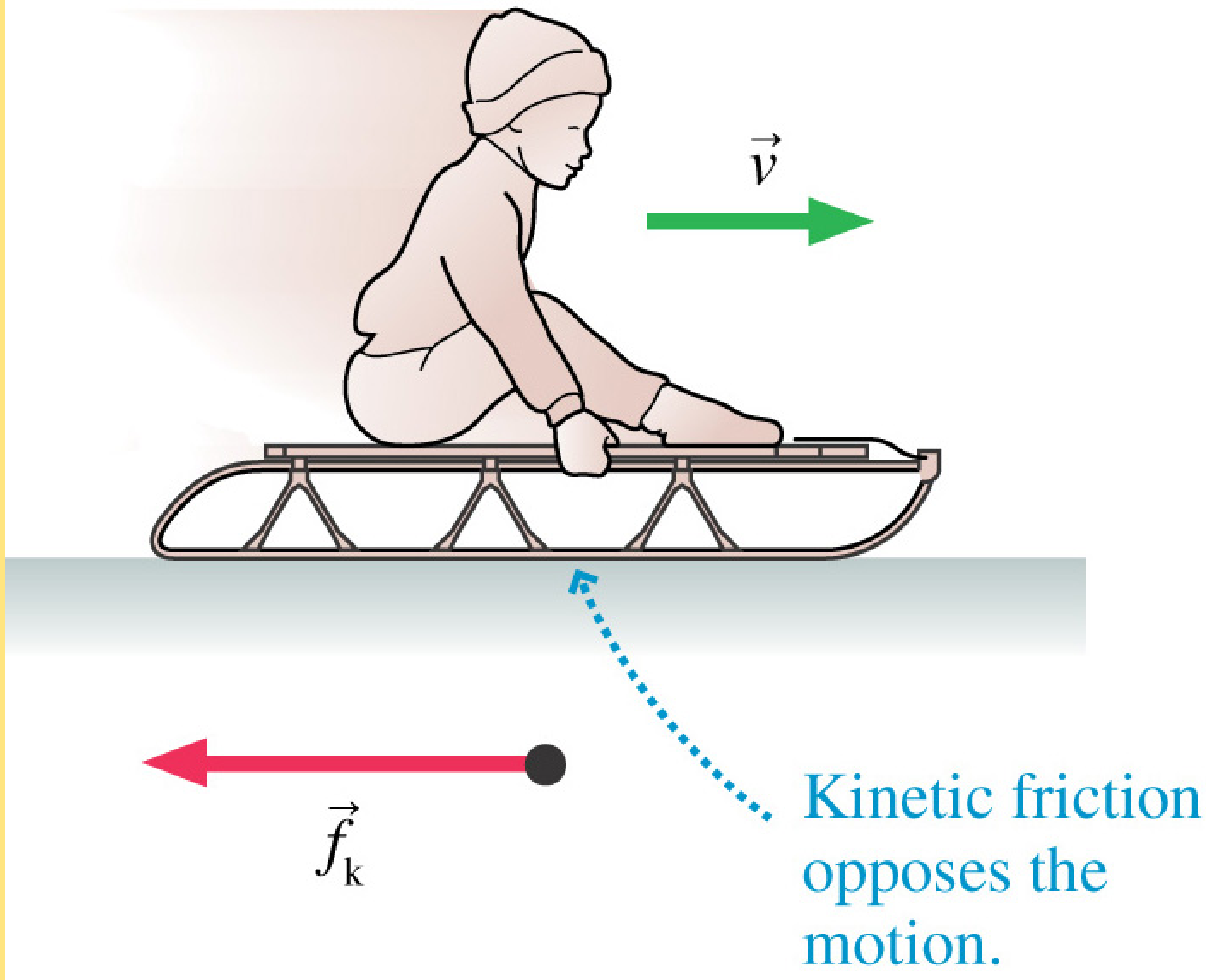
Kinetic Friction

Once we overcome static friction, resistance against movement is weakened. $\vec{f}_k$ opposes $\vec{v}$.

The magnitude $|\vec{f}_k| = \mu_k |\vec{n}|$.

Kinetic friction coefficients μ_k are smaller than static coefficients μ_s.

Experience: $\mu_k < \mu_s < 1$.



Why does friction depend on the magnitude $|\vec{n}|$?

Microscopic analysis: The stationary or moving object causes a small depression in the atom lattice of the surface.

Depression is deeper if $|\vec{n}|$ is greater.

