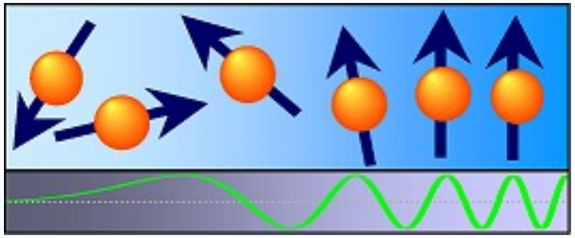
Experimental Physics
EP1 MECHANICS

- The Laws of Motion -



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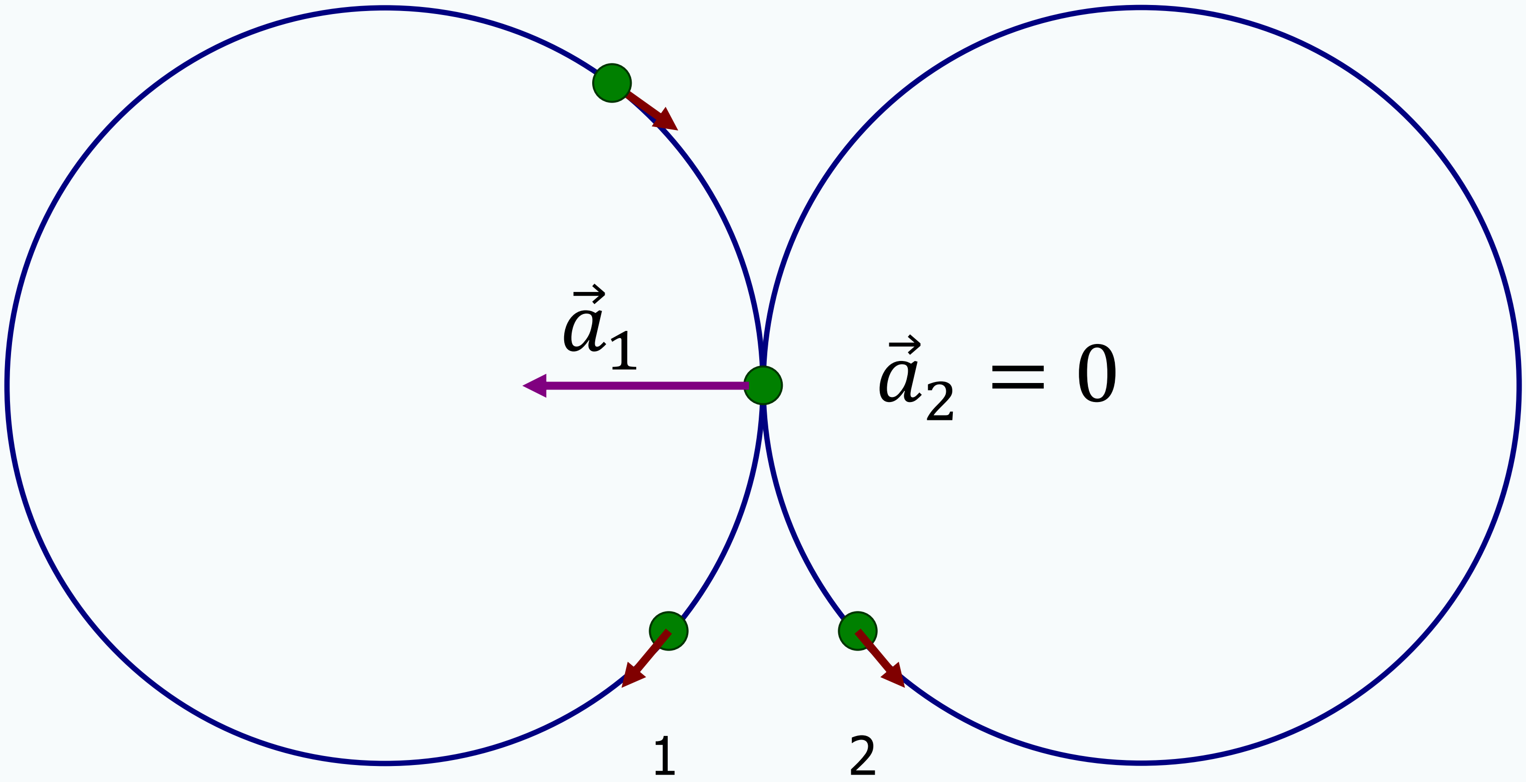
From Kinematics to Dynamics



