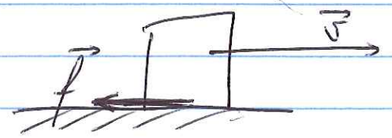
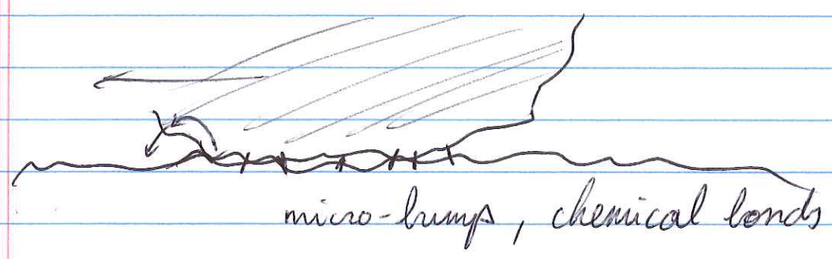
* Friction : resistance against motion,
direction is against relativ



macroscopic



micro-bumps, chemical bonds

Is friction useful?

No - tear & wear
- inefficiency in mechanical system
20% of energy in fuel is there to overcome friction

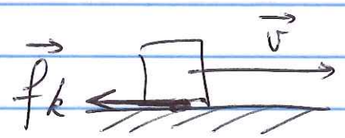
Yes: - walk

Study of friction = tribology
da Vinci (1600)

1) independent of contact area
2) independent of relative velocity ($\vec{v} > 0$)

3) proportional to normal force

* Kinetic friction ($\vec{v} > 0$)

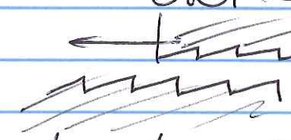


$f_k = \mu_k N$ ← force

μ_k coefficient of kinetic friction

force

μ_k dimensionless, no units, just a number
0.01 — 1 or larger



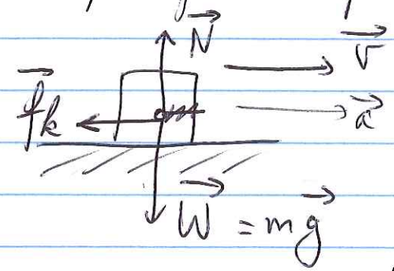
μ_k depends on surface and object

* Static friction ($\vec{v} = 0$)

$0 \leq f_s \leq \mu_s N$ ← coefficient of static friction

f_s is as large as needed to maintain $a = 0$
and if f_s needs to be larger than $\mu_s N$
→ object will start moving

Example of kinetic friction:



what will be $\vec{a}$?

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

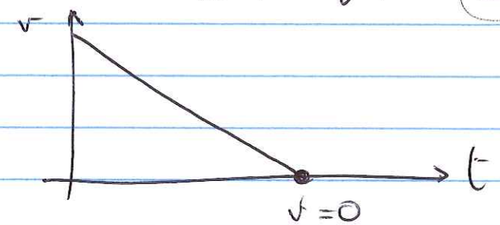
$$\begin{cases} x: -f_k = ma_x \\ y: N - mg = ma_y = 0 \end{cases} \quad (2^{nd} \text{ law})$$

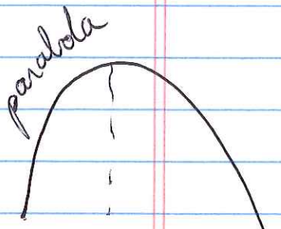
$$\hookrightarrow \underline{N = mg}$$

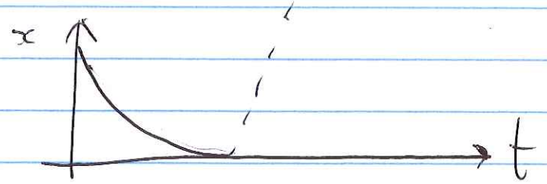
$$a_x = -\frac{1}{m} f_k \qquad f_k = \mu_k N = \mu_k mg$$

$$\downarrow$$

$$a_x = -\frac{1}{m}(\mu_k mg) = \underline{-\mu_k g}$$







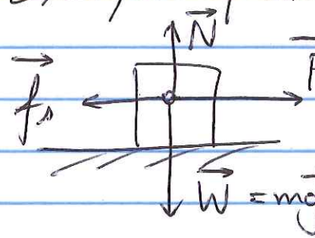
* Connection between μ_k and μ_s

μ_s : chemical bonds exist, and they need to be broken

μ_k : bonds are already broken

$$\mu_s \geq \mu_k$$

* Example of static friction



$N = mg$

if $\vec{F}_{ext} = 0$, $\longrightarrow$ $f_s = 0$

if $\vec{F}_{ext} \neq 0$, then $f_s \neq 0$

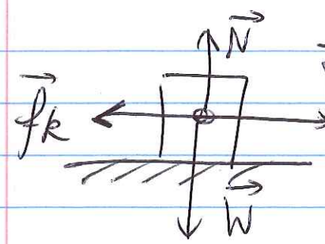
$$F_{ext} - f_s = ma_x = 0$$

$$f_s = F_{ext}$$

$$0 \leq f_s \leq \mu_s N = \mu_s mg$$

as long as $F_{ext} \leq \mu_s mg$, object will remain stationary

if $F_{ext} > \mu_s mg$, object will start moving



$$F_{ext} = \mu_s mg$$

$$f_k = \mu_k mg \leq \mu_s mg$$

$$ma_x = F_{ext} - f_k = \mu_s mg - \mu_k mg$$

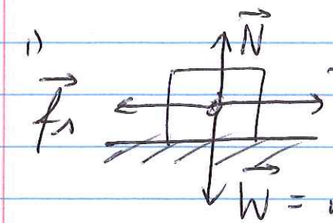
$$= (\mu_s - \mu_k) mg$$

$$a = (\mu_s - \mu_k) g$$

* Example: a block of wood on a wooden floor with $\mu_s = 0.5$ and $\mu_k = 0.3$. mass = 1 kg
I push with a force of 10 N

1) will the block move?
2) yes? what is the acceleration
no? how much harder should I push?

1)

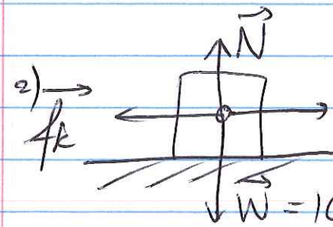


$0 \leq f_s \leq \mu_s N = 5N$

$F_{ext} = 10N > 5N$

↳ yes, will move

2)



$ma_x = F_{ext} - f_k = \mu_k N$

$a_x = \frac{1}{m}(5N - 3N) = \frac{2N}{m}$

$a_x = 2\ m/s^2$