Polishing the surfaces (or adding a fluid) changes μ drastically.

Watch out: $\vec{f}$ and $\vec{n}$ are perpendicular.

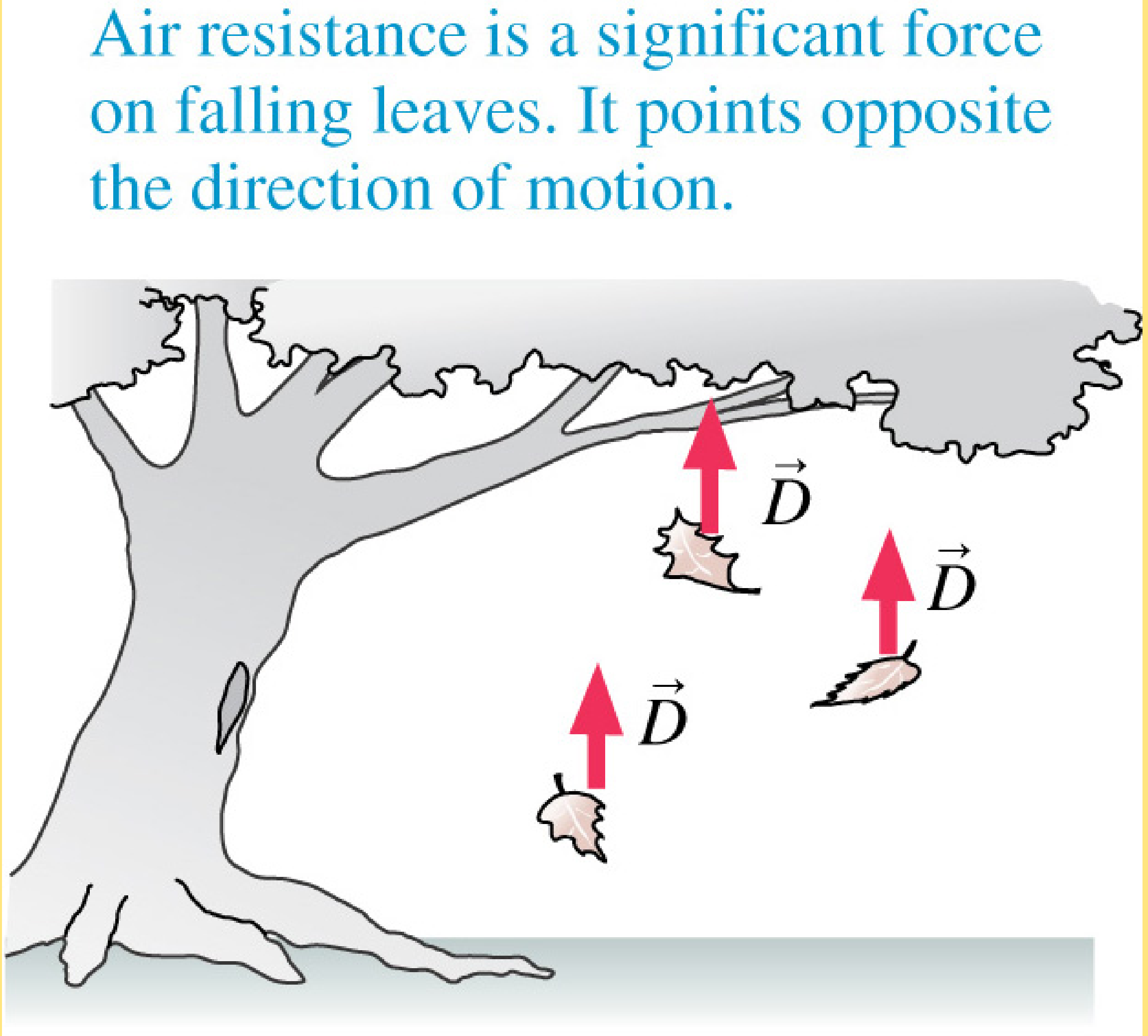
Yet, $|\vec{f}|$ and $|\vec{n}|$ are proportional.

Drag

Analogy to kinetic friction:

$\vec{D}$ opposes velocity vector $\vec{v}$.

However: $|\vec{D}|$ is proportional to $|\vec{v}|$ or $|\vec{v}|^2$



Observation:

Leaves fall with near-constant velocity. Why?

Gravity provides constant acceleration $g = 9.8\ \mathrm{m/s^2}$.

Downward velocity grows linearly in time.