Newton's First Law

An object continues to be in rest or continues its motion with a constant velocity unless it is acted on by an unbalanced force.

$$\vec{F}_{net} = \sum \vec{F} = 0 \qquad \vec{F}_{net} = \sum \vec{F} \neq 0$$

Inertial reference system; law of inertia

Newton's Second Law

The acceleration $\vec{a}$ of an object is inversely proportional to its mass m and is directly proportional to the acting force $\vec{F}$.

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

- defines force:

The force required to produce an acceleration of 1 m/s^2 is defined to be 1 newton (N).

- defines mass:

Mass is a measure of the resistance to acceleration.

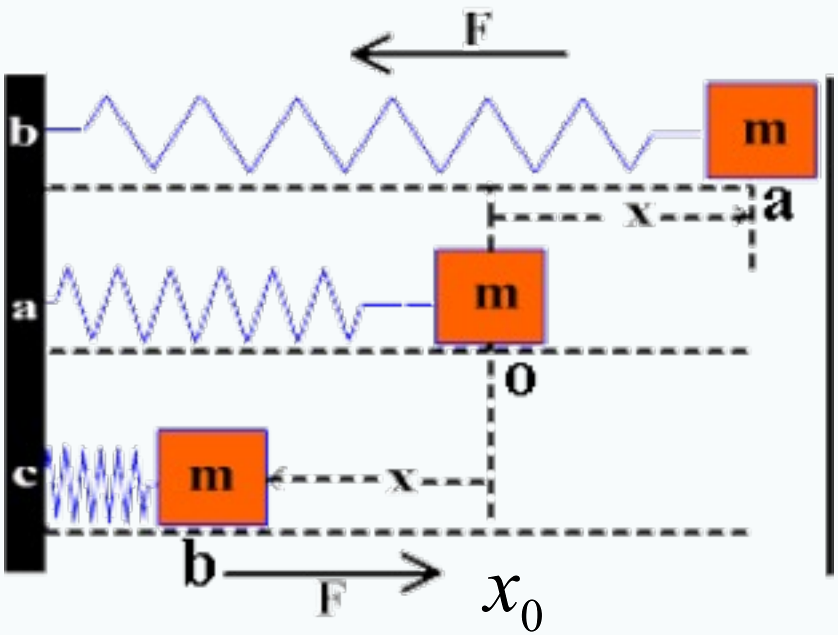
1 N = 1 kg m / s^2

$$\frac{m_1}{m_2} = \frac{a_2}{a_1}$$

Hooke's law

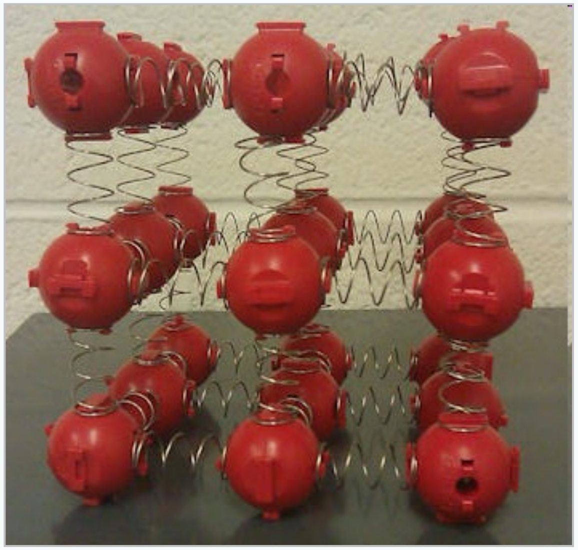
$$F = -k(x - x_0)$$

F is negative



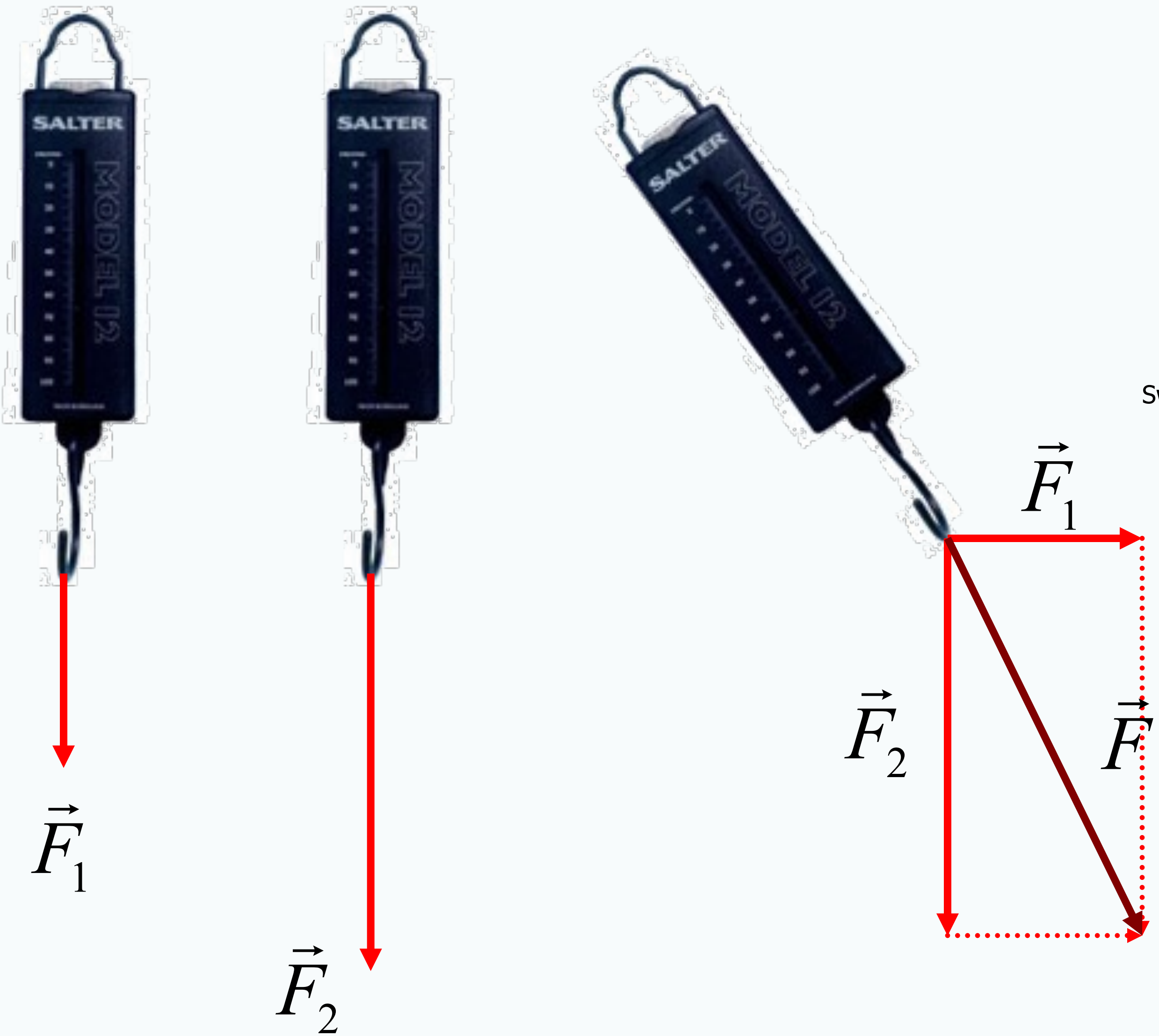
x_0

k is the force constant of the spring



F is positive

How to measure forces

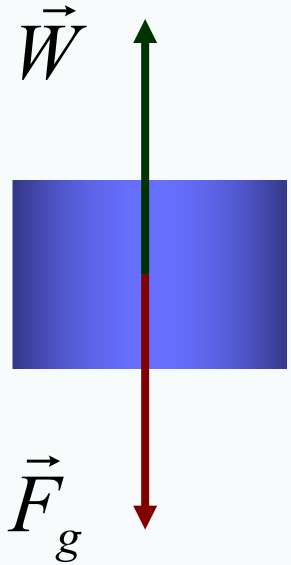


Switch activation force testing

Weight

$$\vec{F}_g = m\vec{g}$$

The weight *W* of a body is a net force requiring to prevent the body from falling freely.



