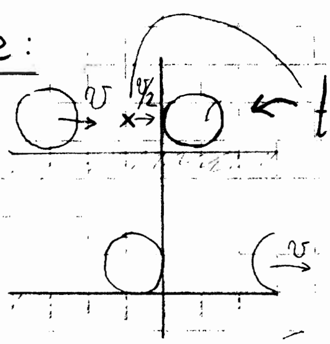
$$v_1 + v_1' = v_2'$$

$$v_1' = \frac{m_1 - m_2}{m_1 + m_2} \cdot v_1$$

$$v_2' = \frac{2 \cdot m_1}{m_1 + m_2} \cdot v_1$$

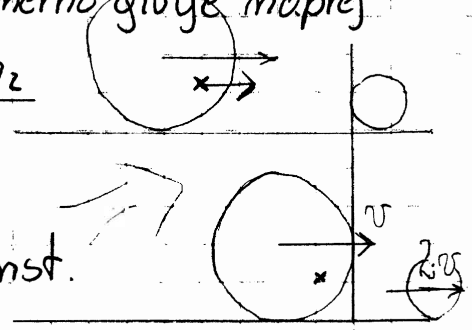
- enake mase:

$v_1' = 0$



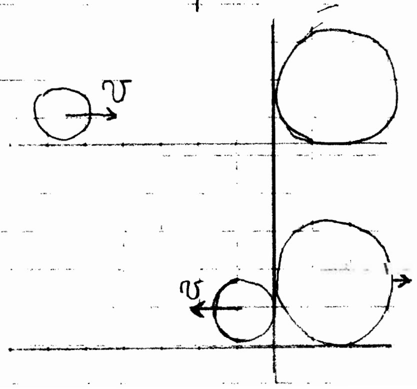
težišče se enakomerno giblje naprej

- $m_1 \gg m_2$

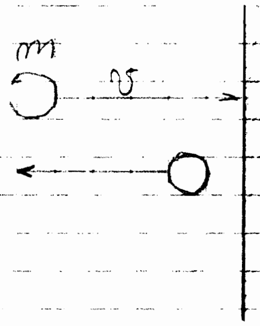


$v_{tež} = konst.$

- $m_2 \gg m_1$



Elastični odboj od stene

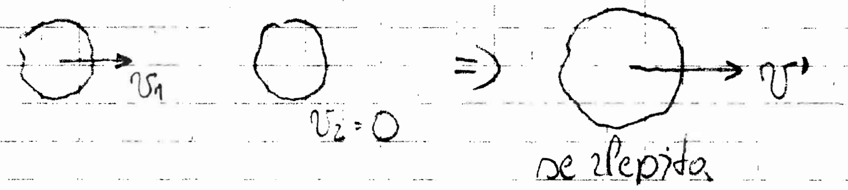


Odboj $M \gg m \Rightarrow \boxed{v' = -v}$ Odbojni zakon

Isto kot da se male krogle zaleti z veliko večjo

- Neelastični trk

$\sum F = 0 \Rightarrow$ ohranja gibalno količino



$$m \cdot v_1 = (m_1 + m_2) \cdot v'$$

$$v' = \frac{m_1 \cdot v_1}{m_1 + m_2}$$

Sprememba kinetične energije:

$$\Delta K = \left(\frac{1}{2} m_1 \cdot v_1^2\right) - \left(\frac{1}{2}\overbrace{(m_1 + m_2)}^{2m} \cdot v'^2\right)$$

če sta enaki

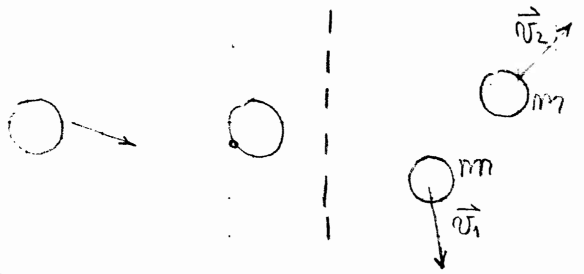
$$= \frac{1}{2} m \left(v_1^2 - 2v'^2\right)$$

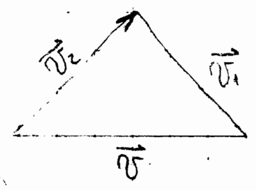
$$= \frac{1}{2} m \left(v_1^2 - \frac{2m^2 \cdot v_1^2}{4m^2}\right) = \frac{1}{4} m v_1^2$$

pol kinetične energije se spremeni v notranjo

$$\boxed{\frac{1}{2} K \Rightarrow W_n}$$

pri vsakem trku je to največ možno





$$\sum F = 0 \Rightarrow \vec{p} = \text{konst}$$

vsota obeh sil je seštevanje vektorjev

začetek : $\vec{p} = m \cdot \vec{v}$

konec : $\vec{p} = m \cdot \vec{v}_1 + m \cdot \vec{v}_2$

GRAVITACIJA

$$F = \varkappa \cdot \frac{m \cdot M}{r^2}$$

gravitacijska konstanta

$$\varkappa = 6{,}67 \cdot 10^{-11}\ Nm^2/kg^2$$

kapa

Zakon blizu zemeljskega površja:

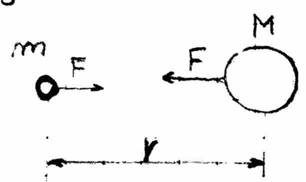
$$r = r_0 + h$$

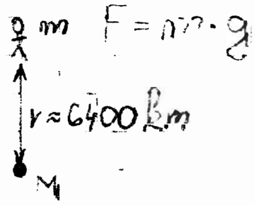
$$F = m \cdot \frac{\varkappa M}{(r_0+h)^2} = m \frac{\varkappa M}{r_0^2\left(1+\frac{h}{r_0}\right)^2} \approx \quad \left(\frac{h}{r_0} \to 0\right)$$

$$= m \cdot \frac{\varkappa M}{r_0^2} = m \cdot g \Rightarrow \boxed{g = \frac{\varkappa M}{r_0^2}}$$

$$g = 9{,}81\ m/s^2$$

Velja za dve točkasti telesi:





V zemeljskem površju:

$r < r_0$

$$F = \varkappa \frac{m \cdot M'}{r^2}$$

$M = \rho \cdot V = \rho \cdot \frac{4}{3}\pi r^3$ masa

$V = \frac{4}{3}\pi r^3$ volumen krogle

$\rho = \frac{M}{V} = \frac{M}{\frac{4}{3}\pi r^3}$ gostota

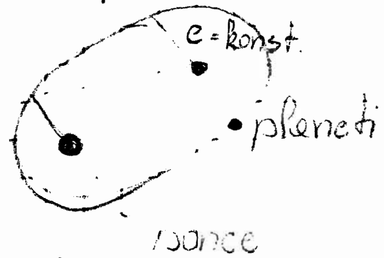
sile znotraj telesa

$$F = \varkappa \frac{m \cdot M'}{r^2} = \varkappa \frac{m \cdot M}{r^2}\left(\frac{r}{r_0}\right)^3 = \varkappa \frac{m \cdot M}{r_0^3} r \qquad M' = M \cdot \left(\frac{r}{r_0}\right)^3$$

KEPLERJEVI ZAKONI

- gibanja planetov

1) Vse orbite planetov so elipse s soncem v enem od gorišč:



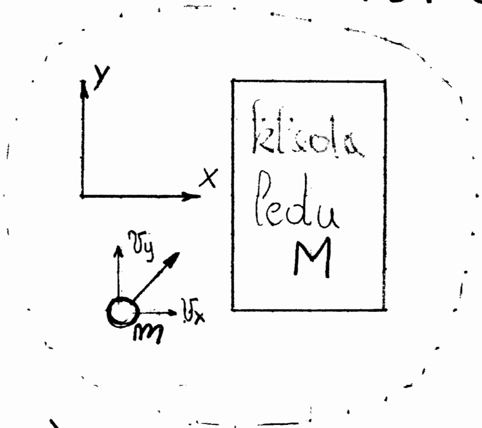
2) Površinska hitrost planetov je konstantna

3) $t_0^2 \propto r^3$ sorazmerni

$$\Rightarrow F = m \cdot a = m \cdot (\overset{\frac{1}{t_0^2}}{\omega^2} r) \qquad \omega = \frac{2\pi}{t_0}$$

$$F = \gamma \cdot \frac{Mm}{r^2} \qquad t_0^2 \propto r^3$$

SISTEM in OKOLICA zunanje in notranje sile



sistem 1) Sistem dve telesi

-> samo notranje sile ob trku

-> $\sum_i F_i = 0$ (zunanjih sil)

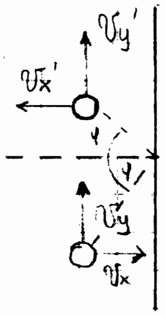
-> ohranitev gibalne količine

1) a) prožen trk , $\Delta K = 0$

-> y komponenta: $\left(\sum_i F_i\right)_y = 0 \Rightarrow P_y = konst.$

-> $v_y' = v_y$

-> x komponenta: trk dveh teles $M \gg m$



-> $v_x' = -v_x$

2) Sistem samo telo m: $\sum_i \vec{F}_i \neq 0$; zun. sile ob trku niso $\emptyset$

$\left(\sum_i \vec{F}_i\right)_y = 0$

Newtonov zakon: $\sum_i \vec{F}_i = \frac{d\vec{p}}{dt} = m \cdot \vec{a} = m \cdot \frac{d\vec{v}}{dt}$

za y komponento: $\frac{dp_y}{dt} = 0 \Rightarrow p_y = konst. \Rightarrow v_y = konst.$

2a) elastičen trk $\Rightarrow \Delta K = 0$

$$\tfrac{1}{2} m v^2 - \tfrac{1}{2} m v'^2 = 0$$

$$\tfrac{1}{2} m \left(v^2 - v'^2\right) = 0$$

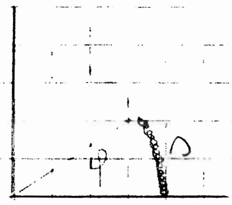
$$v^2 = v'^2$$

$$|v| = |v'|$$

$m \cdot v$ | $2m\left(\frac{v}{2}\right)$ gibanje kolesa

$\frac{1}{2}mv^2$ | $\frac{1}{2}m\left(\frac{v}{\sqrt{2}}\right)^2 + \frac{1}{2}\left(\frac{v}{\sqrt{2}}\right)^2$ - kinetična energija

VRTENJE



ločna dolžina / pot

$s = r \cdot \varphi$

pot = kot · polmer

Polni obrat za 360°

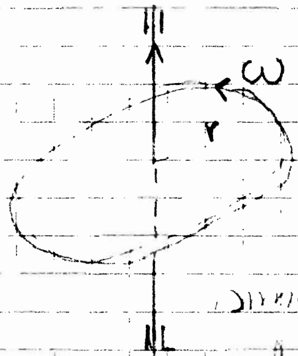
$o = 2\pi r$ (obseg kroga)

$\varphi_{polni} = \frac{o}{r} = 2\pi$ [rad]

Kotna hitrost:

$\overline{\omega} = \frac{\Delta\varphi}{\Delta t}$ - sprememba kota v čas. intervalu

$\omega = \frac{d\varphi}{dt} = \lim_{\Delta t \to 0} \frac{\Delta\varphi}{\Delta t}$



smer je pravilo desne roke

Kotni pospešek:

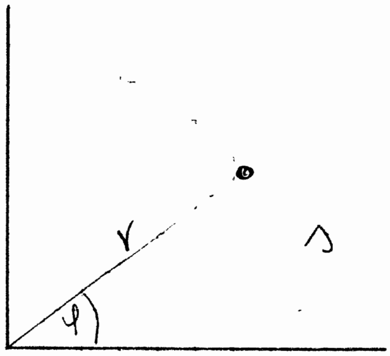
$\overline{\alpha} = \frac{\Delta\omega}{\Delta t}$

$\alpha = \frac{d\omega}{dt} = \frac{d^2\varphi}{dt^2}$

Tabela analogije:

1D gibanje (enakomerno)	Enakomerno pospešeno kroženje
$x = x_0 + v_t + \frac{1}{2}at^2$	$\varphi = \varphi_0 + \omega_t + \frac{1}{2}\alpha \cdot t^2$
$v = v_0 + a \cdot t$	$\omega = \omega_0 + \alpha \cdot t$
$v^2 = v_0^2 + 2a \cdot x$	$\omega^2 = \omega_0^2 + 2\alpha\varphi$

Zveza med kotnimi in kartezičnimi količinami



pot: $s = r\cdot\varphi$

tangentna hitrost: $v_t = \frac{ds}{dt} = \frac{d(r\cdot\varphi)}{dt} = r\cdot\underbrace{\frac{d\varphi}{dt}}_{\omega} = r\cdot\omega$

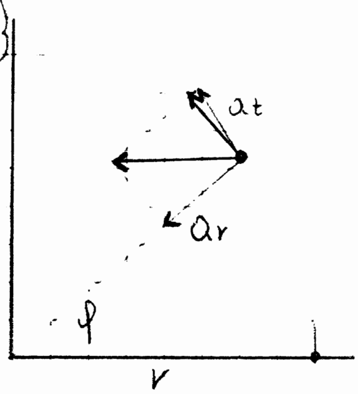
tangentni pospešek: $a_t = \frac{dv_t}{dt} = \frac{d(r\omega)}{dt} = r\cdot\frac{d\omega}{dt} = r\cdot\alpha$

Perioda kroženja: je čas v katerem naredimo en obrat

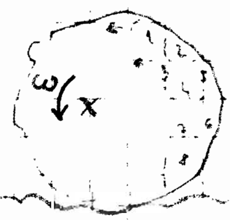
$s = r\cdot\varphi$; $o = 2\pi r$

$\omega = \frac{2\pi}{t_0} \Rightarrow t_0 = \frac{2\pi}{\omega}$

Radialni pospešek:



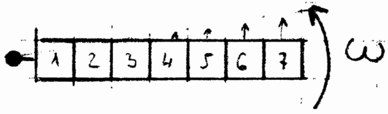
Kinetična energija vrtečih se teles



telo razdelimo na male kose

$K = \frac{1}{2} m_1\cdot v_1 + \frac{1}{2} m_2\cdot v_2 + \frac{1}{2} m_3\cdot v_3 + \dots$

$K = \sum_i \frac{1}{2} m_i\cdot v_i^2$



$v_t = \omega\cdot r$

vsak kos svoje mase se vrti s svojo hitrostjo

$K = \sum_i \frac{1}{2} m_i\cdot v_{ti}^2 =$

$\sum_i \frac{1}{2} m_i (\omega r_i)^2 = \sum_i \frac{1}{2} m_i\cdot\omega^2 r_i^2 = \frac{1}{2}\left(\sum_i m_i\cdot r_i^2\right)\cdot\omega^2$

Vztrajnostni moment se z razdaljo povečuje

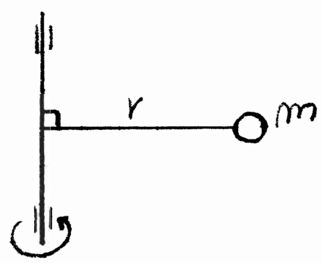
(30) po analogiji z $K = \frac{1}{2} m \cdot v^2$

$$K = \frac{1}{2}\underbrace{\left(\sum_i m_i \cdot r_i^2\right)} \cdot \omega^2$$

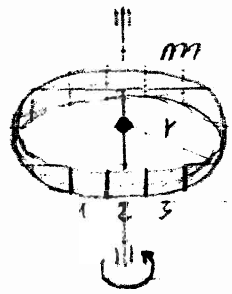
se obnaša

$J = \sum_i m_i \cdot r_i^2$ - vztrajnostni moment

$K = \frac{1}{2} J \cdot \omega^2$ - kinetična energija kroženja (vrtilna)

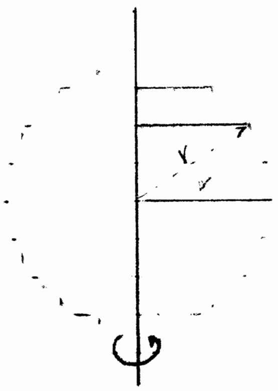


$J = m \cdot r^2$

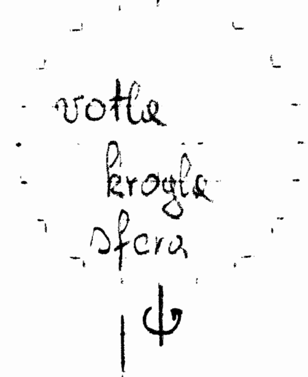


$$J = \sum_i m_i \cdot r^2 = r^2 \cdot \overbrace{\sum_i m_i}^{m}$$

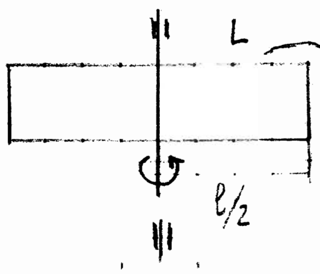
$$J = m \cdot r^2$$



$J = \frac{1}{2} m \cdot r^2$ (vzamemo polovico razdalje največje)