What happens to $|\vec{D}|$?

$|\vec{D}|$ grows with speed $|\vec{v}|$; $\vec{D}$ opposes the weight $m\vec{g}$

At some t: forces balance, terminal velocity is reached

Spring Force

Springs come in different forms

coil spring: stretch and compress

Equilibrium position: no force

Away from equilibrium: restoring force

Hooke's law:

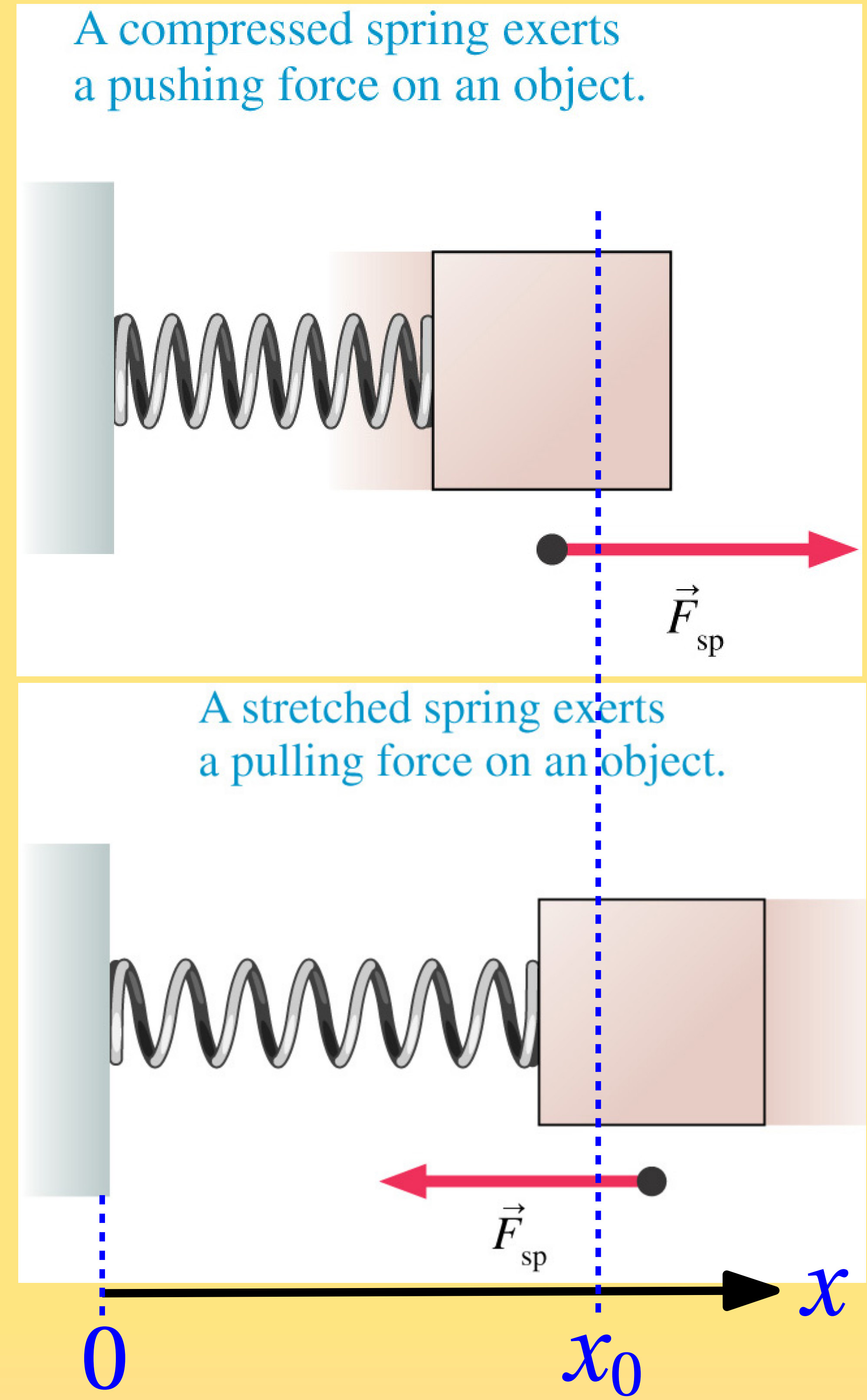
$$F_x = -k(x - x_0)$$

When $x > x_0$: $F_x < 0$, negative, points left

When $x < x_0$: $F_x > 0$, positive, points right

Where is x_0 in the figure?