$$W - F_g = 0$$

$$W = F_g$$

❖ Can your apparent weight be greater than the true weight?

❖ How the mass and the weight of an astronaut changes far away of galaxies?

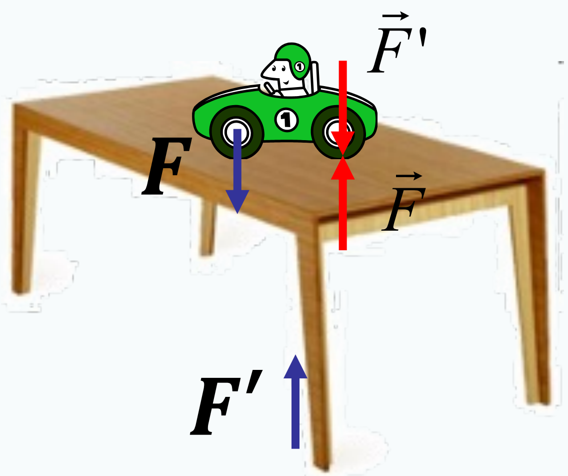
Newton’s Third Law

Forces always occur in pairs. That means that if an object A exerts a force on another object B, then B will exert equal but opposite force on A.

Action-reaction pairs: **law of interaction**

Can the action and reaction forces balance each other?

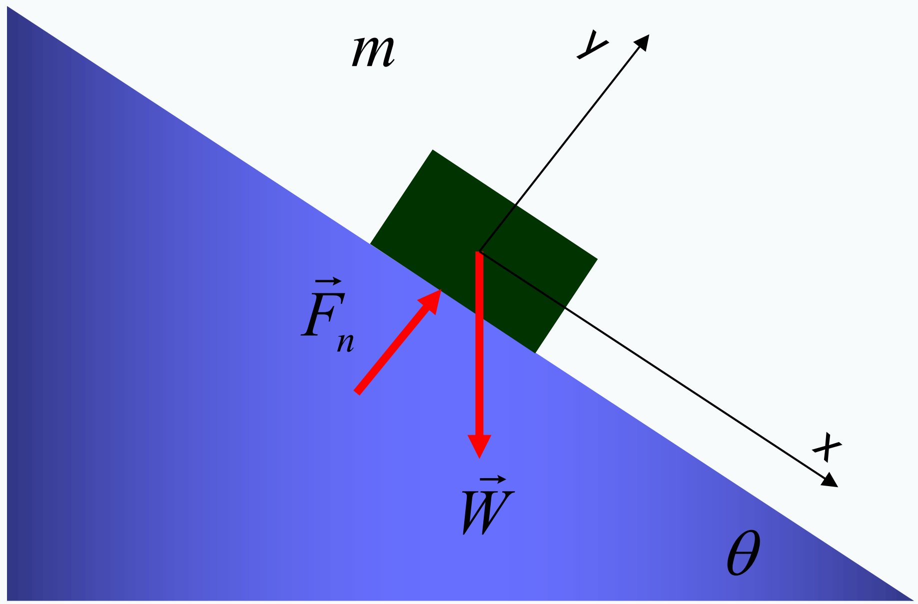
No. They are acting on different objects!



