2.9. Frictional forces

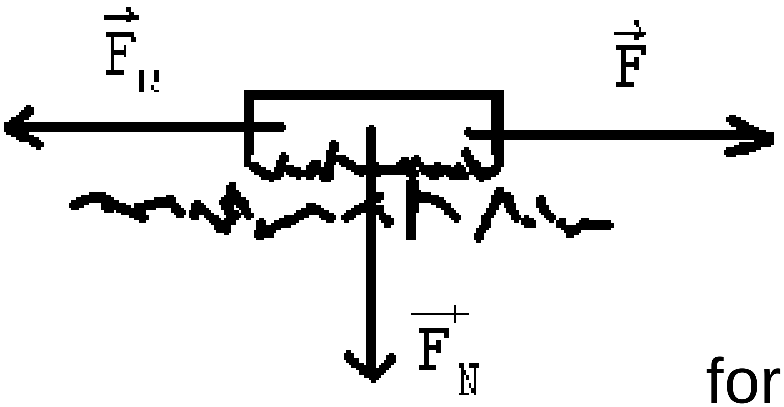
Up until now: Energy conservation

$E_{kin} + E_{pot}$ = constant Exemption: Inelastic collision

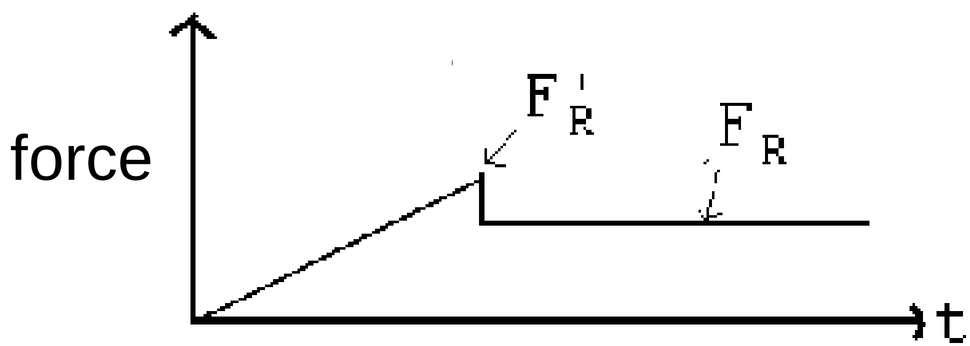
Each real movement faces loss of energy,
e.g. transformation of kinetic energy into thermal energy.

$\Rightarrow$ frictional forces $\vec{F}_R$

Examples: F_R independent of velocity v



At v=0: ',sticktion" F'_R
at $v \neq 0$: ',Slide friction $\vec{F}_R$ "



$F_N = F_g$ Normal force (force that presses bodies together)

$$F'_R \sim F_N \qquad F_R \sim F_N$$

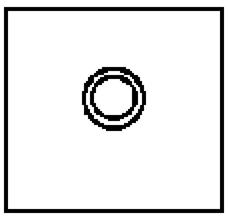
$$F_R = \mu \cdot F_N$$

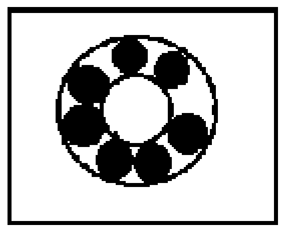
$$F'_R = \mu' \cdot F_N \quad ; \quad \mu' \quad \mu$$

μ' Coeffizient of normal force

μ Coeffizient sliding force

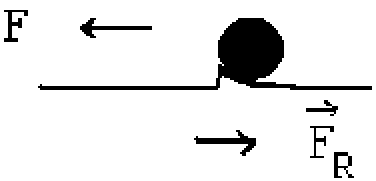
Very strong surface dependent

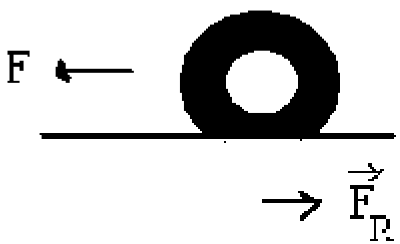


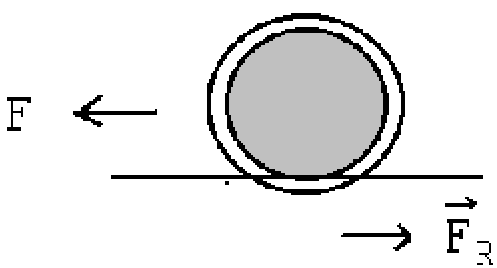


μ Rolling friction at ball bearing very small

"hard Materials" : little rolling friction



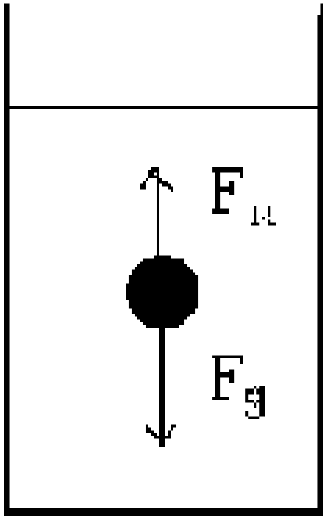




railway

locomotive

b) $F_R \sim v$ Stokes or viscous friction



Body in a fluid or gas!