Force increases linearly with displacement



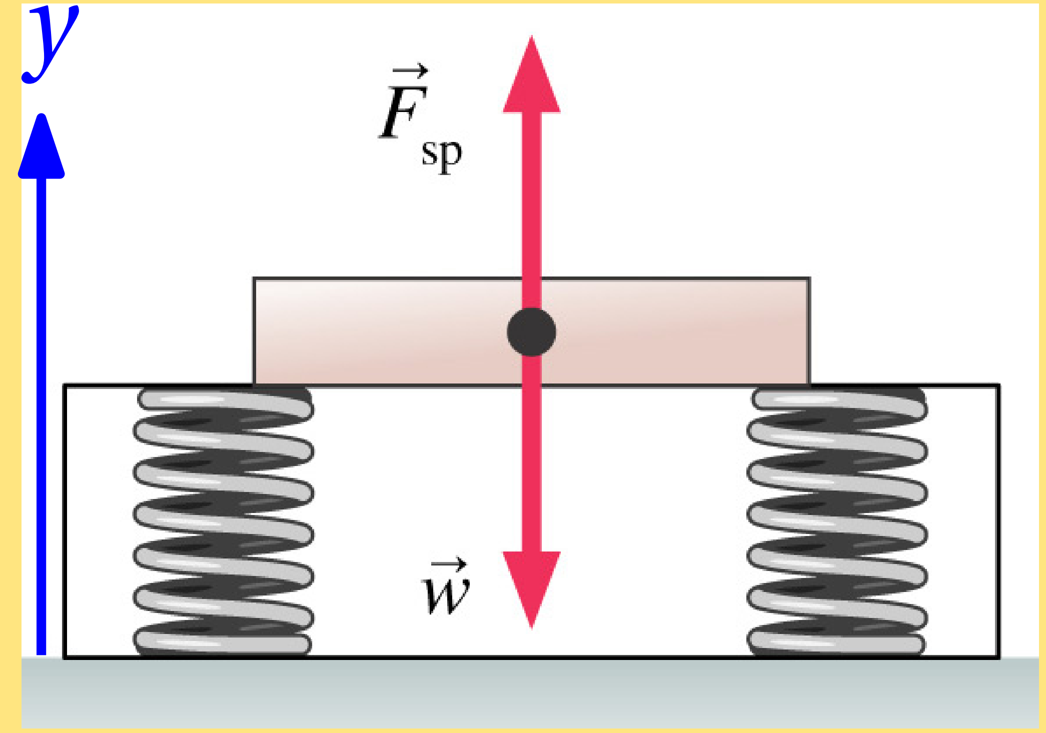
$$F_x = -k\Delta x$$

Model for: bonds (chemistry), pulling quarks out of nucleons(?), stretching rubber bands (elastics), vibrating rod, etc.

Spring Scale

Balance two forces (stationary object):