To remember!

- **The fundamentals of classical mechanics are contained in three <u>Newton's laws of motion</u>.**
- **Reference frames where the Newton's laws are applicable are called <u>inertial reference frames</u>.**
- **The Newton's second law may be considered as a definition of <u>force</u> and <u>mass</u>.**
- **The <u>weight</u> of an object is the gravitational force between the object and the Earth.**
- **There are only <u>four fundamental forces</u>.**

Inclined surface



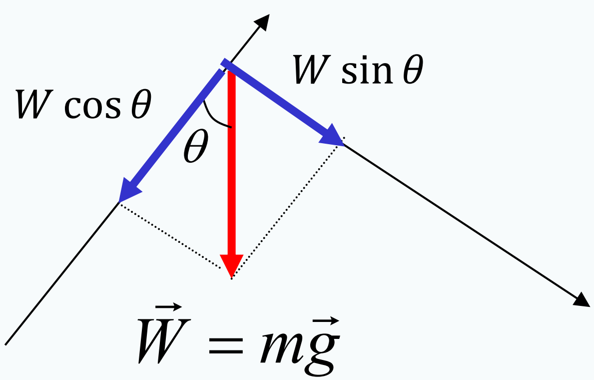
$$\sum F_x = ma_x$$

$$mg\sin\theta = ma_x$$