$J = \frac{2}{3} m \cdot r^2$

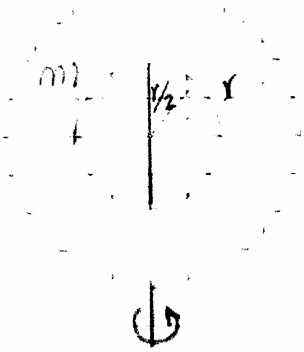


palica

$J = \frac{1}{12} m \cdot L^2$

$J = \frac{1}{3} m \left(\frac{L}{2}\right)^2$

$J = \frac{2}{5} m \cdot r^2$



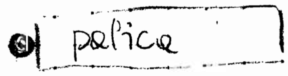
$F = m \cdot a$

$F = (m_1 + m_2) \cdot a$

$$\left.\begin{array}{l} F = M \cdot a \\ F = m_2 \cdot a \end{array}\right\} -$$

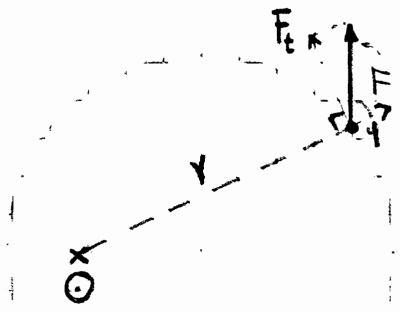
izvotljena krogla

$F = (M - m_1) \cdot a$



$J = \frac{1}{3} m L^2$

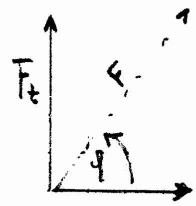
NAVOR



navor

$$\tau = r \cdot F_t$$

$$\tau = r \cdot \sin\varphi$$



$$\vec{\tau} = \vec{r} \times \vec{F}$$ (vektorski produkt)

↳ navor

Newtonova enačba za kroženje

$F_t = m \cdot a_t$ - enačba za tang. komponento

$$\tau = r \cdot F_t = r \cdot m \cdot a_t = r \cdot m \cdot r \cdot \alpha$$

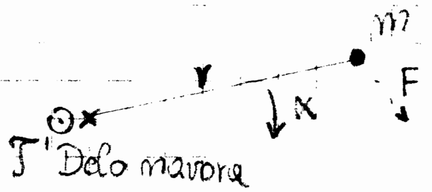
$$\tau = r \cdot m^2 \cdot \alpha$$

$\tau = J \cdot \alpha$ Newtonov zakon za kroženje

Delo navora

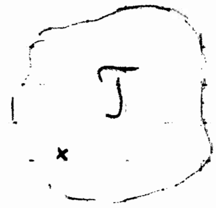
končne začetne

$$\Delta K = K' - K = W$$



$$\Delta K = \tfrac{1}{2} m \cdot r^2 \omega'^2 - \tfrac{1}{2} m \cdot r^2 \omega^2$$

Navor τ pospeši sistem od ω do ω'



$W = F \cdot x$ ena dimenzija

$$\Delta K = \tfrac{1}{2} J \omega'^2 - \tfrac{1}{2} J \omega^2$$

$W = F_t \cdot s = F_t \cdot r \cdot \varphi = \tau \cdot \varphi$ - vrtenje

$\boxed{W = \tau \cdot \varphi}$ Delo je navor krat sprememba kota

Moč navora

$$\overline{P} = \frac{\Delta W}{\Delta t} \qquad P = \frac{dW}{dt} = \frac{d(T\cdot\varphi)}{dt} = T\underbrace{\frac{d\varphi}{dt}}_{\omega} = T\cdot\omega$$

$P = T\cdot\omega$ → analogija na $P = F\cdot v$ (1D)

VRTILNA KOLIČINA

$$\vec{\Gamma} = \vec{r}\times\underbrace{\vec{p}}_{m\cdot\vec{v}} = m\cdot(\vec{r}\times\vec{v})$$

velika gama

$\vec{r}\times\vec{F} = \frac{d\bar{p}}{dt}$ Newtonov zakon za gibanje

$\vec{T} = \frac{d\bar{p}}{dt}$ Newtonov zakon za vrtenje

$$\underset{\vec{T}}{\vec{r}\times\vec{F}} = \vec{r}\times\frac{d\bar{p}}{dt} = \frac{d}{dt}(\vec{r}\times\vec{p})$$

$$\vec{T} = \frac{d\vec{\Gamma}}{dt}$$

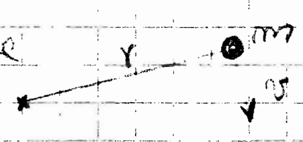
Navor je enak spremembi vrtilne količine na časovno enoto

$\vec{T} = 0 \Rightarrow \vec{\Gamma} = konst.$

zakon o ohranitvi vrtilne količine

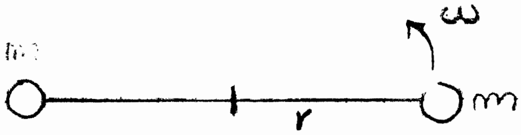
$\vec{\Gamma} = m(\vec{r}\times\vec{v})$

$\Gamma = m\cdot r\cdot v$ – glavne



$\Gamma = mr^2\cdot\omega = J\cdot\omega$

$\Gamma = J\cdot\omega \qquad J = \frac{1}{2}m$



$\Gamma = 2mr^2 \cdot \omega$

$r' = r/10$

$\Gamma' = \Gamma$

$$2mr^2\omega = 2mr'^2\omega'$$

$$2m \cdot r^2 \cdot \omega = 2m\left(\frac{r}{100}\right)^2 \cdot \omega'$$

$$\underline{\omega' = 100\omega}$$

Statično ravnovesje

pogoji:

$\sum_i \vec{F}_i = 0$ ⇒ vsota zunanjih sil = 0

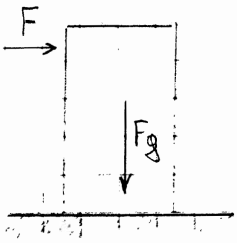
$\sum_i T_i = 0$ ⇒ vsota zunanjih navorov = 0

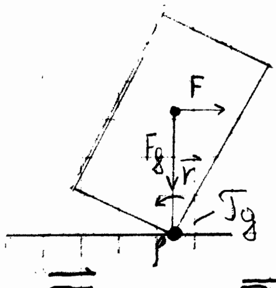
os vrtenja? ⇒ poljubna točka

za katerokoli točko v elementu je enaka 0

⇒ $\vec{\Gamma} = 0$

pogoj



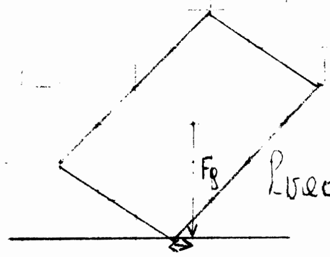


statično ⇒

navor F_g = navor F

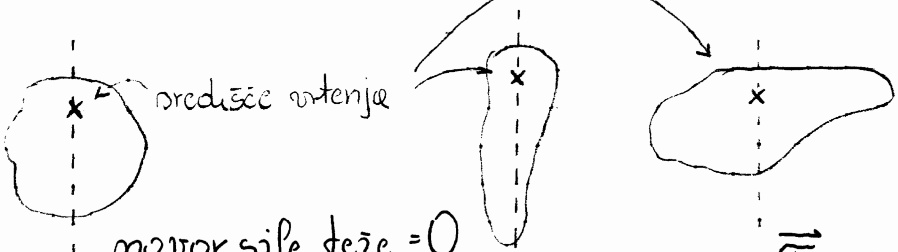
$$\vec{T}_g = \vec{r} \times \vec{F}_g$$

$$T_g = aF_g$$

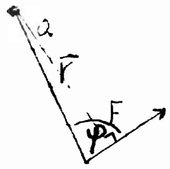


Kvader se prevrne

Težišče visečih teles



navor sile teže = 0
ker je ročica r = 0

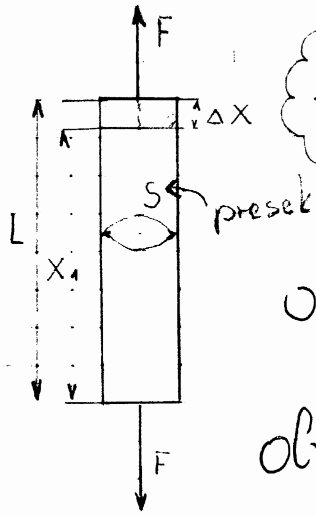


$$\vec{T} = \vec{r} \times \vec{F}$$

$$T = r \cdot F \cdot \sin\varphi = \underbrace{(r \cdot \sin\varphi)}_{\text{ročica}} \cdot F$$

Težišče je vedno pod mestom kjer je telo pripeto.

Elastičnost teles

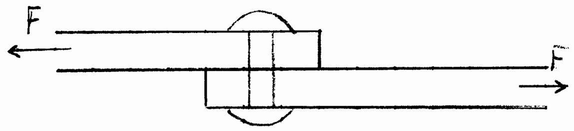


$$\frac{F}{S} = k \frac{\Delta x}{L}$$ ← velja za raztezanje in stiskanje

k – prožnostni modul (linearni raztezek)

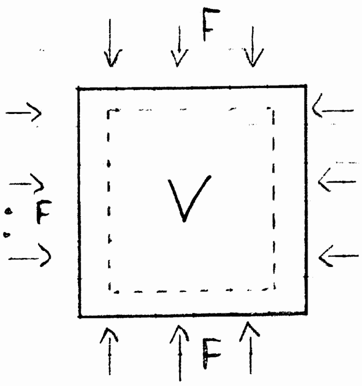
Obremenitev na vlek

Obremenitev na strig:



$$\frac{F}{S} = k_s \cdot \frac{\Delta x}{L}$$

- Raztezanje in stiskanje
- strižne deformacije
- prostorninske deformacije:

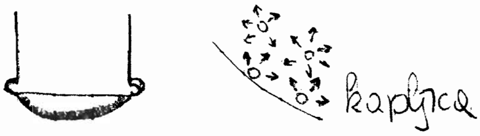


$$p = k_v \frac{\Delta V}{V}$$

k_v – volumski koefici

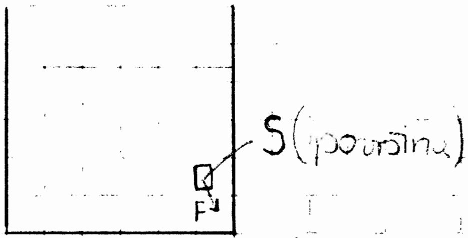
TEKOČINE

- kapljevine in plini



So vse snovi, ki povzamejo obliko posode

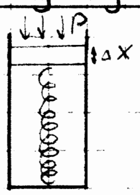
- Gostota: $\rho = \frac{m}{V}$ $[kg/m^3] = [g/cm^3]$



$p = \frac{F}{S}$ $[N/m^2 = Pa]$

$10000\,Pa = 10^5\,Pa = 1\,bar$

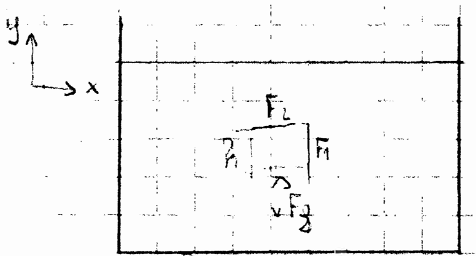
- merjenje tlaka (mehansko)



$\Delta V = \rho \cdot \Delta X$

$p = k \cdot \frac{\Delta V}{\Delta X}$

Tlak v mirujočih tekočinah



$\sum_i \vec{F_i} = 0$ (miruje)

$\sum_i \vec{F_{ix}} = 0$

$p_1 = \frac{F_1}{S}$, $p_2 = \frac{F_2}{S}$

$p_2 \cdot S + F_g = p_1 \cdot S$

$F_g = m \cdot g = \rho \cdot V \cdot g = \rho \cdot S \cdot h \cdot g$

$F_2 + F_g = F_1$

$p_2 \cdot S + \rho \cdot S \cdot h \cdot g = p_1 \cdot S \;/ : S$

$p_1 = p_2 + \rho \cdot g \cdot h$ odvisnost tlaka mirujoče tekočine z globino

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$p_0 = 1\,bar = 10^5\,Pa = 10^5\,N/m^2$

$\boxed{p = p_0 + \rho \cdot g \cdot h}$ za računanje tleke v globinah

• p

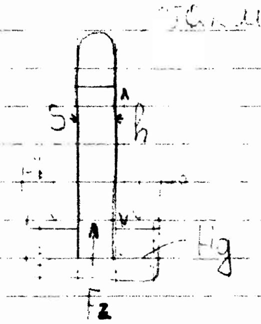
$\rho_{VODE} = 1000\,kg/m^3 = 1\,kg/dm^3$

$\rho_{ZRAKA} = 1{,}2\,kg/dm^3$

$2 \cdot p_0 = p_0 + \rho_r \cdot g \cdot h$

$p_0 = \rho_r \cdot g \cdot h \Rightarrow h = \frac{p_0}{\rho_r \cdot g} = \frac{10^5\,N\,m^3\,s^2}{10^3 \cdot 10\,m\,m^2} =$

$h = 10\,\frac{kg\,m\,m^3\,s^2}{s^2\,kg\,m\,m^2} = \underline{\underline{10\,m}}$



$p_0 = \rho_{Hg} \cdot g \cdot h$

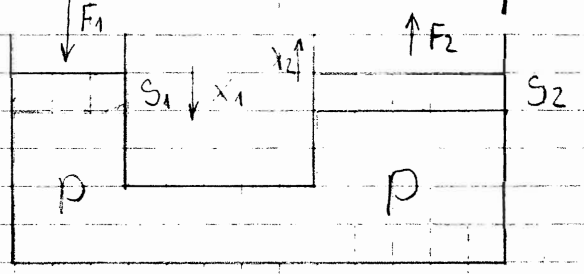
$F_z = p_0 \cdot S = F_{g_{Hg}} = m \cdot g = \rho_{Hg} \cdot S \cdot h \cdot g \Rightarrow p_0 = \rho_{Hg} \cdot g \cdot h \Rightarrow$

$\rho_{Hg} = 13{,}6\,t/m^3$

$\frac{h}{p_0} = \frac{1}{\rho_{Hg} \cdot g} = \frac{m^3\,s^2}{13{,}6 \cdot 10^3\,kg\;10\,m} = \frac{1}{1{,}3 \cdot 10^5} \approx \underline{\underline{10^{-5}\,m/Pa}}$

$1\,mm\,Hg = 1\,Torr$

Hidravlični prenos sil



$\boxed{F_2 = F_1 \cdot \frac{S_2}{S_1}}$

$\boxed{x_2 = x_1 \cdot \frac{S_1}{S_2}}$

$\frac{F_1}{S_1} = \frac{F_2}{S_2}$

$V = V$

$S_1 \cdot x_1 = S_2 \cdot x_2$

$W = F \cdot x$

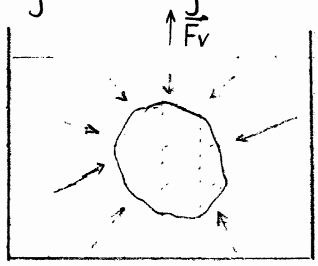
delo na obeh straneh

$F_1 \cdot x_1 \,,\; F_2 \cdot x_2 = F_1 \cdot \frac{S_2}{S_1} \cdot x_1 \cdot \frac{S_1}{S_2} = F_1 \cdot x_1$

Delo je enako na obeh straneh (isto)

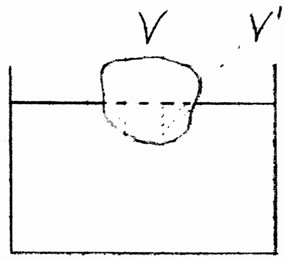
Arhimedov princip - eureka (vzgon)

Telo je lažje za težo izpodrinjene tekočine.



vzgon: $\boxed{F_v = \rho_v \cdot V \cdot g}$

Predmet lažji od vode:



$\rho \cdot V \cdot g = \rho_v \cdot V_v \cdot g$

$\boxed{\rho \cdot V = \rho_v \cdot V_v}$

$\rho_{LEDU} = 0{,}91\ kg/cm^3$

NIHANJE

1 Herz = 1 nihaj na sekundo $[s^{-1}, 1/s]$

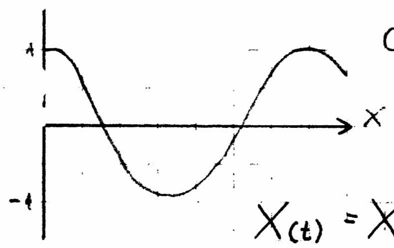
Perioda $T = \frac{1}{f}$ $[s]$ $\boxed{T = 2\pi\sqrt{\frac{m}{k}}}$

frekvenca $f = \frac{1}{T}$ $[s^{-1}, 1/s]$ $\boxed{f = \frac{1}{2\pi}\sqrt{\frac{k}{m}}}$ večji ko je k večja je frekvenca

$\boxed{\omega' = \omega_0 \cdot \varphi \cdot l}$ - hitrost pri kotu φ

inercija (večja ko je m manjša bo f)

Harmonično nihanje



odmik po eni periodi:

$X_{(t)} = X_0 \cdot \cos\underbrace{(\omega t + \varphi)}_{\text{faza}}$

$t,\ t+T$

$t: x_0 \cdot \cos(\omega t + \varphi)$

$t+T: x_0 \cdot \cos(\omega(t+T) + \varphi)$

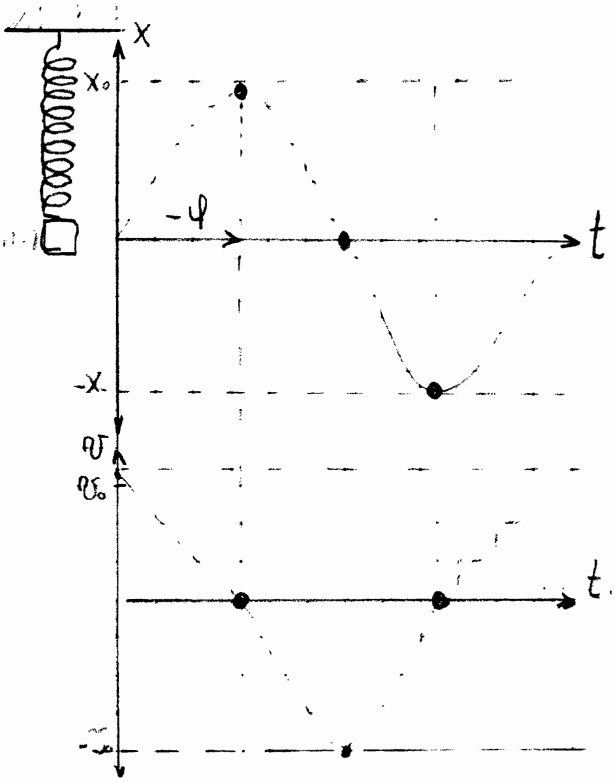
$\omega t + \varphi = \omega(t+T) + \varphi \pm 2\pi$ "360°"

$\omega T = 2\pi$

$\boxed{F = -k \cdot x}$ $\omega = \frac{2\pi}{T}$ $\boxed{\omega = 2\pi f}$ kotna hitrost

- hitrost $v(t) = \frac{dx}{dt}$

$$v(t) = \underbrace{-x_0 \cdot \omega}_{v_0 \text{ amplituda hitrosti}} \cdot \sin(\omega t + \varphi)$$



- pospešek: $a = \frac{dv}{dt}$ $a(t) = -x_0 \cdot \omega^2 \cdot \cos(\omega t + \varphi)$

na prejšnji strani

Newt. zakon: $F = m \cdot a = -m \cdot x_0 \cdot \omega^2 \cdot \cos(\omega t + \varphi) = -m \cdot \omega^2 \cdot x$

$$F = -m \cdot \omega^2 \cdot x$$

Za elastične deformacije vemo: $F = -k \cdot x \Rightarrow m \cdot \omega^2 = k$

$$\omega^2 = \frac{k}{m} \Rightarrow \omega = \sqrt{\frac{k}{m}}$$

$$\omega = 2\pi \cdot f \Rightarrow f = \frac{1}{2\pi}\sqrt{\frac{k}{m}}$$

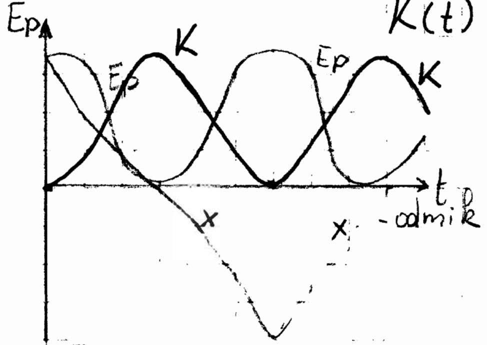
Energija nihanja

prožnostna energija: $\boxed{E_p = \frac{1}{2} k x^2}$; $F = k \cdot x$

$$E_{p(t)} = \frac{1}{2} k x^2_{(t)} = \frac{1}{2} k x_0^2 \cos^2(\omega t + \varphi)$$

kinetična energija: $\boxed{K = \frac{1}{2} m \cdot v^2}$

$$K_{(t)} = \frac{1}{2} m \cdot v^2_{(t)} = \frac{1}{2} m \cdot x_0^2 \cdot \omega^2 \cdot \sin^2(\omega t + \varphi)$$



celotna energija:

$$E = E_p + K = \frac{1}{2} \overset{m\cdot\omega^2}{k} x_0^2 \cos^2(\omega t + \varphi) + \frac{1}{2} m x_0^2 \omega^2 \sin^2(\omega t + \varphi)$$

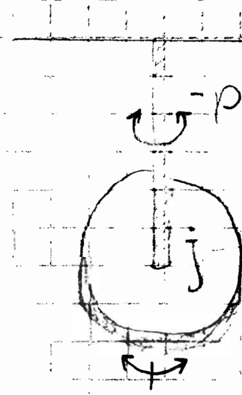
$$= \frac{1}{2} m x_0^2 \omega^2 \underbrace{\left(\cos^2(\omega t + \varphi) + \sin^2(\omega t + \varphi)\right)}_{1}$$

$$\boxed{E = \frac{1}{2} m \cdot \omega^2 \cdot x_0^2}$$

celotna energija se ohranja $\quad E = \frac{1}{2} k \cdot x_0^2 \quad E = \frac{1}{2} m \cdot v_0^2$

Energija se iz prožnostne pretaka v kinetično in nazaj.

Torzijsko nihanje



- palica iz vzmetnega jekla

vztrajnostni moment

kakšna je povezava med navorom in kotom φ?

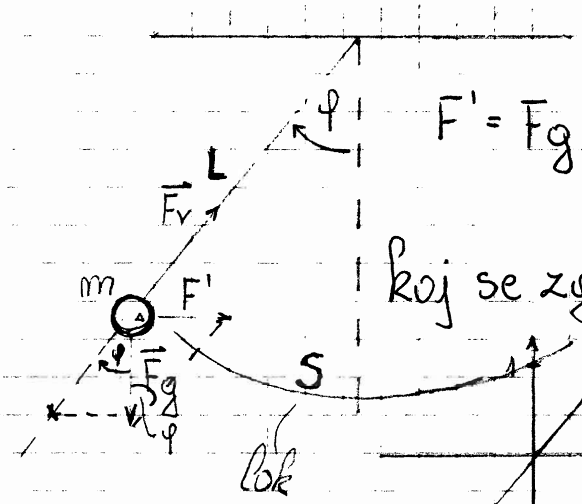
$$\boxed{T = -k \cdot \varphi}$$

- zakon za torzijo

$$\boxed{f = \frac{1}{2\pi} \sqrt{\frac{K}{J}}}$$

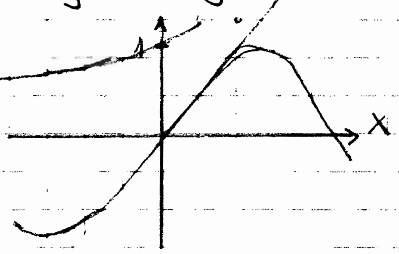
1D gibanje	vrtenje
F	T
x	φ
v	ω
a	α
m	J

Matematično nihalo



$F' = F_g \cdot \sin\varphi = \boxed{m \cdot g \cdot \sin\varphi}$ "Hookov zakon"

kaj se zgodi za majhne odmike (kote): $\varphi \ll 1$



linearni približek

$\sin\varphi \approx \varphi$

$F' \approx m \cdot g \cdot \varphi \qquad S = L \cdot \varphi = \varphi = \frac{S}{L}$

$\boxed{F'' \approx m \cdot g \cdot \frac{S}{L}}$ – linearizirani Hookov zakon

Hookov zakon

primerjamo z $F = k \cdot x \Rightarrow k = \frac{m \cdot g}{L}$

$f = \frac{1}{2\pi}\sqrt{\frac{k}{m}} = \frac{1}{2\pi}\sqrt{\frac{m \cdot g}{L \cdot m}} = \frac{1}{2\pi} \cdot \sqrt{\frac{g}{L}} \qquad \boxed{f = \frac{1}{2\pi}\sqrt{\frac{g}{L}}}$

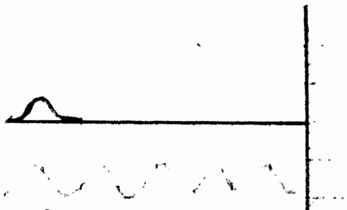
$T = 2\pi\sqrt{\frac{L}{g}} \Rightarrow T^2 = 4\pi^2 \frac{L}{g} \Rightarrow \boxed{g = 4\pi^2 \frac{L}{T^2}}$

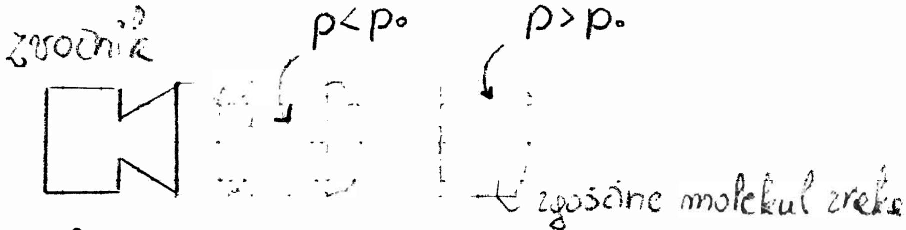
$\frac{L = 1\,m}{T = ?}$

$T = 2\pi\sqrt{\frac{1\,m\,s^2}{10\,m}} = \frac{2\pi}{\sqrt{10}}\,s = \underline{\underline{1{,}98\,s}}$

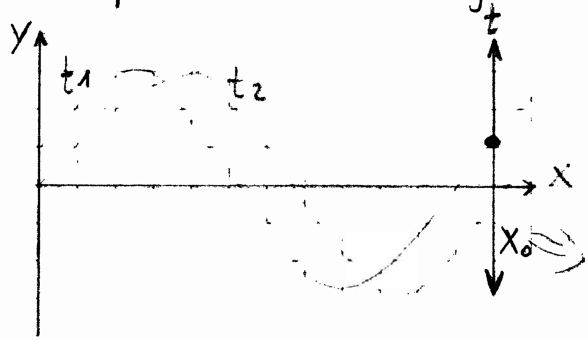
Nihanje je periodično spreminjanje količine (gibanje)

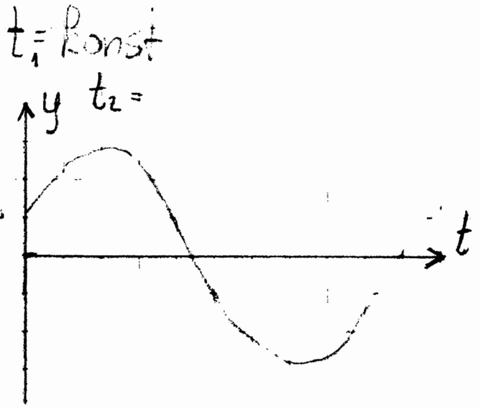
VALOVANJE





transferzalno valovanje   longitudinalno valovanje

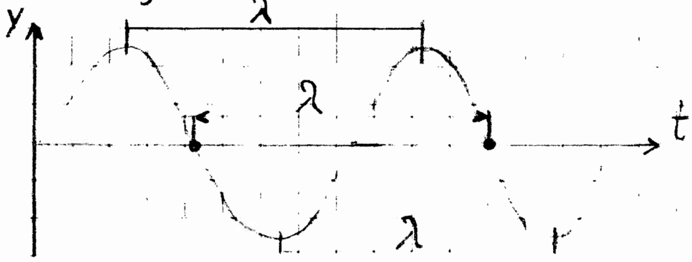




$$y = y_0 \cdot \sin(kx - \omega t)$$

valovanje, ki se razširja na desno

valovna dolžina :



- faza ob t: $kx + \omega t$ v neki točki x_0

- faza t v točki $x_0 + \lambda$: $k(x_0 + \lambda) - \omega t$

- razlika faze $\pm 2\pi$: $kx_0 - \omega t = k \cdot (x_0 + \lambda) - \omega t \pm 2\pi$

$$= kx_0 + k\lambda - \omega t \pm 2\pi$$

$$\Downarrow$$

$$k \cdot \lambda = 2\pi \qquad k = \frac{2\pi}{\lambda}$$

valovno število

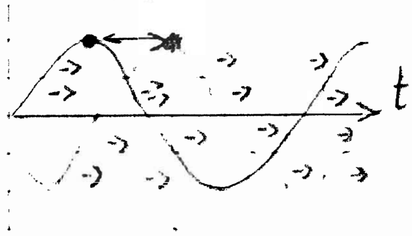
- faza v točki x_0 za t : $kx_0 - \omega t$

- faza v točki x_0 za $t + T$: $kx_0 - \omega(t + T)$

$\Rightarrow$ - razlike $\pm 2\pi$

$$\omega T = 2\pi \qquad \omega = \frac{2\pi}{T}$$

Hitrost:



$$y = y_0 \cdot \sin(kx - \omega t)$$

$$kx - \omega t = \text{konst.}$$

$$kx - \omega t \;\Big|\; \frac{d}{dt} \quad \text{(odvajamo)}$$

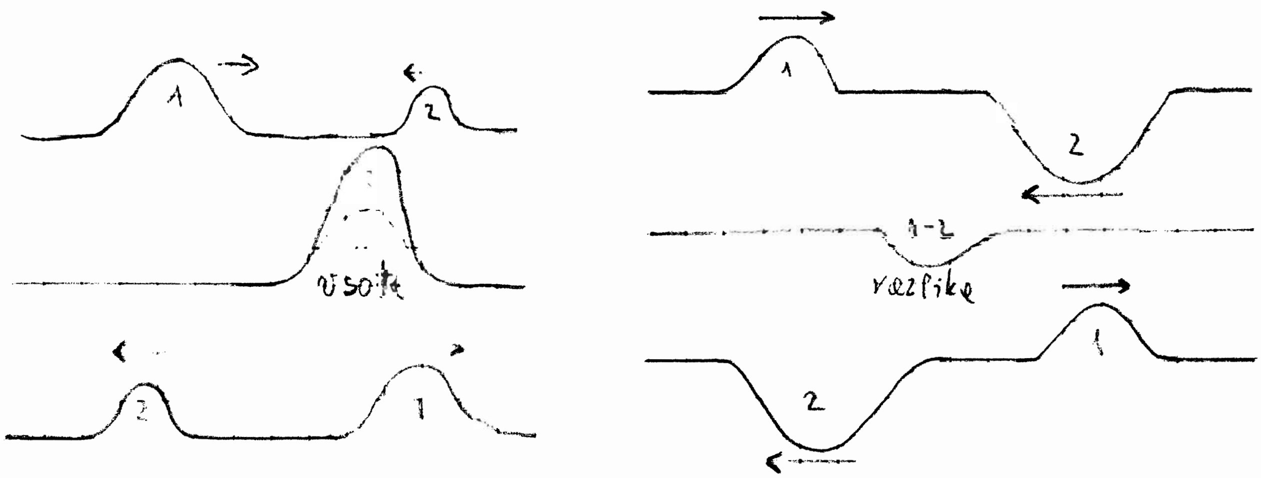
$$\left.\begin{aligned} k\frac{dx}{dt} - \omega &= 0 \\ \frac{dx}{dt} &= v \end{aligned}\right\} \quad k \cdot v = \omega \qquad v = \frac{\lambda}{2\pi} \cdot \frac{2\pi}{T}$$

$$v = \frac{\omega}{k} \qquad v = \frac{\lambda}{T} \qquad v = \lambda \cdot f$$

fazna hitrost valovanja

Princip superpozicije nihanja in valovanja

- Prekrivajoča valovanja si ne spreminjajo ne smeri, ne frekvence in ne hitrosti razširjanja
- Če se seštevata dve valovanji: $y(t) = y_1(t) + y_2(t)$



Interferenca valovanj

$$y_1(t) = y_0 \cdot \sin(kx - \omega t)$$

$$y_2(t) = y_0 \cdot \sin(kx - \omega t + \varphi)$$

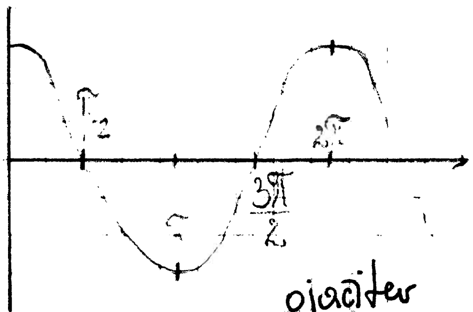
princip superpozicije: $y(t) = y_1(t) + y_2(t)$

$$y(t) = y_0\left[\sin(kx-\omega t) + \sin(kx-\omega t+\varphi)\right]$$

$$\sin\alpha + \sin\beta = 2\cdot\sin\tfrac{1}{2}(\alpha+\beta)\cdot\cos\tfrac{1}{2}(\alpha-\beta)$$

$$y(t) = 2y_0\ \sin(kx-\omega t+\tfrac{1}{2}\varphi)\cdot\cos\tfrac{\varphi}{2}$$

$$= \left[2y_0\cos\tfrac{\varphi}{2}\right]\sin(kx-\omega t+\tfrac{1}{2}\varphi)$$



(konstruktivna interferenca)

-> $y = 0 \Rightarrow$ amplituda $2y_0$

oslabitev

-> $\frac{\varphi}{2} = \frac{\pi}{2} \Rightarrow \cos\frac{\varphi}{2} = 0$ $(\varphi = \pi)$