$$\vec{F}_{sp} + \vec{w} = 0$$

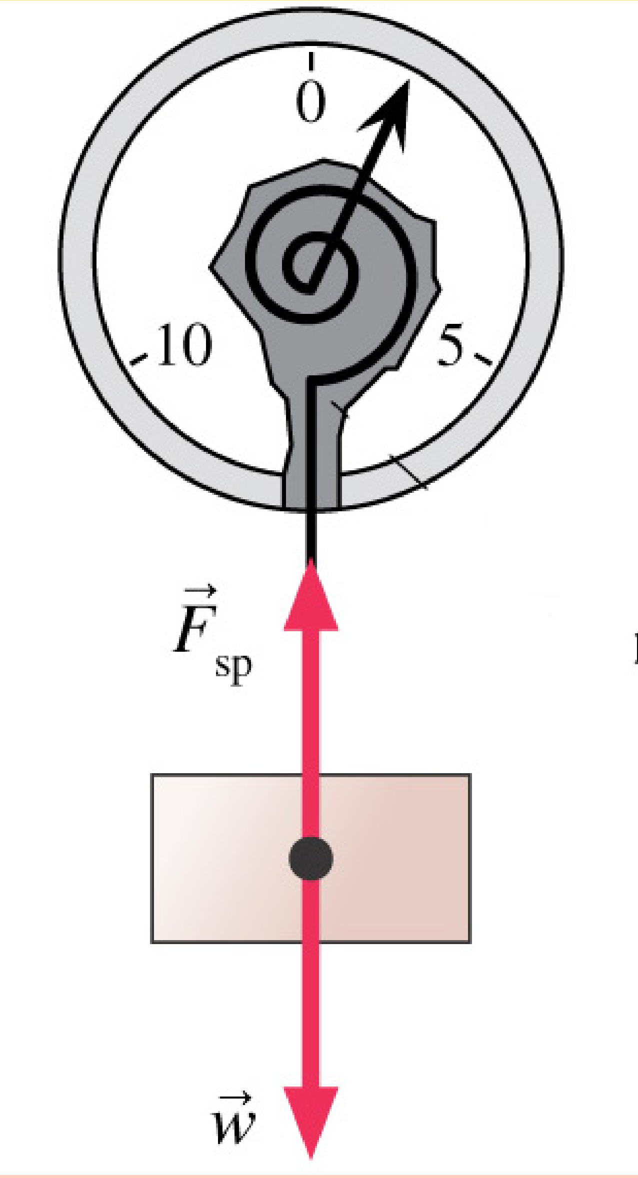


$$F_y = -k\Delta y \,;\; w_y = -mg$$

Given $\vec{w} = m\vec{g}$, $g = 9.8\ \mathrm{m/s^2}$, measure the mass m of the object?

Knowledge of the spring constant k, and measurement of the displacement Δy determines the mass m

$$m = -\frac{k\Delta y}{g}$$



what happens when the spring gets tired ?

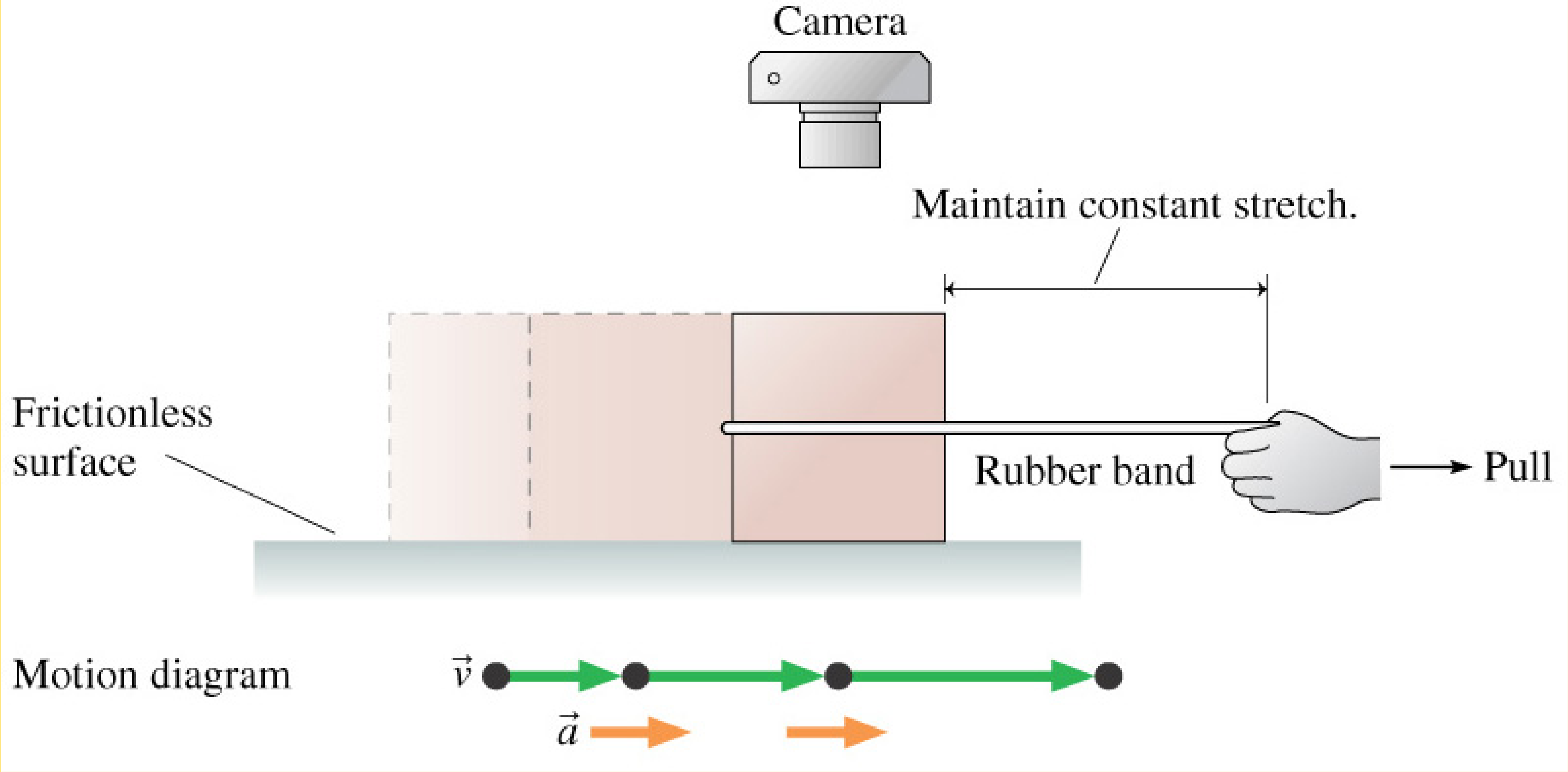
what does the scale read on the moon?