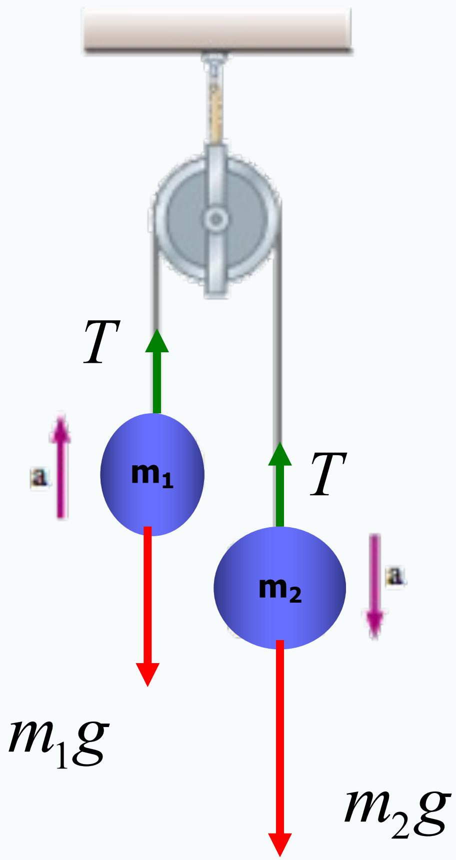
$$a_x = g\sin\theta$$

$$\sum F_y = 0$$

$$F_n - mg\cos\theta = 0$$



Attwood Machine



$$\sum F_y = ma_y$$

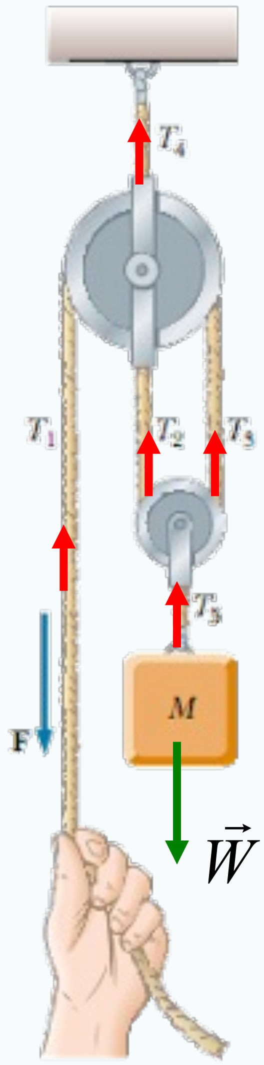
$$T - m_1 g = m_1 a$$

$$T - m_2 g = -m_2 a$$

$$a = g\,\frac{m_2 - m_1}{m_2 + m_1}$$

$$T = g\,\frac{2m_2 m_1}{m_2 + m_1}$$

Multi-pulley system



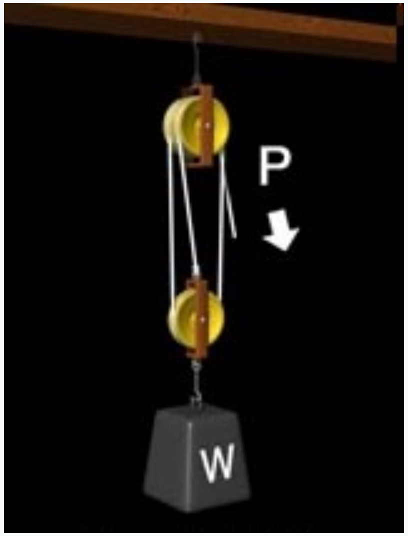
$$\sum F_y = 0$$

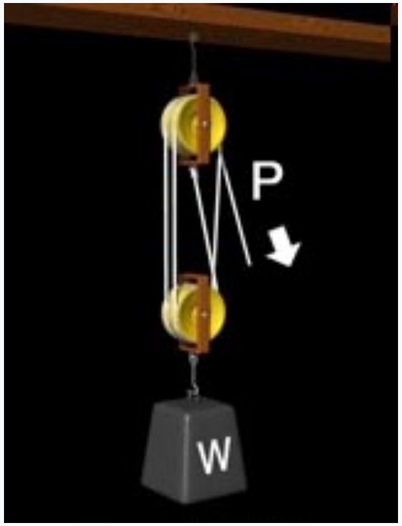
$$T_5 = W$$

$$T_2 + T_3 = W$$

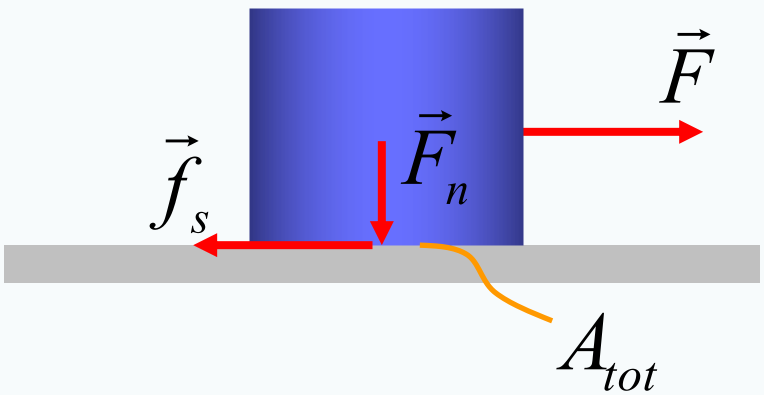
$$T_1 = T_3 = T_2$$