(destruktivna interferenca)

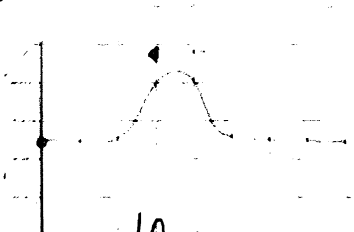
ojačitev

-> $\frac{\varphi}{2} = \pi \Rightarrow \boxed{\varphi = 2\pi}$, $\cos\frac{\varphi}{2} = -1$ (valovi obrnejo $\cap \to \cup$)

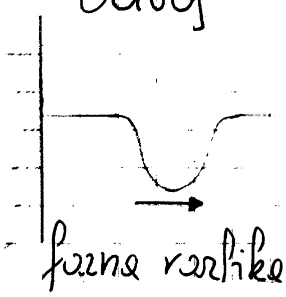
(konstruktivna interferenca

-> $\frac{\varphi}{2} = \frac{3\pi}{2} \Rightarrow \varphi = 3\pi$, $\cos\frac{\varphi}{2} = 0$ (destr. interferenca)

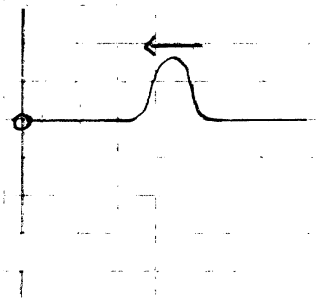
- se menjata konstruktivna in destruktivna interferenca

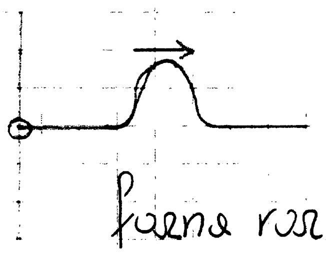


odboj

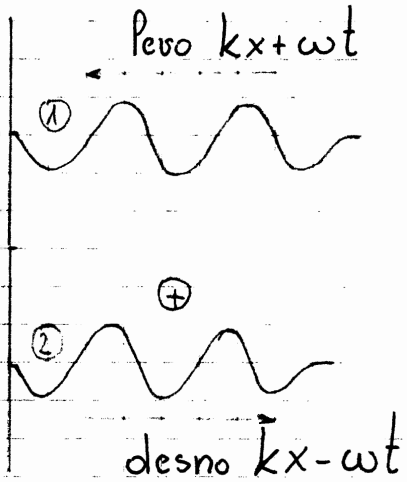


fazna razlika $\varphi = \pi$





fazna razlika $\varphi = 0$

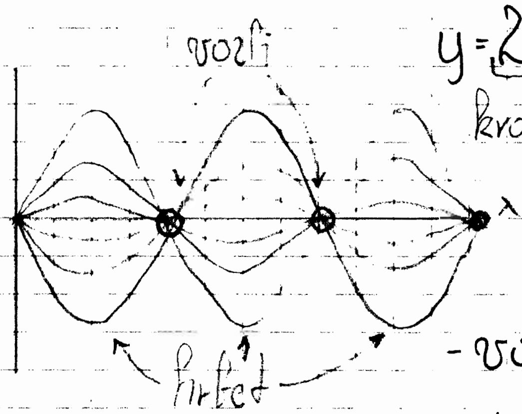


$$y_1(t) = y_0 \sin(kx+\omega t)$$

$$y_2(t) = y_0 \sin(kx-\omega t)$$

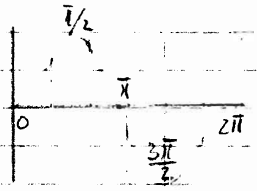
$$y = y_1 + y_2$$

$$\sin\alpha + \sin\beta = 2\sin\tfrac{1}{2}(\alpha+\beta)\cos\tfrac{1}{2}(\alpha-\beta)$$



$$y = \underbrace{2y_0 \sin kx}_{\text{krajevno odvisna amplituda nihanja}} \cdot \cos\omega t$$

- vozli: ničle $\sin kx$



$$kx = n\cdot\pi \quad ; \quad n = 1, 2, 3, \ldots 0$$

$$k = \frac{2\pi}{\lambda}$$

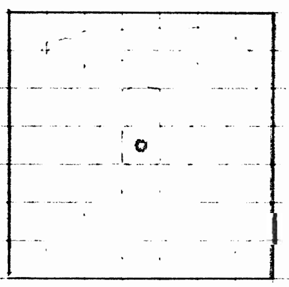
vozli: $x = \dfrac{n\cdot\lambda}{2}$

- vozli: max $\sin kx$

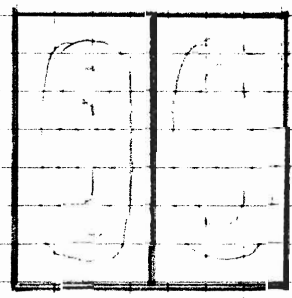
$$kx = (n+\tfrac{1}{2})\pi$$

$$\frac{2\pi x}{\lambda} = (n+\tfrac{1}{2})\pi \Rightarrow x = (n+\tfrac{1}{2})\frac{\lambda}{2} \Rightarrow \text{hrbet}$$

valovanje:

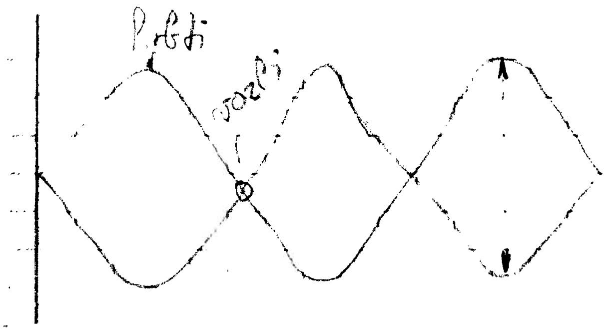


$$v = \lambda \cdot f$$



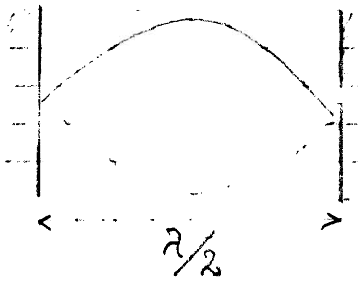
vozelne črte

Stoječe valovanje in resonanca



Vozli se pojavijo pri razdalji:

$$x = \frac{n\cdot\lambda}{2} = n\cdot\frac{v\cdot T}{2} = n\cdot\frac{v}{2f}$$



Prva osnovna frekvenca nam daje nižino tona

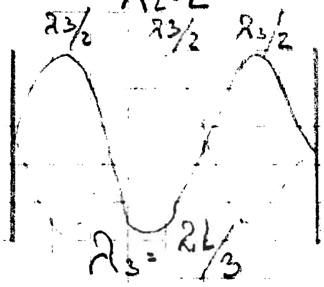
$$\lambda = 2\cdot L$$

$$\lambda\cdot f = v \Rightarrow f = \frac{v}{\lambda} = \frac{v}{2L}$$ - prva lastna frekvenca strune

Druga osnovna frekvenca

$$f_2 = v/L = 2\cdot f_1$$

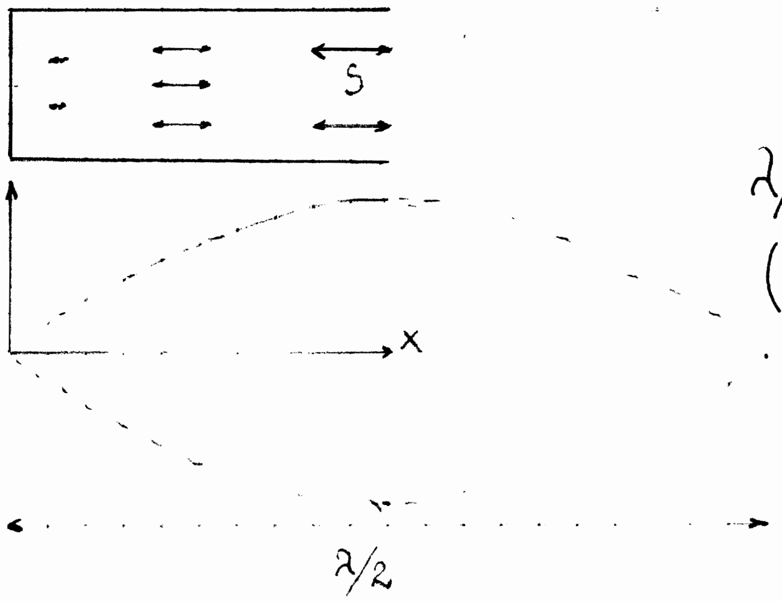
$\lambda_2 = L$



Tretja osnovna frekvenca nam daje barvo tona

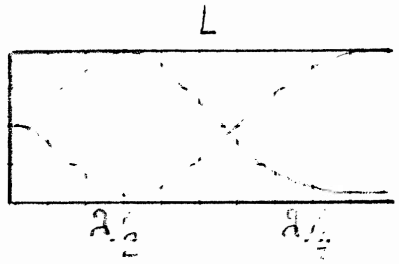
$f_3 = 3\cdot f_1$ $\qquad \lambda_3 = \frac{2L}{3}$

$$\boxed{\lambda_n = \frac{2L}{n}} \qquad \boxed{f_n = n\cdot f_1}$$



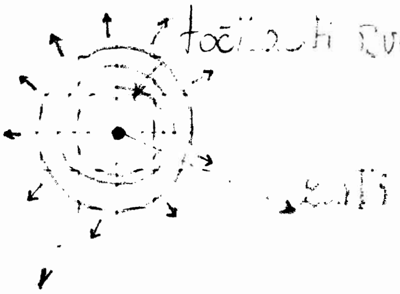
$\lambda/4 = L \Rightarrow \lambda = 4 \cdot L$

(Lastna valovna dolžina polodprte cevi)



$$\frac{3\lambda_2}{4} = L \Rightarrow \lambda_2 = \frac{4L}{3} \;;\; f_2 = \frac{v}{\lambda_2} = \frac{3v}{4L}$$

Zvok (Nihanje zraka)



Zvok se razširja pravokotno na žarke

$$v = \sqrt{\frac{\text{elastičnost}}{\text{inercija}}}$$

V primeru zvoka: $\sqrt{\frac{\mathcal{H}}{\rho}}$ ← kapa (stisljivost zraka); ← gostota zraka

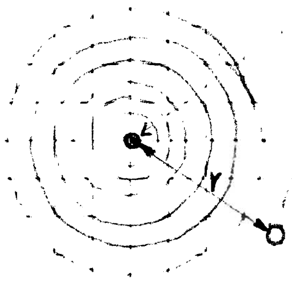
$$\Delta p = \mathcal{H} \frac{\Delta V}{V}$$

Tipične hitrosti:

		m/s
- aluminij		6420
- železo		5941
- granit		6000
- zrak pri	0°C	331
- zrak	20°C	343
- helij		965
- voda	0°C	1402
- voda	20°C	1482
- vodik		1284
- morska voda		1522

JAKOST zvoka

Točkast izvor P_{iz}



detektor zvoka

Jakost: $I = \dfrac{P_{iz}}{4\pi r^2}$

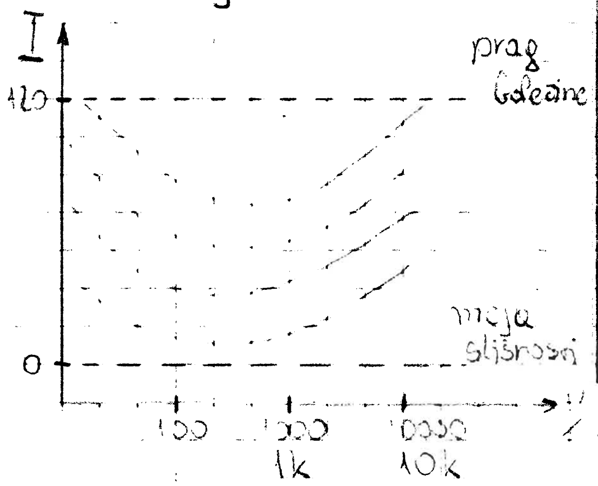
površina sfere z radijem r

$\beta = 10 \cdot \log \dfrac{I}{I_0}$ [db]

$I_0 = 10^{-12}\ W/m^2$

Tabela jakosti zvoka:

	[db]
- meja slišnosti	0
- šumenje listja	10
- pogovor	60
- rock koncert	110
- meja bolečine	120
- reaktivni motor	130



Percepcija jakosti zvoka

Občutek jakosti zvoka se poveča za 10 decibelov, če se jakost zvoka poveča za desetkrat.

Utripanje

kalibrirani izvor: $s_1 = s_0 \cdot \cos \omega_1 t$

$$s_2 = s_0 \cdot \cos \omega_2 \cdot t \quad \text{- inštrument}$$

$$s(t) = s_1 + s_2 = s_0 (\cos \omega_1 t + \cos \omega_2 t)$$

$$\cos \alpha + \cos \beta = 2 \cdot \cos \frac{\omega_1 + \omega_2}{2} t \cdot \cos \frac{\omega_1 - \omega_2}{2} \cdot t$$

$$\omega_2 = \omega_1 + \Delta\omega \qquad \Delta\omega \ll \omega_1$$

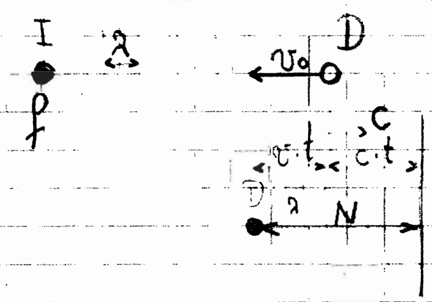
$$s(t) = 2 s_0 \cdot \cos(\omega_1 + \Delta\omega/2) \cdot t \cdot \cos(\Delta\omega/2 \cdot t)$$

$$s(t) = 2 \cdot s_0 \cdot \underbrace{\cos \Delta\omega/2 \cdot t}_{\text{modulacija "utripanje"}} \cdot \cos \underbrace{(\omega_1 + \Delta\omega/2)}_{\underbrace{\approx \omega_1}_{x \cdot \cos \omega_1 t}} \cdot t$$

To se uporablja za uglaševanje instrumentov

Dopplerjev efekt

1. fiksen izvor



$t = 0$

$$N = \frac{c \cdot t + v \cdot t}{\lambda}$$

$$f' = \frac{N}{t} = \frac{c + v}{\lambda} =$$

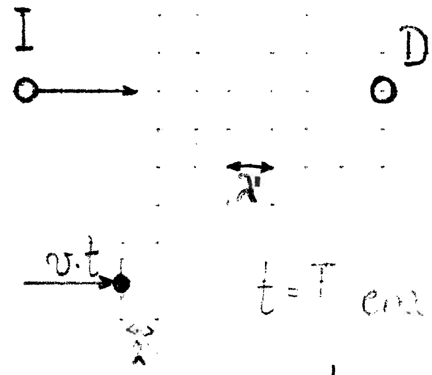
$\lambda \cdot f = c$ (valovanje) $\quad f' = f \cdot \frac{c+v}{c}$

Dopplerjev pojav za premikajoč sprejem (pozitiven pomeni gibanje proti izvoru. frekvenca se zniža

če pa se gibaš od izvora $f' = f \cdot \frac{c - v}{c}$ in se f zviša

$\nu' = \nu$.