what does the scale read in a freely falling elevator?

AVOID ACCELERATED REFERENCE FRAMES !

Discover Newton's 2nd Law

Virtual experiment to find relation between force and acceleration



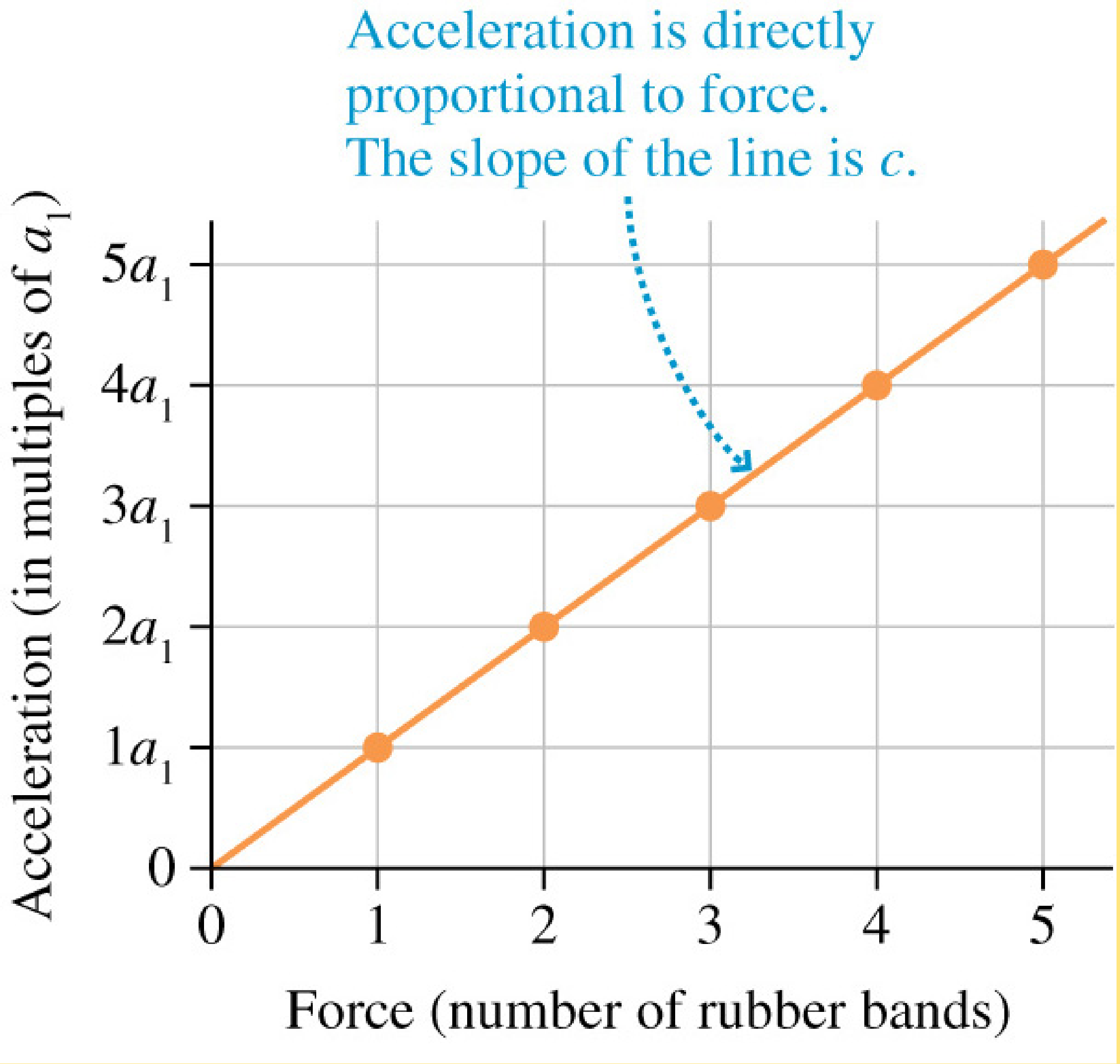
Constant stretch Δx: constant force applied (Hooke's law)

Obtain $\vec{v}(t)$, $\vec{a}(t)$ from motion diagram. Find that a_x is constant

Repeat experiment with more rubber bands in parallel, same Δx.
n rubber bands result in $n-$fold force. Why?