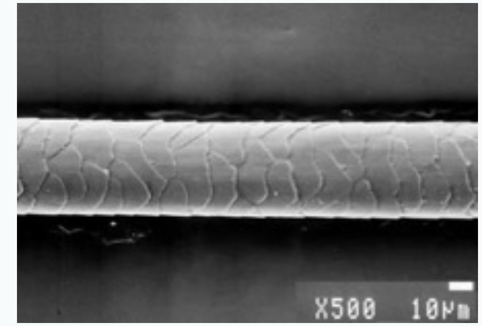
$$\boxed{F = W/2}$$

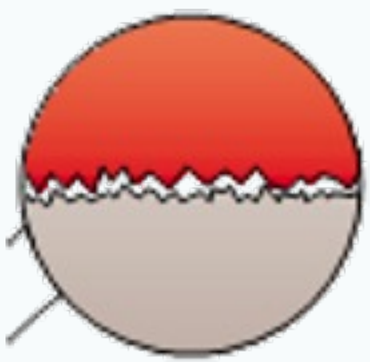


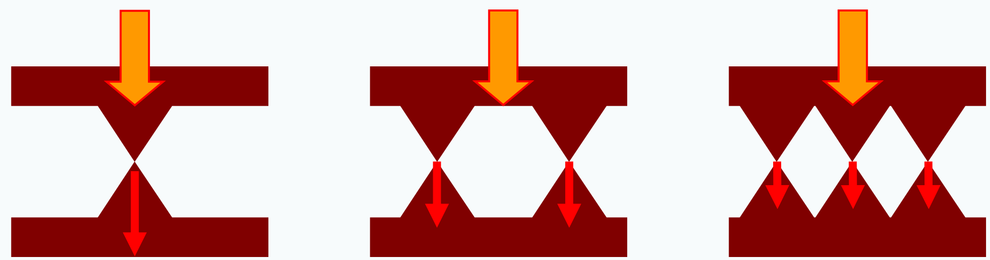


Static friction









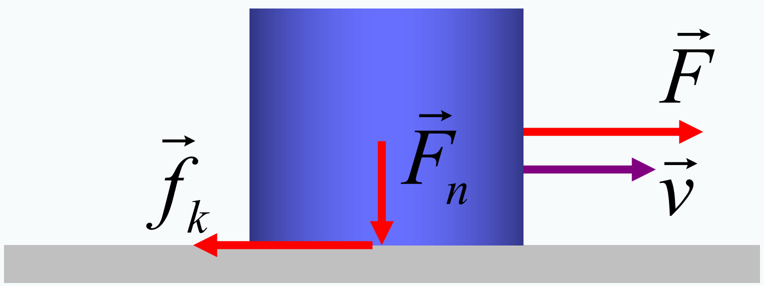
$$F_n = \sum_{i=1}^{N} F_{n,i} = N \times f_n = N \times \frac{F_n}{N}$$

$$f_{s,\max} = \mu_s F_n$$

$$f_{s,\max} \cancel{\propto} \; area$$

$$\boxed{f_s \le \mu_s F_n}$$

Kinetic friction



$$\boxed{f_k = \mu_k F_n}$$

Experimental observations:

- $\mu_k < \mu_s$
- μ_k **does not depend on the area**
- μ_k **nearly constant for speeds between 1 cm/s and 10 m/s**