2. Izvor se giblje



$t = 0$

$t = T$ ena perioda

$$\lambda' = c \cdot T - v \cdot T$$

$$\lambda' = (c - v) \cdot T = \frac{c - v}{f}$$

ob času t : $N = \frac{c \cdot t}{\lambda'} = \frac{c \cdot t}{c - v} \cdot f$

$$f' = \frac{N}{t} = f \frac{c}{c - v}$$

$$f' = f \frac{c}{c - v}$$

gibajoč izvor (pozitivna v izvora gibanje proti sprejemu zvoka)

Če pa se izvor oddaljuje: $f' = f \frac{c}{c + v}$ ✓

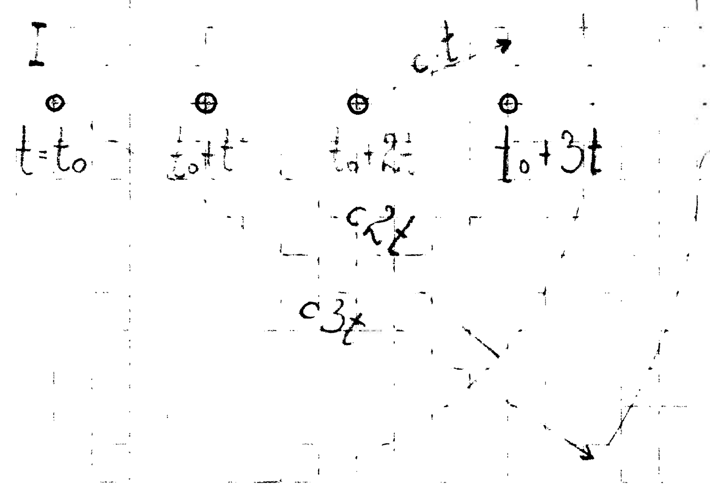
$$f' = f \frac{c + v_D}{c - v_i}$$

hkratno gibanje v isto smer

I $\xrightarrow{v_i}$ $\qquad$ $\xrightarrow{v}$ $\qquad v_D = -v_i$

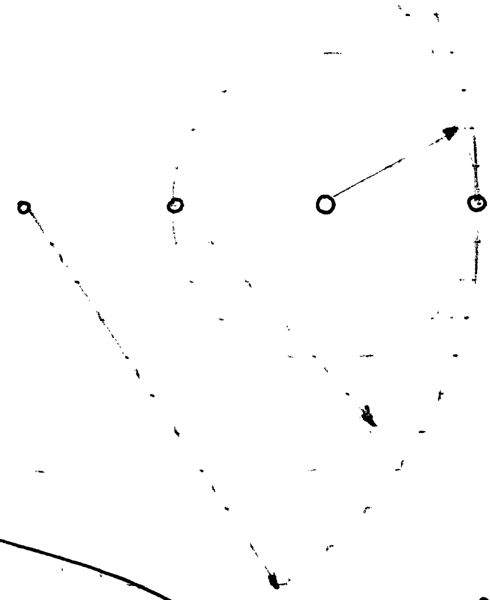
$$f' = f \cdot \frac{c - v_i}{c - v_i} = f$$

v 3D prostoru:



slika fronte

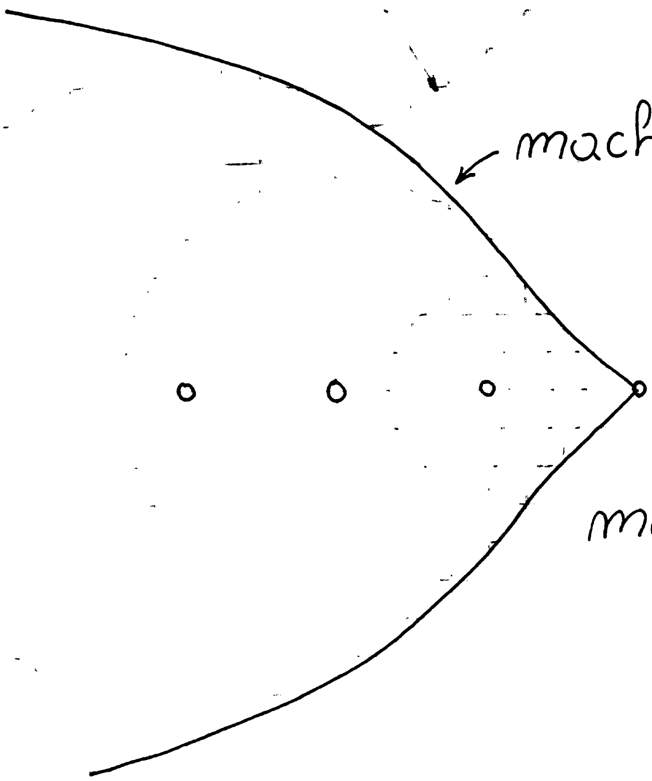
zahitrost manjšo od zvočne $v < c$



trenutna

$v = c$

izvor se giblje s hitrostjo zvoka



machovo čelo

$v > c$ izvor se giblje s hitrostjo večjo od zvoka

machovo število $= \frac{v}{c}$

za svetlobo pa velja: $z = \frac{\lambda' - \lambda}{\lambda}$

λ' - izmerjena valovna dolžina

λ - prava (izsevana)

rdeči premik

Termodinamika

- Temperaturo teles bomo spremljali s Kelvinovo temperaturno skalo.

- Temperatura nima zgornje meje, ima pa spodnjo mejo imenovano "absolutna ničla"

K

10^{30} vesolje tik po nastanku

10^{8} najvišja temperatura dosežena v laboratoriju

10^{4} površina sonca 6500 K

tališče volframa

10^{2} voda zmrzuje

10^{0} vesolje sedaj

10^{-9} Jedrsko spinsko ohlajevanje

Ničelni zakon termodinamike

- Lastnosti snovi so odvisne od temperature: (gostota, agregatno stanje, volumen, dolžina, upornost, tlak zaprtega plina)
- Te lastnosti uporabljamo za izdelavo termometrov
- Termično ravnovesje med termometrom in merjenim telesom

Osnovni zakon termodinamike: če je telo T v termičnem ravnovesju s telesom A in telo T v termičnem ravnovesju z B iz tega sledi, da je telo A v termičnem ravnovesju z B.

$$T \xleftrightarrow{rav} A \quad \text{in} \quad T \xleftrightarrow{rav} B \Rightarrow A \xleftrightarrow{rav} B$$

Merjenje temperature

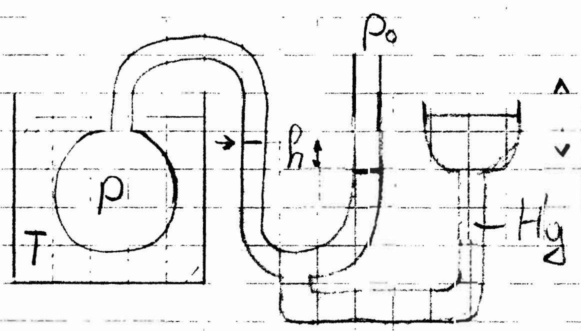
Temperaturna skala mora zadoščati:

- potrebujemo ponovljiv naravni pojav
- tališče ledu, vrelišče vode je preveč odvisno od tlaka
- <u>trojna točka vode</u> obstaja točka vode pri natančno eni vrednosti zunanjega tlaka, kjer imamo vsa tri agregatna stanja.

Po SI standardu: $T_3 = 273,16\,K$.

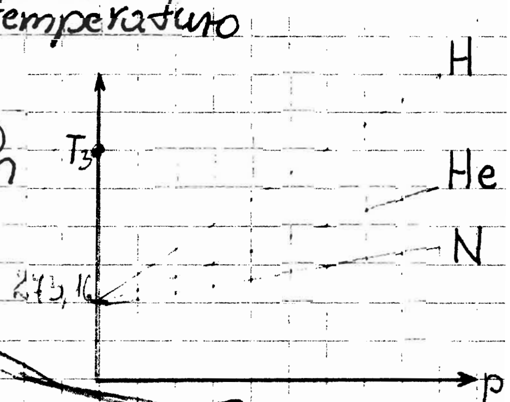
- Vrednost je izbrana tako, da je širina Kelvinove stopinje enake celzijevi
- Skupaj z absolutno ničlo dobimo celotno skalo

Plinski termometer s konstantno temperaturo



$$p = p_0 + \rho \cdot g \cdot h$$

Def: $T = C \cdot p$



Definicija je zelo malo odvisna od izbire plina.

$$T_3 = C \cdot p_3$$

$$T = T_3 \left(\frac{p}{p_3}\right)$$

Definicija Kelvinove skale:

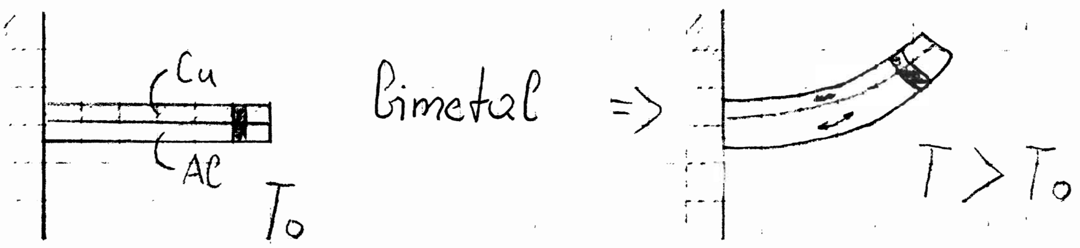
$$T = T_3 \left(\lim_{m \to 0} \frac{p}{p_3} \right)$$

m … masa plina

Celzijeva temperaturna skala [°C]

$$T_{°C} = T_K - 273{,}15 \ [°C]$$

Termične deformacije



$\Delta l = l \cdot \alpha \cdot \Delta T$

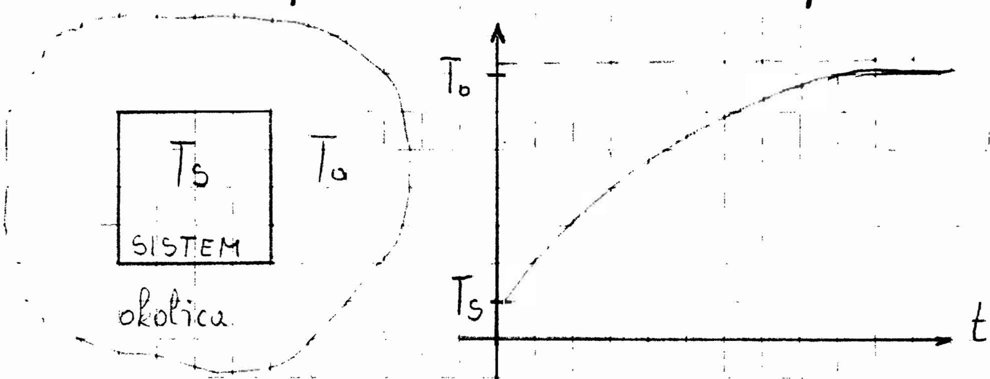
linearno raztezanje: $\frac{\Delta L}{L} = \alpha \Delta T$

$\beta = 3 \cdot \alpha$

Volumsko raztezanje: $\frac{\Delta V}{V} = \beta \cdot \Delta T$

$\Delta V = V \cdot \beta \cdot \Delta T$
$= V \cdot 3\alpha \cdot \Delta T$

Temperatura in toplota



Sistem je v termičnem stiku z okolico

- Prenešena energija = <u>Toplota</u>
- Sprejeta toplota spremeni notranjo energijo sistema (Skupna kinetična in potencialna energija atomov in molekul)

- Toplota je pozitivna, če povečuje notranjo energijo
- Toplota je energija, ki se prenese med sistemom in okolico zaradi temperaturnih razlik

Toplotna kapaciteta

$$Q = C(T_2 - T_1)$$

toplota — toplotna kapaciteta

Specifična toplota: $Q = c \cdot m(T_2 - T_1)$ $\quad c = \frac{C}{m}$

specifična toplota

1 kalorija je energija, ki jo potrebujemo, da 1 vode segrejemo za 1°C. Spec. toplota za vodo je 4,2 kJ/kg

$$1 cal = 4,2 kJ$$

Molska specifična toplota

1 mol snovi ima $N_A = 6,02 \cdot 10^{23}$ elementarnih gradnikov

avogadrovo število

Specifična toplota pri faznih spremembah (agregatnega stanja)

$$Q = c_T \cdot m$$

talilna specifična toplota (za vodo 333 kJ/kg)

$$Q = c_i \cdot m$$

specifična izparilna toplota (vode 2256 kJ/kg)

Toplota in delo

1. Zakon termodinamike: energijski zakon

$$\Delta E_n = E_2 - E_1 = Q - W$$

sprejeta toplota

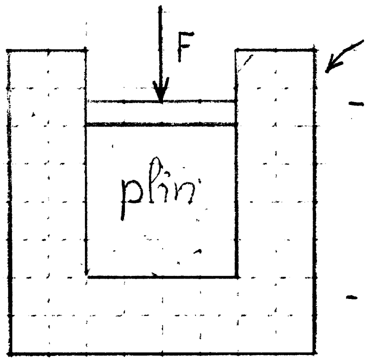
oddano delo

Sprememba notranje energije

Notranja energija se povečuje, če dodajamo energijo s toploto, ali se zmanjšuje, če sistem oddaja delo.

Q in W sta vedno gledana iz stališča sistema

Posebni primeri: a) Sprememba pri konstantni temperaturi



- če odstranimo silo F se plin razpne v novo ravnovesno lego
- Proces se zgodi dovolj hitro in ker so stene izolirane, prenosa toplote ni

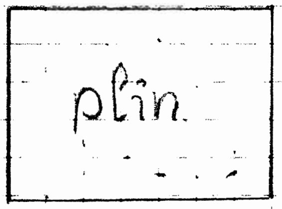
$$\Delta E_n = -W \qquad Q = 0$$

To imenujemo adiabatski proces

$$\frac{p_1 \cdot V_1}{T_1} = \frac{p_2 \cdot V_2}{T_2} \qquad p \cdot V = \frac{m \cdot R \cdot T}{M}$$

$$\rho = \frac{p \cdot M}{R \cdot T}$$

b) Spremembe pri konstantnem volumnu:

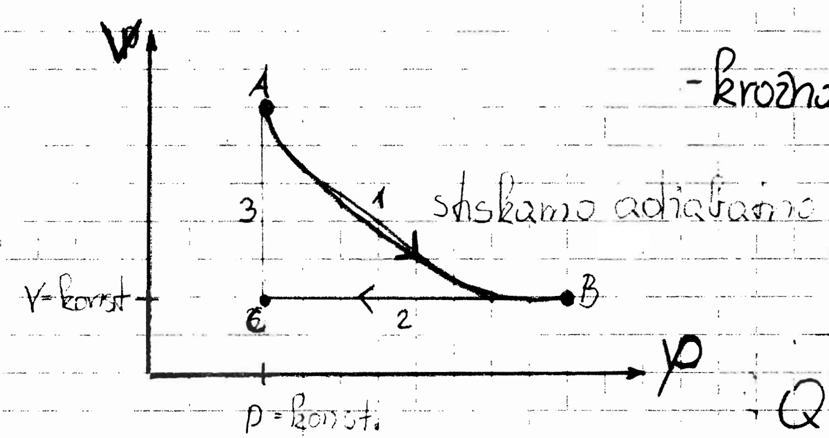


$V = \text{konst.}$ → ni premikov

$\Delta W = 0$

$\Delta E_n = Q$

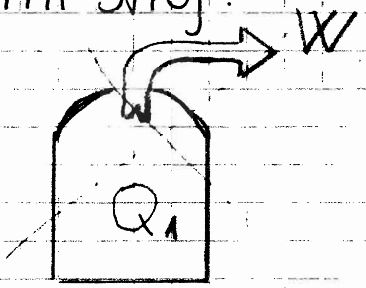
c) Ciklična sprememba:

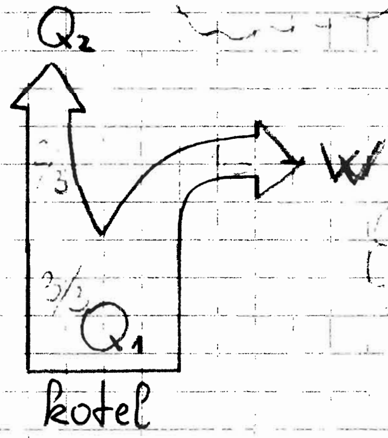


- krožna sprememba A → B → C → A
- Vrnemo se v točko istega stanja (p, V, T)

$Q = W \Leftarrow \Delta E_n = 0$

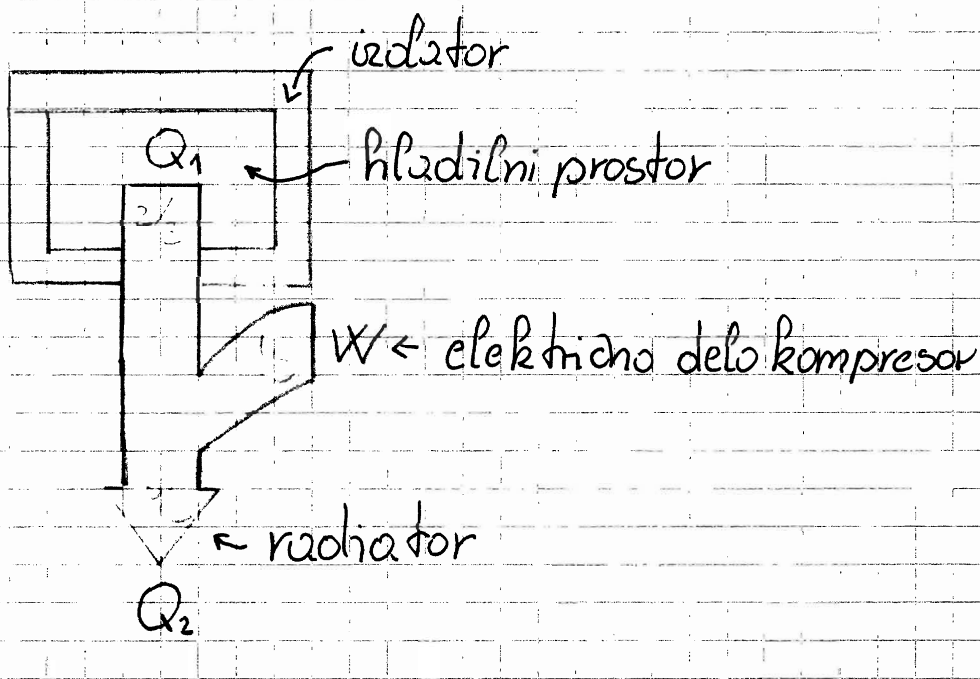
Parni stroj:





$$\eta = \frac{W}{Q_1}$$

Hladilnik:

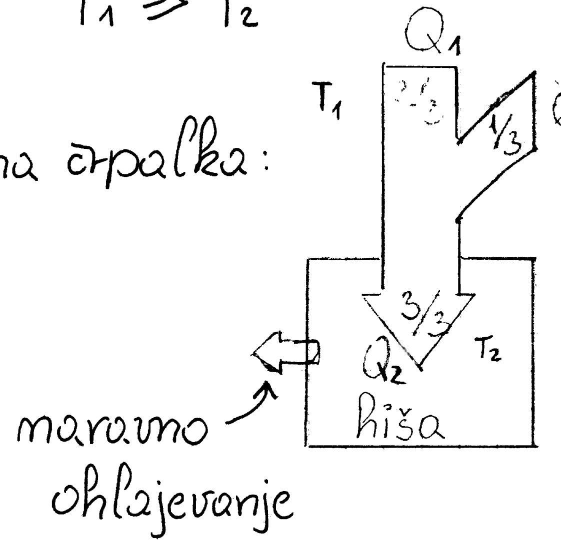


$$\eta = \frac{Q_1}{W}$$

Izkoristek je večji, kadar je večja temperaturna razlika

$T_1 \gg T_2$

Toplotna črpalka:

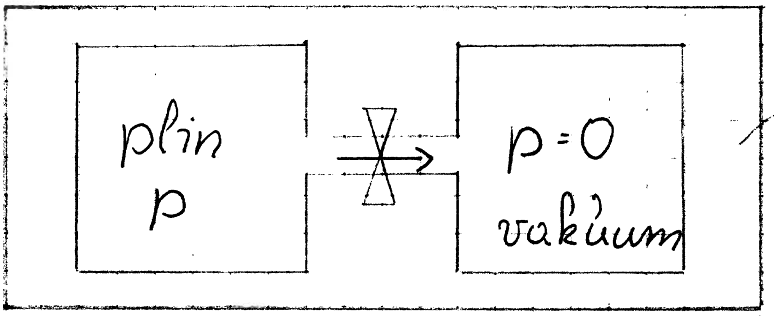


- hladimo okolico

$T_2 > T_1$

$$\eta = \frac{W}{Q_2}$$

d) Ekspanzija v prazen prostor:



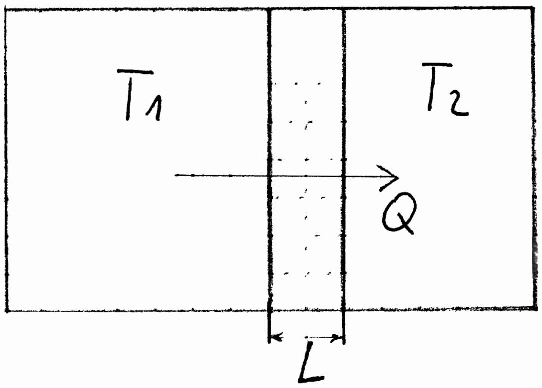
izolacija

- plin se razširja v prazen prostor

Nič se ne spremeni

$$\left.\begin{matrix} W = 0 \\ Q = 0 \end{matrix}\right\} \Delta E_n = 0$$

Prenos toplote (toplotna prevodnost)



$T_1 > T_2$

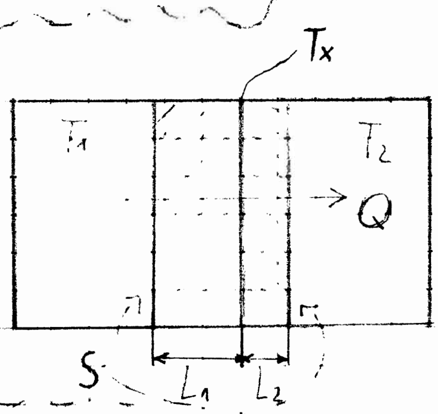
$$j = k \cdot S \, \frac{T_2 - T_1}{L}$$

toplotni tok

toplotna upornost: $R = \frac{L}{k}$

$$j = S \cdot \frac{\Delta T}{R}$$

prenos toplote



za več različnih izolatorjev v sistemu:

$$j = S \cdot \frac{T_1 - T_x}{R_1} = S \, \frac{T_x - T_2}{R_2}$$

$$j = S \, \frac{\Delta T}{\sum_i R_i}$$

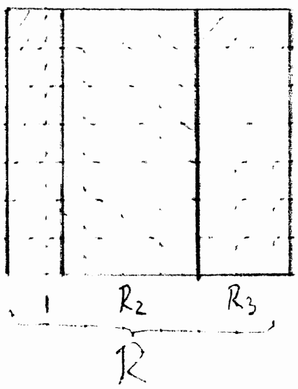
$$R_i = \frac{L_i}{k_i}$$

$$(T_1 - T_x) R_2 = R_1 (T_x - T_2)$$

$$T_1 \cdot R_2 - T_x \cdot R_2 = T_x \cdot R_1 - T_2 - R_1$$

$$-T_x (R_2 + R_1) = -(T_1 \cdot R_2 + T_2 \cdot R_1)$$

$$T_x = \frac{T_1 \cdot R_2 + T_2 \cdot R_1}{R_1 + R_2}$$



Upornosti se seštevajo

Konvekcija

Je način prenosa toplote preko medija (centralna kurjava, morski tokovi,)

Toplotno sevanje

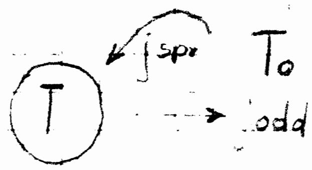
Je prenos toplote z elektromagnetnim sevanjem

$$j_{odd} = (1-a)\sigma S T^4$$ — koliko svetlobnega toka oddaja
Stefanov zakon

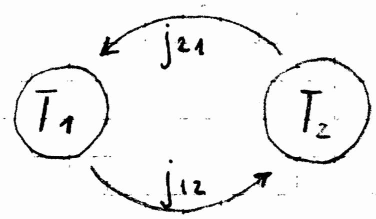
$a = 1 \Rightarrow$ belo telo (idealno zrcalo)

a - albedo, refleksivnost $a = 0 \Rightarrow$ črno telo

σ - Stefanova konstanta $\rightarrow 5{,}67 \cdot 10^{-8} \ \frac{W}{m^2 K^4}$

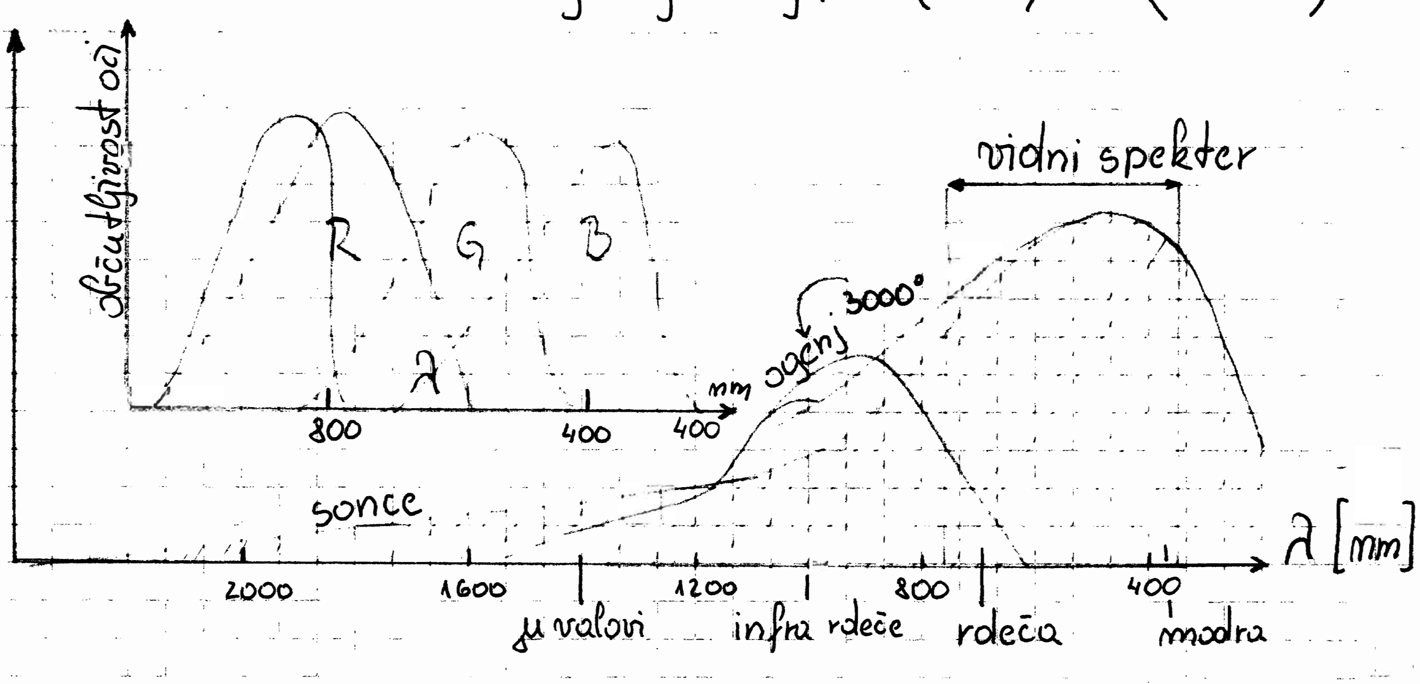


$$j_{spr} = (1-a)\sigma S T^4$$

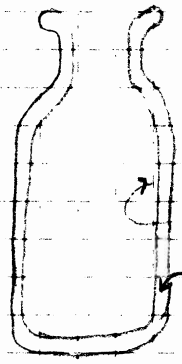


$$j_{21} = j_{12} \Rightarrow T_1 = T_2$$

$$\Delta j = j_{odd} - j_{spr} = (1-a) S \sigma (T^4 - T_0^4)$$



termovka



posrebreno $a \approx 1 \Rightarrow$ čimmanj sevanja

vakuum: preprečimo konvekcijo

Najboljši možen izolator

Črna ohlapna obleka povzroča konvekcijo in s tem hladi

21. 2. 2007

Entropija in 2. Zakon Termodinamike

- Entropijski postulat

Neobrnljiv proces v zaprtem prostoru vedno povečuje Entropijo. Entropija se v zaprtem prostoru nikoli ne zmanjšuje.

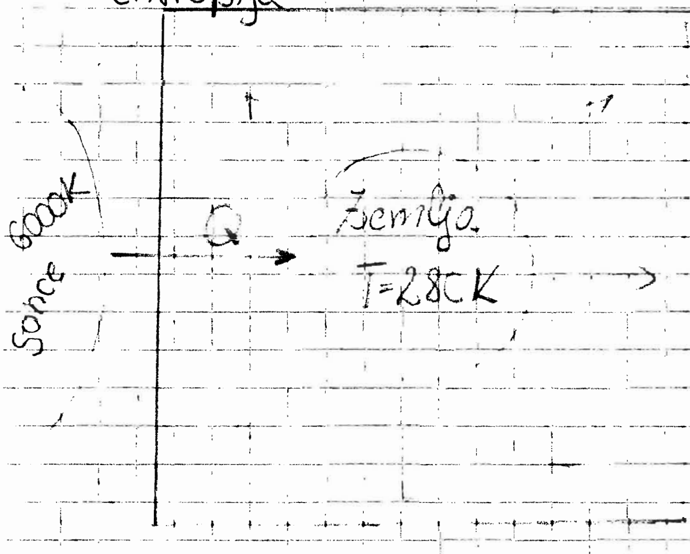
Entropiji se lahko reče tudi smer časa

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

izmenjena toplota

temperatura

entropija



Na odprtih podsistemih lahko zmanjšujejo entropijo

$$\Delta S = \frac{Q}{6000K} - \frac{Q}{280K}$$

- Entropija je v statistični fiziki merilo za nered

- Sistem, ki si zmanjšuje entropijo, si povečuje urejenost

ELEKTROMAGNETIZEM

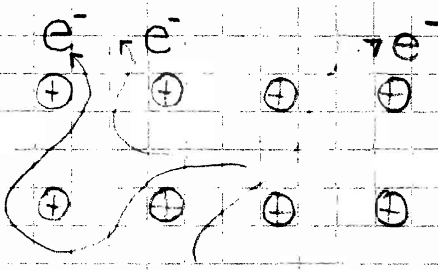
- ~~Elektro~~magnetične sile so poznali že stari Grki
- Jantarju se po Grško reče elektron in od tod ime elektrike
- 1820 je Nemški znanstvenik odkril povezavo med električnim tokom in magnetizmom
- Od takrat govorimo o elektromagnetnih silah
- Faraday je naredil ogromno poizkusov, ki jih je nato v enačbe pretvoril Maxwell

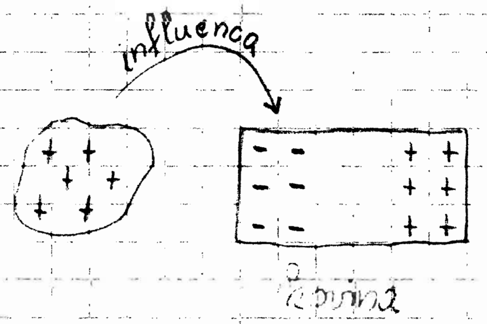
Električni naboj

→ Predmeti so nevtralni
→ Lahko se naelektrijo
→ Naelektreni predmeti se lahko: - odbijajo
- privlačita

→ Benjamin Franklin je na podlagi tega sklepal, da obstajata dve vrsti nabojev ⊕ - pozitivni
⊖ - negativni

- Izolatorji (naboj je nepremičen)
- Prevodniki (naboji se gibljejo) - kovine so zaradi mikroskopske kristalne strukture v pravilni mreži dobri prevodniki





- Superprevodniki so elementi ki so pri dovolj nizkih temperaturah brez upornosti

Coulombov zakon

$$F = \frac{1}{4\pi\varepsilon_0}\cdot\frac{e_1\cdot e_2}{r_{12}^2}$$

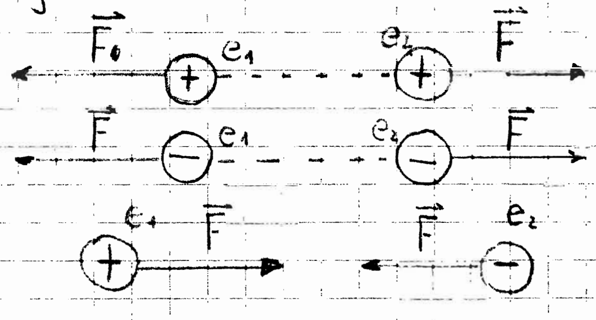
Sila med dvema nabojema

SI enote: e - naboj [As] = [C] (1As = 1C)

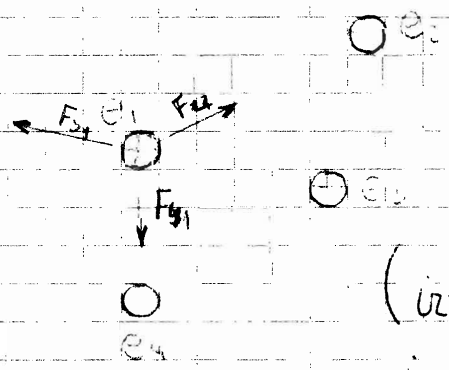
ε_0 - konstanta $8,85\cdot10^{-12}\left[\frac{(As)^2}{N m^2}\right]$

Električne sile v vesolju ne vplivajo, ker ni velikih razlik v polarizaciji v vesolju.

Predznak sile:



Sila vedno kaže v smeri zveznice med nabojema.
Elektrostatska sila je centralna sila.