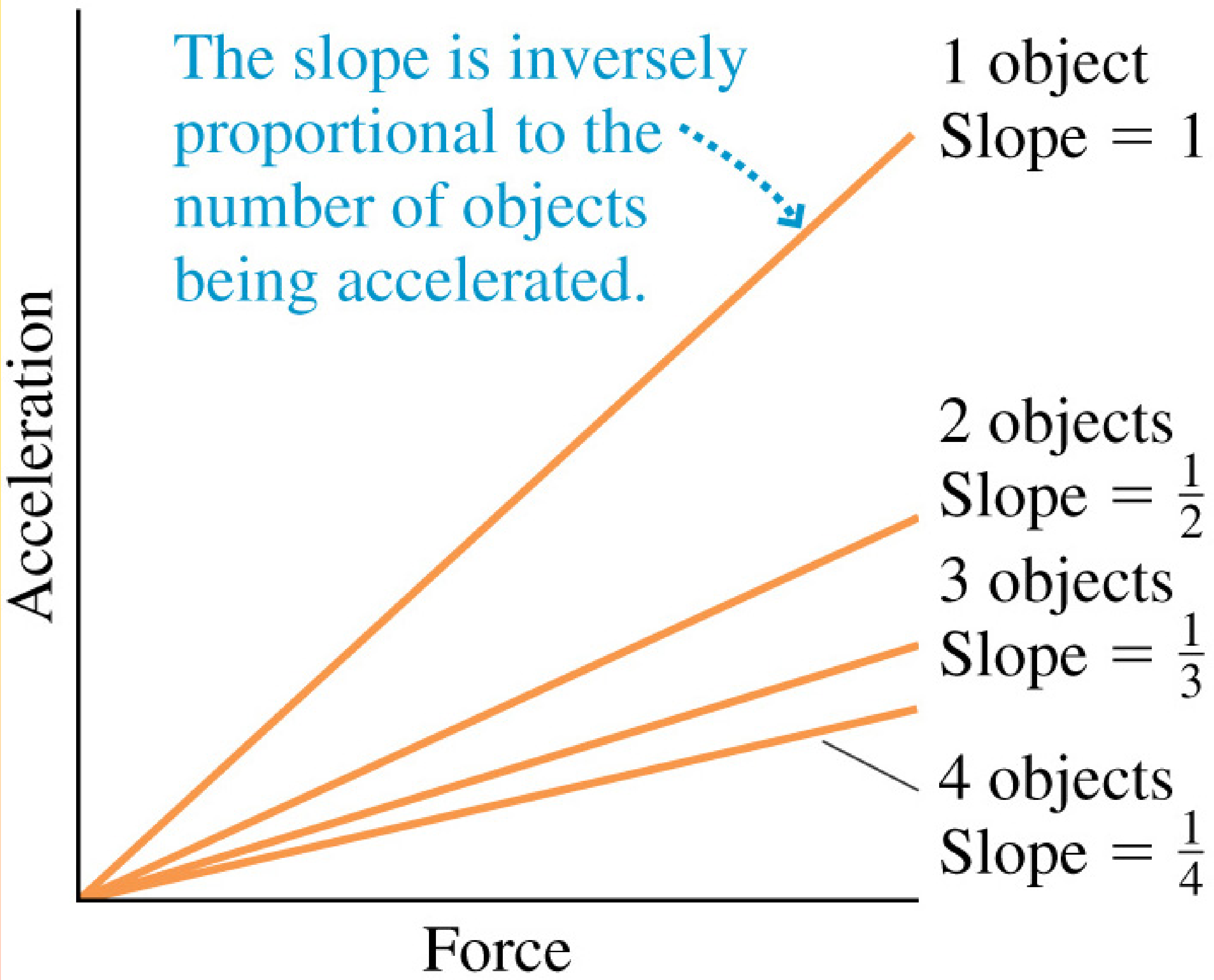
Now graph a_x versus F_x.

$$\vec{a} = \vec{F}/m \quad \text{or} \quad m\vec{a} = \vec{F}$$



Observed acceleration of fixed mass m is proportional to the applied force

Increase the mass m in integer multiples; observe decreased slope in the above graph



The Law

Kinematics:

acceleration = 2nd derivative of position vector $\vec{r}(t)$

$$\frac{\mathrm{d}^2\vec{r}}{\mathrm{d}t^2} = \frac{1}{m}\vec{F}_{\text{net}}$$

what does it mean ?