$\vec{F} \sim -\vec{v}$ If v ',strong enough'',

then $F_R = F_g \Rightarrow \quad m\,\ddot{x} = F_g - F_R = 0$

$$\Rightarrow \ddot{x} = 0$$

$\Rightarrow$ Constant velocity

C) $F_R = k \cdot v^2$ Newton friction

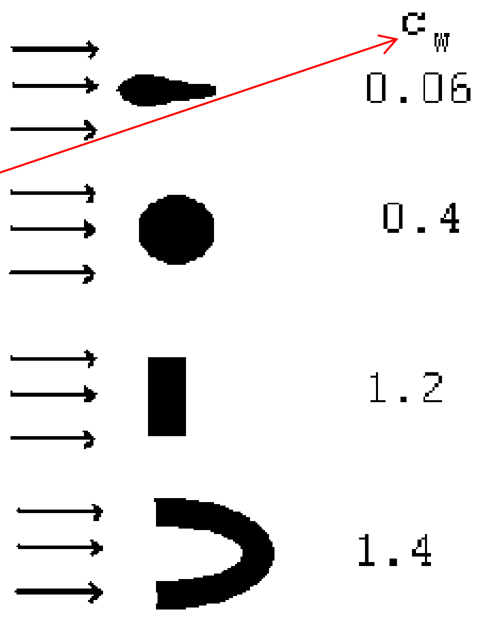
Fast movement through a fluid

$k = \frac{1}{2} \cdot c_w \cdot \rho \cdot A$ $\quad c_w$: Coefficient of friction: pure number

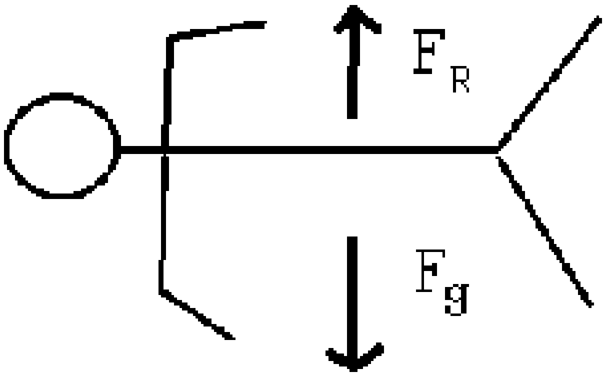
ρ : Dencity of fluid

A: stream in area

c_w depends on the shape



e.g.: Fall of a human beeing in a gravitational field with air resisteance



Equation of motion:

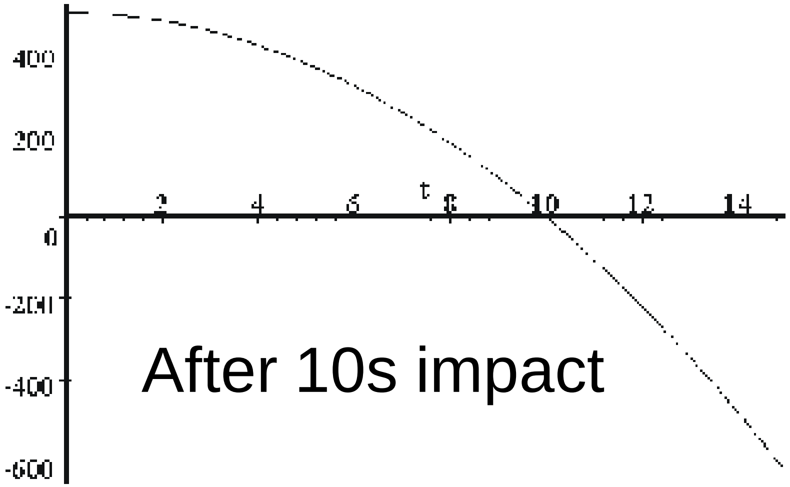
$$m \cdot \ddot{x} = -m \cdot g + k \cdot \dot{x}^2$$

If $|\vec{F}_g| = |\vec{F}_R| \Rightarrow \ddot{x} = 0$

The body sinks with constant velocity v_L :

Free fall from 500m(without air):