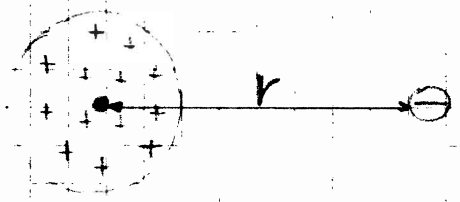


V tem primeru velja načelo superpozicije

(izračunamo silo glede na vsak elektron in nato vse sile seštejemo)

$$\vec{F} = \vec{F}_{21} + \vec{F}_{31} + \vec{F}_{41}$$

- Sferično simetrično nabita telesa lahko obravnavamo kot točkasto telo



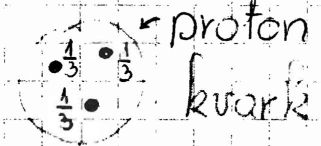
Kvantizacija naboja

- Naboj ni zvezna količina, ampak je celoštevilčni večkratnik

$$e = N \cdot e_0$$

e_0 = - naboj enega elektrona = $1{,}6 \cdot 10^{-19}$ As

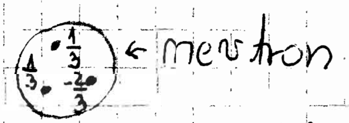
	oznaka	naboj
elektron	e^-	$-e_0$
proton	p	e_0
nevtron	n	0



Proton in nevtron sta sestavljena iz 3 kvarkov

$\pm 1/3\, e_0,\ \pm 2/3\, e_0$

Vsi delci sestavljeni iz kvarkov so hadroni



Elektroni in Pozitroni niso sestavljeni iz kvarkov in jih imenujemo leptoni

Zakon o ohranitvi naboja

- Naboj lahko samo premeščamo
- Ohranitev na nivoju atomov

masno število

$$^{238}U \longrightarrow {}^{234}Th + {}^{4}He$$

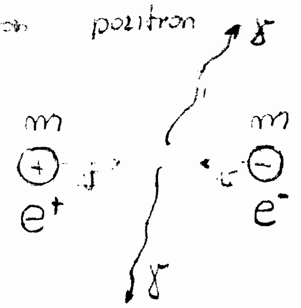
$$Z = 92(p) = 90(p) + 2(p)$$

- Pri anihilaciji velja:

žarek γ

$$e^- + e^+ \longrightarrow \gamma + \gamma$$ - naboj $-1 + 1 = 0$

elektron pozitron



$$\vec{p} = \vec{p_1} + \vec{p_2} = m \cdot v + m \cdot (-v) = 0$$

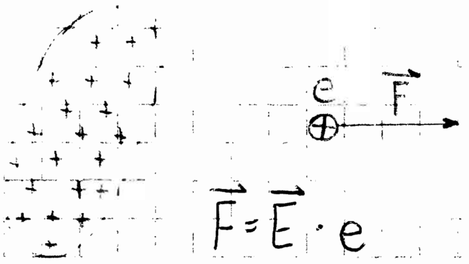
- Produkcija para

$$\gamma + \gamma \rightarrow e^- + e^+$$ (zelo redko)

$$\gamma + A \rightarrow e^- + e^+ + A$$ (rentgensko slikanje)

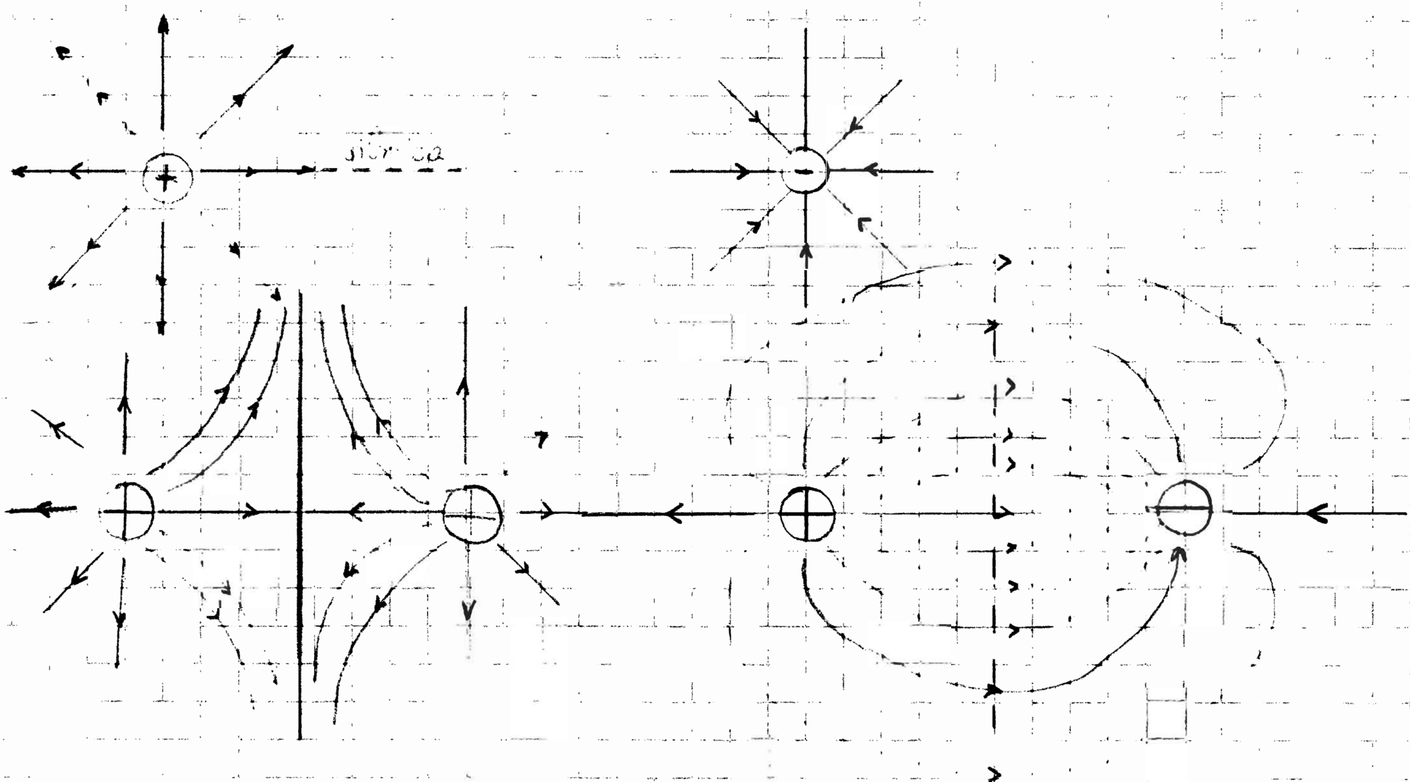
Elektricno polje

27. 2. 2007

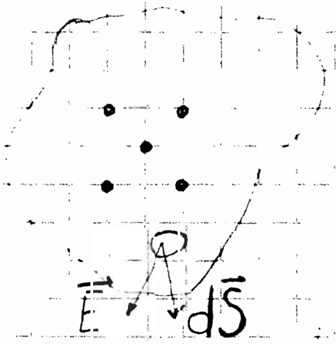


$\vec{F} = \vec{E} \cdot e$

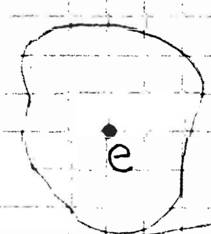
$$\boxed{\vec{E} = \frac{\vec{F}}{e}}$$



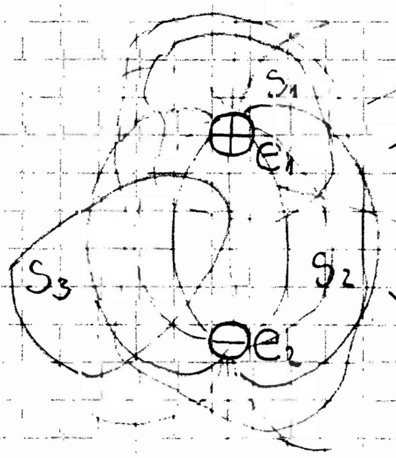
Gaussov zakon



$$\varepsilon_0 \oint \vec{E} \cdot d\vec{S} = e$$



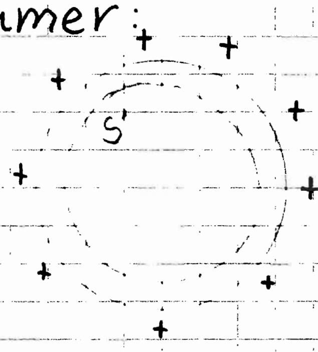
$$\varepsilon_0 \oint_{S_3} \vec{E} \cdot dS = 0$$



$$\varepsilon_0 \oint_{S_1} \vec{E} \cdot d\vec{S} = e_1$$

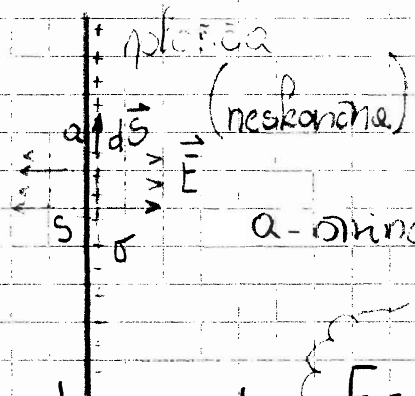
$$\varepsilon_0 \oint_{S_2} \vec{E} \cdot d\vec{S} = e_1 + e_2$$

Primer:



$$\varepsilon_0 \oint_{S'} \vec{E}\cdot d\vec{S}' = \emptyset \Rightarrow \vec{E} = 0$$

Znotraj prevodnih votlih predmetov je električni naboj 0 (Faradayeva kletka)



$$\sigma = \frac{e}{S}$$

a - stranica $\varepsilon_0 \oint \vec{E}\cdot d\vec{S} = \varepsilon_0 2 \cdot S \cdot E = \sigma \cdot S$

neodvisno od razdalje $E = \frac{\sigma}{2\varepsilon_0}$ Električno polje v bližini razsežne nabite plošče

Električno polje je od naboja neodvisen zapis električnih sil.

Električni potencial

- Elektrostatska sila je konzervativna (pri vseh premikih in spremembah je odvisno samo začetno in končno stanje)
- Električni potencial $\Delta U = U_2 - U_1$ → končno stanje, ↳ začetno stanje

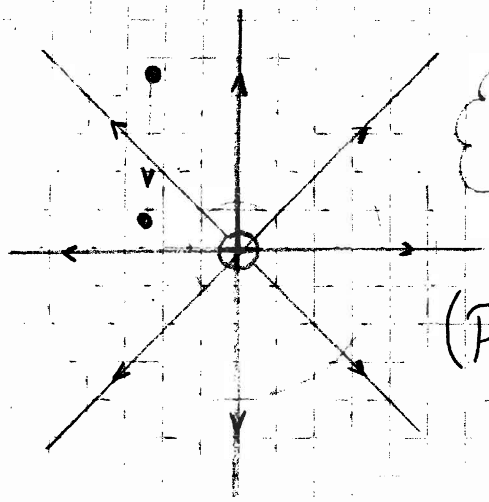
$$-W = e \cdot \Delta U$$

opravljeno delo

Po dogovoru za začetno stanje izberemo ustreza neskončno razmaknjenim nabojem in za ta primer definiramo $U_\infty = 0$

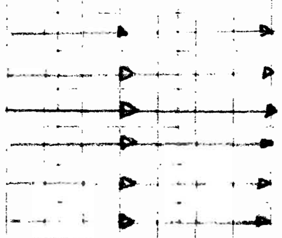
$$\Delta U = U_2 - U_1 = (U_2 - \underset{0}{\underset{\parallel}{U_\infty}}) - (U_1 - \underset{0}{\underset{\parallel}{U_\infty}})$$

enote za el. potencial $[J/As = V]$ Volt



$$U = \frac{e}{4\pi\varepsilon_0 \cdot r}$$

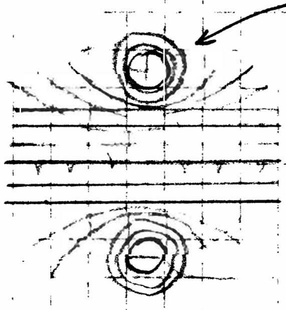
Velja samo za točkasti naboj
(Potencial v okolici točkastega polja)



$\vec{E}$ = konst.

Ekvipotencialne ploskve ali ploske z enakim potencialom.

potencial v okolici točkastega naboja

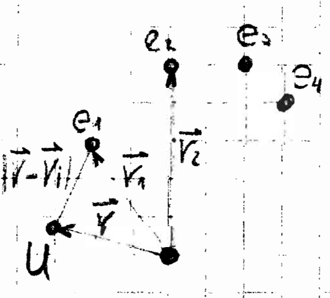


Ekvipotencialne ploskve

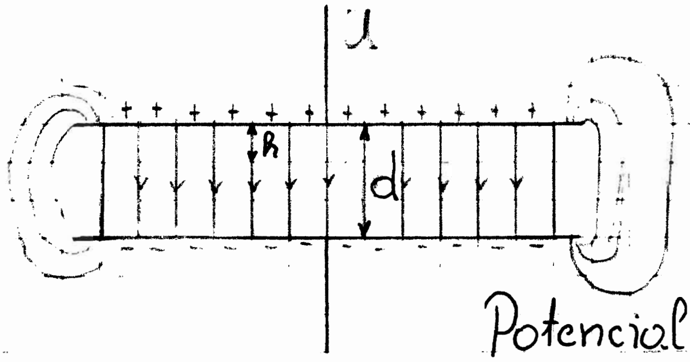
Sistem nabojev

$U = \sum U_i$

$$U(\vec{r}) = \sum_i \frac{e}{4\pi\varepsilon_0 \, |\vec{r} - \vec{r}_i|} = \frac{1}{4\pi\varepsilon_0} \sum \frac{e_i}{|\vec{r} - \vec{r}_i|}$$



Kondenzator



el. polje nabite plošče:

$$E = \frac{\sigma}{2 \cdot \varepsilon_0}$$

Potencial v gravitacijskem polju:

$$U = m \cdot g \cdot h$$

El. potencial v bližini razsežne nabite plošče:

$$U = \frac{\sigma}{2 \cdot \varepsilon_0} \cdot h$$

El. potencial v kondenzatorju:

$$U = \frac{\sigma \cdot h}{\varepsilon_0}$$ (dve polovici +, - ali se seštevata)

$$U = \frac{e \cdot h}{\varepsilon_0 S}$$

$$\sigma = \frac{e}{S}$$

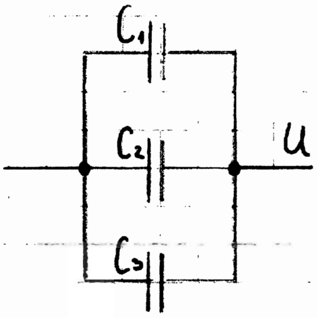
Potencialna razlika med ploščama: $$U = \frac{e \cdot d}{\varepsilon_0 \cdot S}$$

$$U = \frac{e}{C} \; ; \; C = \frac{e}{U} \; [As/V = F]$$

$$C = \frac{\varepsilon_0 S}{d}$$

C-kapaciteta kondenzatorja [F]

Paralelna vezava kondenzatorjev



$$e = C \cdot U$$

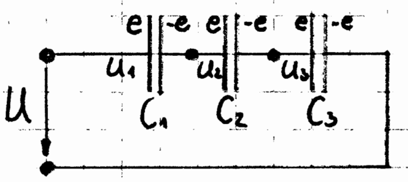
$$\left.\begin{aligned} e_1 &= C_1 \cdot U \\ e_2 &= C_2 \cdot U \\ e_3 &= C_3 \cdot U \end{aligned}\right| \sum e_1 + e_2 + e_3 = C_1 \cdot U + C_2 \cdot U + C_3 \cdot U = (C_1 + C_2 + C_3) \cdot U$$

ekvivalent

$e = C \cdot U$

$$C = C_1 + C_2 + C_3$$

Zaporedna vezava kondenzatorjev



$$U = U_1 + U_2 + U_3 \qquad U = \frac{e}{C}$$

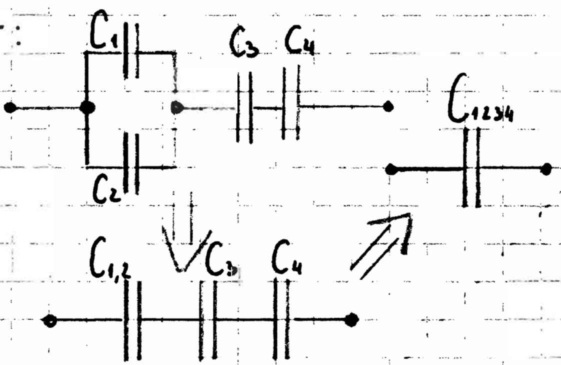
$$\left.\begin{aligned} U_1 &= \frac{e}{C_1} \\ U_2 &= \frac{e}{C_2} \\ U_3 &= \frac{e}{C_3} \end{aligned}\right\} \sum U_1 + U_2 + U_3 = e\left(\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}\right)$$

$$U = \frac{e}{C_{nad}}$$

$$C_{nad} = \frac{1}{1/C_1 + 1/C_2 + 1/C_3}$$

$$1/C_{nad} = \sum_i 1/C_i$$

Primer:

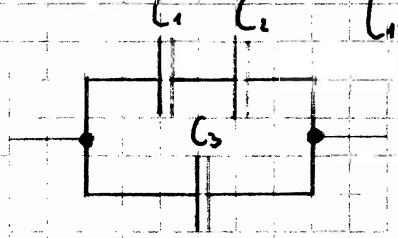


$$C_{1234} = \frac{1}{1/C_{12} + 1/C_3 + 1/C_4} = \frac{1}{1/C_1{+}C_2 + 1/C_3 + 1/C_4}$$

$$C_{1,2} = C_1 + C_2$$

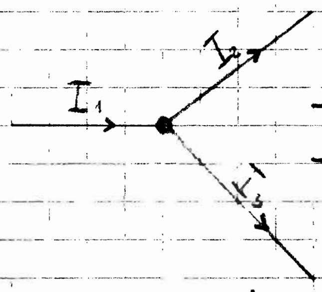
$$C_{123} = C_{12} + C_3 = \frac{1}{1/C_1 + 1/C_2} + C_3$$

kombinacija vezav



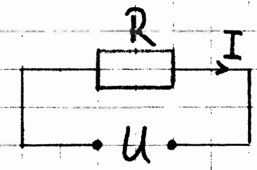
Električni tok

$$I = \frac{\Delta e}{\Delta t} \qquad \boxed{I = \frac{e}{t}} \quad [As/s = A]$$



$$I_1 = I_2 + I_3$$

Upornost

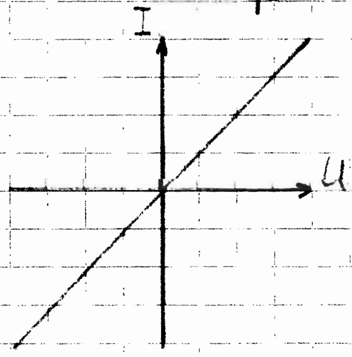


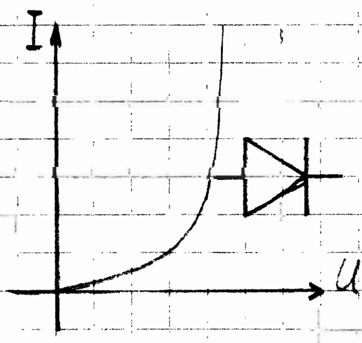
$$R = \frac{U}{I} \; ; \; U = I \cdot R \qquad I = \frac{U}{R}$$