A net force acts on a body of mass $m \implies$ motion is determined

Another use:

$$\vec{F} = m\vec{a} = m\frac{\mathrm{d}^2\vec{r}}{\mathrm{d}t^2}$$

what does it mean ?

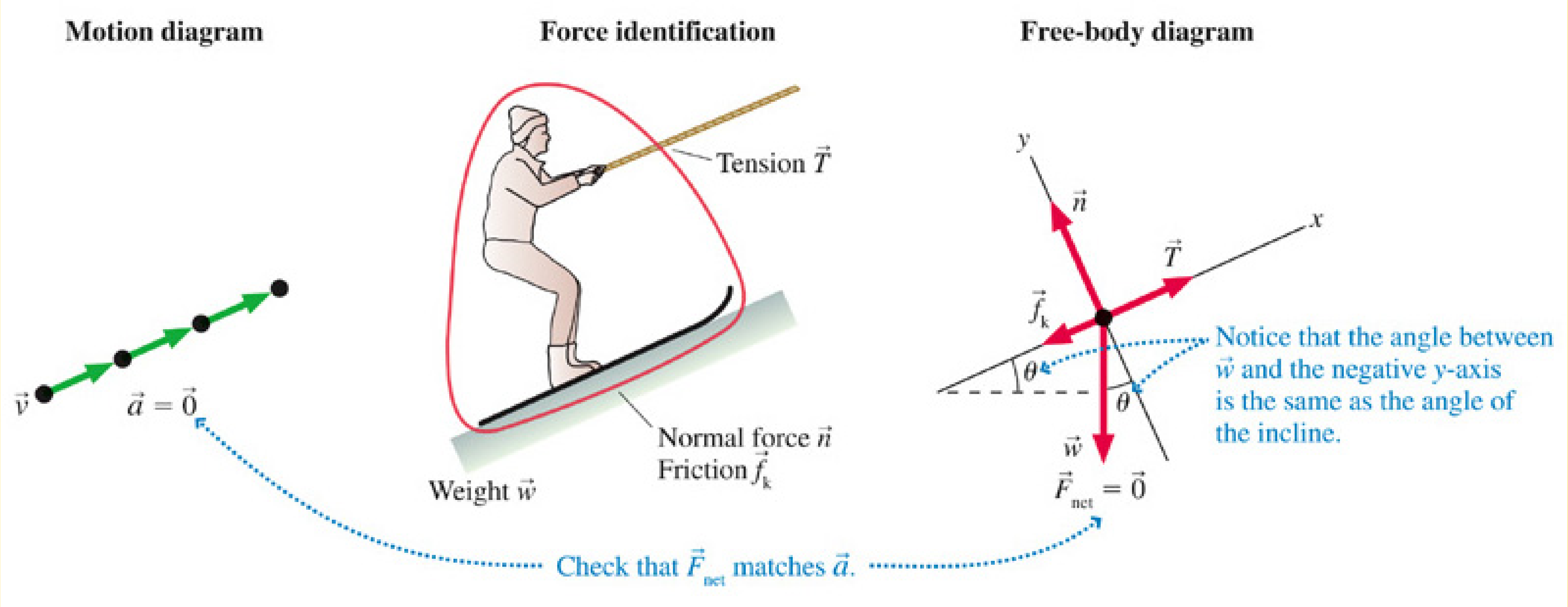
Known $\vec{a}$ for a body of mass $m \implies$ figure out net force

Free-body Diagram

Problem-solving strategy: construct $\vec{F}_{net}$

Example: skier pulled up the hill with constant velocity (tow lift)

Motion diagram: what is the skier's acceleration vector ?



Forces? gravity, string tension force, normal force, kinetic friction (excluded: pushing wind, skier changing weight, balancing arms)

Draw a vector diagram separate (!) from the figure

Move all force vectors to the point representing the mass!