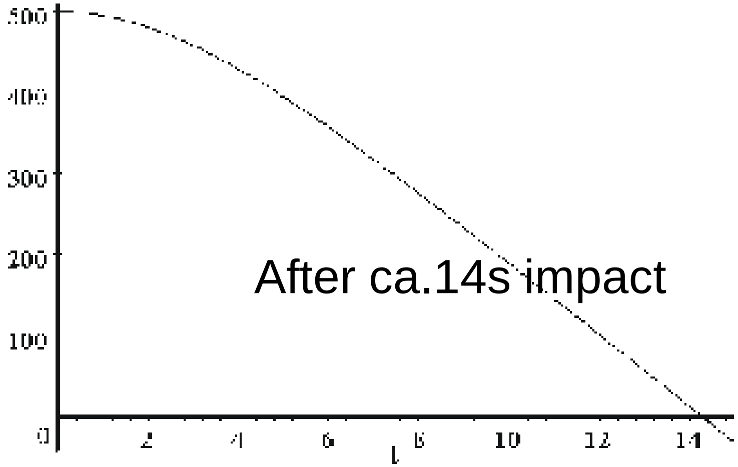
$$z(t) = -5t^2 + 500$$

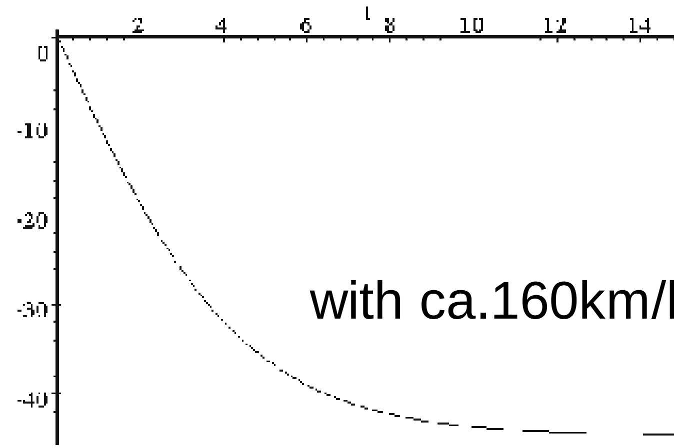


Free fall 500m with air:

$$z(t) = -200.0\ln(\cosh .22361t) + 500$$

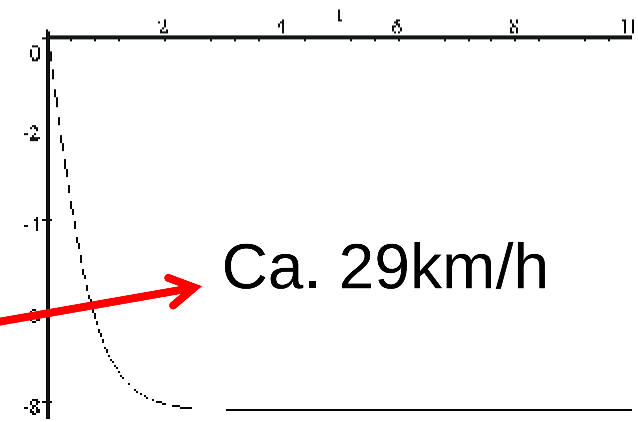
$$\frac{d}{dt}(-200.0\ln(\cosh .22361t) + 500) = -44.722\frac{\sinh .22361t}{\cosh .22361t}$$



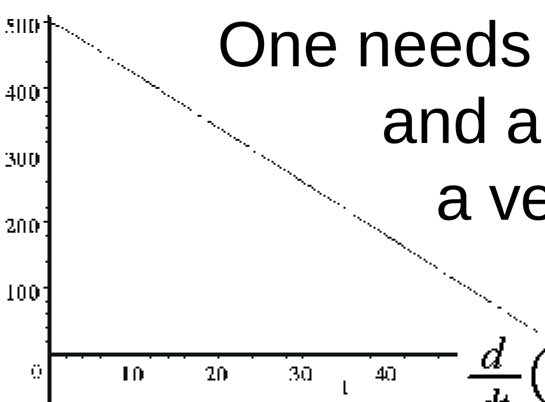


With parachute 20 m^2:

$$\frac{d^2z}{dt^2} - 0.5 \cdot 0.3 \cdot \left(\frac{dz}{dt}\right)^2 + 10 = 0$$



One needs more than 60s and arrives with a velocity of



$$\frac{d}{dt}(-6.6667\ln(\cosh 1.2247t)) = -8.1647\frac{\sinh 1.2247t}{\cosh 1.2247t}$$

Remark concerning cars

Tires take part with ca. 20% of friction.

At ca. 50km/h: Rolling friction=air resistance
at 100km/h : Air resistance reaches a value
of around 3-4 times rolling friction