$R = R(U, I)$

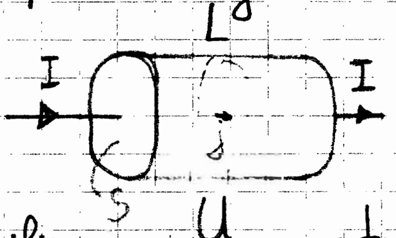
Ohmov zakon

$R \neq R(U, I)$ upornost je neodvisna od napetosti in polaritete napetosti





- enota za upornost $[\Omega] = [V/A]$
- upornost je lastnost električnega elementa



električno polje $E = \frac{U}{L}$

sp. upornost: $\rho = \frac{E}{j} = \frac{S}{L} \cdot R$

Specifična upornost snovi (ρ)

gostota el. toka: $j = \frac{I}{S}$

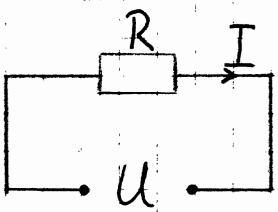
$$R = \rho \cdot \frac{L}{S}$$

Električna moč

$W = e \cdot U$ $\qquad P = \frac{\Delta W}{\Delta t}$ povprečna moč

$P = U \cdot \frac{de}{dt}$ $\qquad P = \frac{dW}{dt}$ trenutna moč

$$\boxed{P = U \cdot I}$$ - električna moč

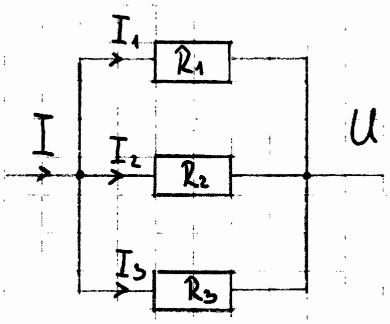


el. moč na porabniku (uporu)

$$\boxed{P = R \cdot I^2} = \boxed{\frac{U^2}{R}}$$

28.2.2007

Vezave uporov paralelno (Vzporedno)



Napetost je na vseh uporih enaka

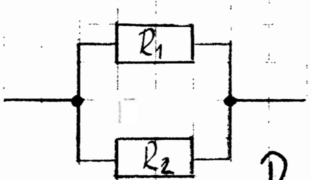
$$\left.\begin{aligned} I_1 &= \frac{U}{R_1} \\ I_2 &= \frac{U}{R_2} \\ I_3 &= \frac{U}{R_3} \end{aligned}\right\} \sum \quad I_1 + I_2 + I_3 = U \cdot \left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \right)$$

$$I = U / R_{nad}$$

$$1/R_{NAD} = 1/R_1 + 1/R_2 + 1/R_3$$

vzporedna vezava: $\boxed{\frac{1}{R_N} = \sum_i \frac{1}{R_i}}$

Primer: Dva upora R_1, R_2



$$1/R_{NAD} = 1/R_1 + 1/R_2$$

$$\boxed{R_{NAD} = \frac{R_1 \cdot R_2}{R_1 + R_2}}$$

velja za sistem dveh uporov

$R_1 = 1 k\Omega$

$R_2 = 3 k\Omega$

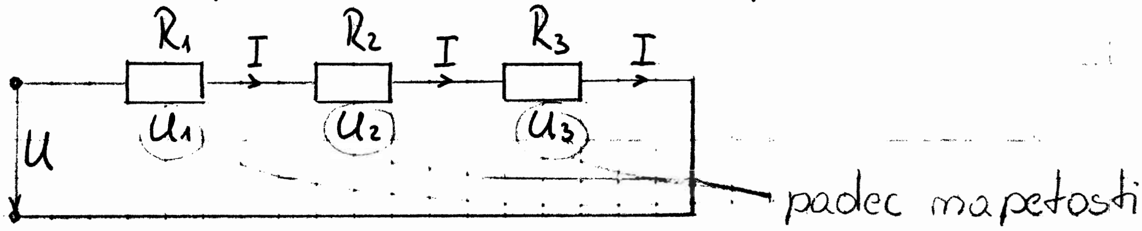
$R_N = ?$

$$R_N = \frac{1 \cdot 3 k\Omega}{4 k\Omega} = 0{,}75 k\Omega$$

Nad. upor je manjši od najmanjšega upora

(63) Primer: $R_2 \to \infty$ $\qquad R_N = \dfrac{R_1 \cdot \cancel{R_2}}{\underbrace{R_1 + \cancel{R_2}}_{\text{gre proti } \varnothing}} \approx R_1$

Zaporedna vezava uporov



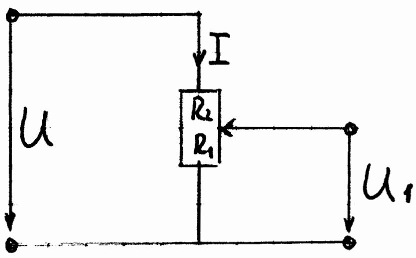
$$U = U_1 + U_2 + U_3 \quad ; \quad U = R \cdot I$$

$$\left.\begin{aligned} U_1 &= R_1 \cdot I \\ U_2 &= R_2 \cdot I \\ U_3 &= R_3 \cdot I \end{aligned}\right\} \sum U_1 + U_2 + U_3 = (R_1 + R_2 + R_3) \cdot I \Rightarrow U = R_{NAD} \cdot I$$

$$R_{NAD} = R_1 + R_2 + R_3$$

Za zaporedno vezavo velja: $R_N = \sum_i R_i$

Delilnik napetosti:

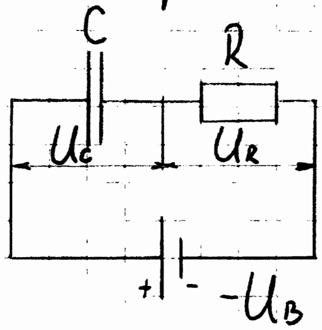


$$R = R_1 + R_2$$

$$U_1 = R_1 \cdot I = R_1 \frac{U}{R} =$$

$$= \underbrace{\frac{R_1}{R_1 + R_2}}_{\text{med 0 in 1}} \cdot U$$

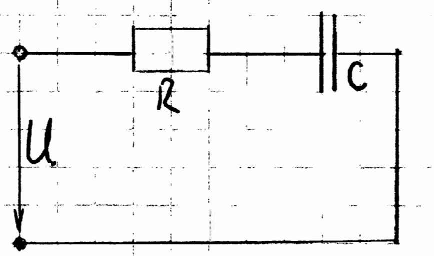
Napetost v zaprtem krogu



$$U_B = U_R + U_C \Rightarrow U_R + U_C - U_B = 0$$

Vsota napetosti v zaključenem tokokrogu je enaka nič (če izvore štejemo kot negativne)

Polnjenje kondenzatorja:



$$U_R + U_C - U = \emptyset$$

$$R \cdot I + \frac{e}{C} - U = \emptyset$$

$$R \cdot \frac{de}{dt} + \frac{e}{C} - U = \emptyset$$

$$e(t) = C \cdot U \left(1 - e^{-t/RC}\right)$$

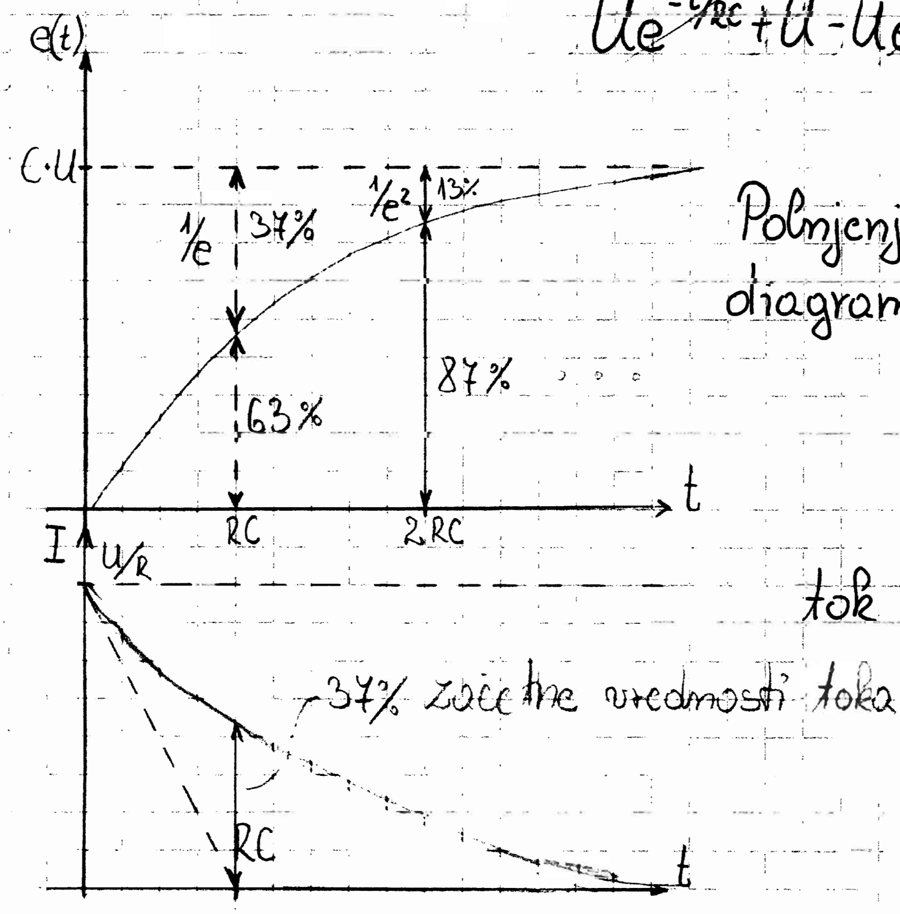
$$C = \frac{e}{U_C} \Rightarrow U_C = \frac{e}{C}$$

$$I = \frac{de}{dt}$$

$$\frac{de}{dt} = CU\left(- - 1/RC \cdot e^{-t/RC}\right) = \frac{U}{R} e^{-t/RC}$$

$$R \frac{U}{R} e^{-t/RC} + \frac{CU(1 - e^{-t/RC})}{C} - U = 0$$

$$\cancel{Ue^{-t/RC}} + U - \cancel{Ue^{-t/RC}} - U = 0$$



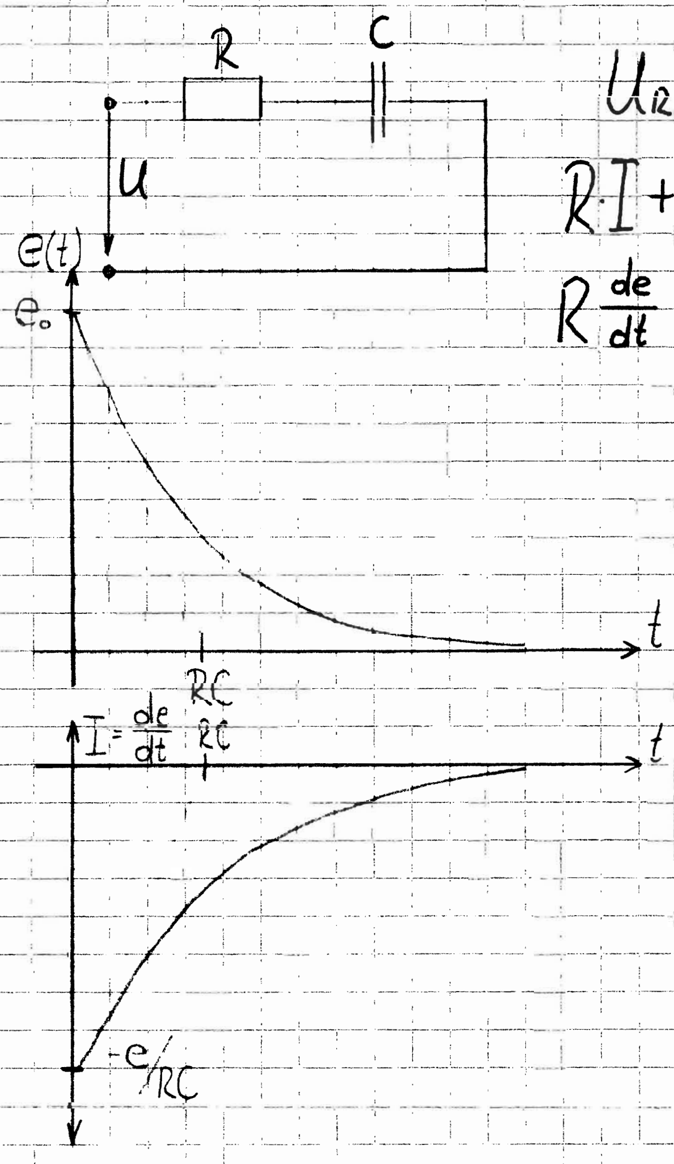
Polnjenje kondenzatorja po diagramu $e(t) - t$ in $I - t$

tok skozi vezje

Razpadni čas : $t_R = R \cdot C$ (časovna konstanta)

Razpolovni čas : $t_{1/2} = R \cdot C \cdot \ln 2$

Praznenje kondenzatorja



$$U_R + U_C = 0$$

$$RI + \frac{e}{C} = 0$$

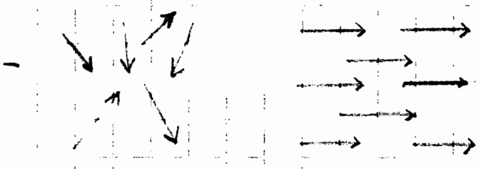
$$R\frac{de}{dt} + \frac{e}{C} = 0$$

$$e(t) = e_0 \cdot e^{-t/RC}$$

$$\frac{de}{dt} = \frac{e_0}{-RC} e^{-t/RC}$$

$$-\cancel{R}\frac{e_0}{\cancel{R}C} e^{-t/RC} + \frac{e_0 e^{-t/RC}}{C} = \underline{\underline{0}}$$

Magnetno polje

- Permanentni magneti (stalni)
- Elektromagneti
-  magnetne domene

naključno urejene silnice

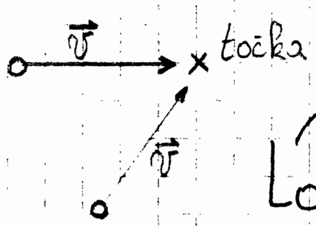
- intrinzično magnetno (notranje) polje osnovnih delcev
- Def. el. polja $\vec{E} = \frac{F}{e_t}$ (sila na testni naboj)

Tega za magnetno polje ne moremo uporabiti, saj ne obstajajo magnetni naboji (e_m)

Imamo samo dipola N - sever (north)
S - jug (south)

Severni pol magneta je tisti, ki bi se obrnil proti severu

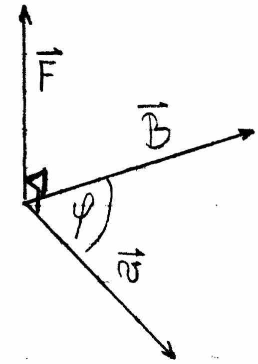
- V določeni smeri na naboj ne deluje nobena sila (kadar je hitrost vzporedna z magnetnim poljem.
V vse ostale smeri se sila obnaša kot $F \propto v \cdot \sin\varphi$



$$\boxed{F = e \cdot \vec{v} \times \vec{B}}$$

Lorenzova sila na gibajoč naboj v magnetnem polju

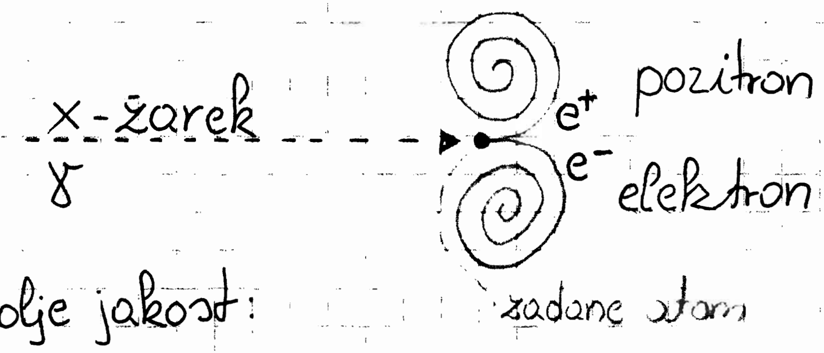
Pravilo desne roke (od prejšnje strani)



Slika velja za pozitiven naboj

Velikost sile: $\boxed{F = e v B \sin\varphi}$ φ - kot med $\vec{v}$ in $\vec{B}$

-Meglična komora



Enota za magnetno polje jakost:

$$\left[\frac{N}{Am}\right] = [T]$$ tesla

manjša enota [G] Gauss $1G = 10^{-4}\,T$

zemeljsko magnetno polje ≈ 1 Gauss