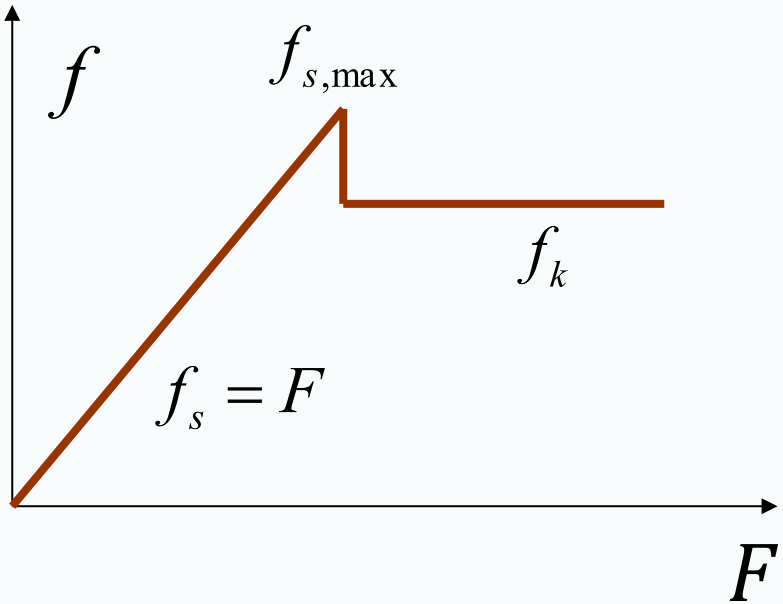


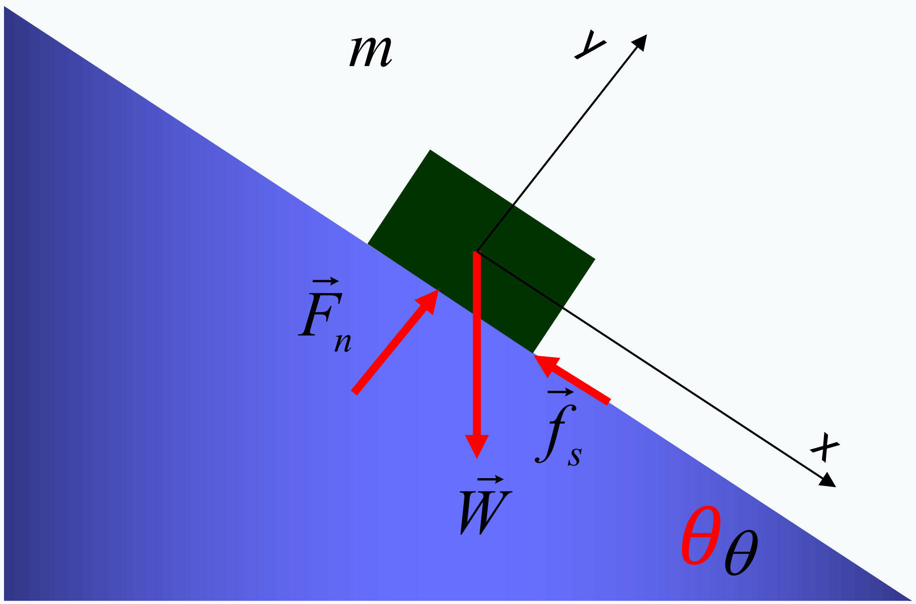
TABLE 5.2 Coefficients of Friction[a]

	μ_s	μ_k
Steel on steel	0.74	0.57
Aluminum on steel	0.61	0.47
Copper on steel	0.53	0.36
Rubber on concrete	1.0	0.8
Wood on wood	0.25–0.5	0.2
Glass on glass	0.94	0.4
Waxed wood on wet snow	0.14	0.1
Waxed wood on dry snow	—	0.04
Metal on metal (lubricated)	0.15	0.06
Ice on ice	0.1	0.03
Teflon on Teflon	0.04	0.04
Synovial joints in humans	0.01	0.003

[a] All values are approximate. In some cases, the coefficient of friction can exceed 1.0.

* How do wheels work?

Inclined surface with friction



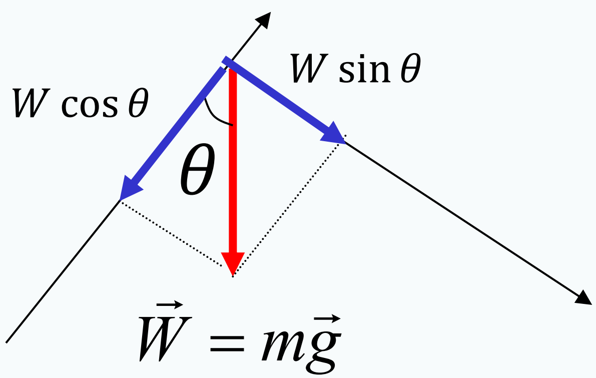
$$\sum F_x = ma_x$$

$$mg\sin\theta - f_s = 0$$

$$\sum F_y = 0$$

$$F_n - mg\cos\theta = 0$$

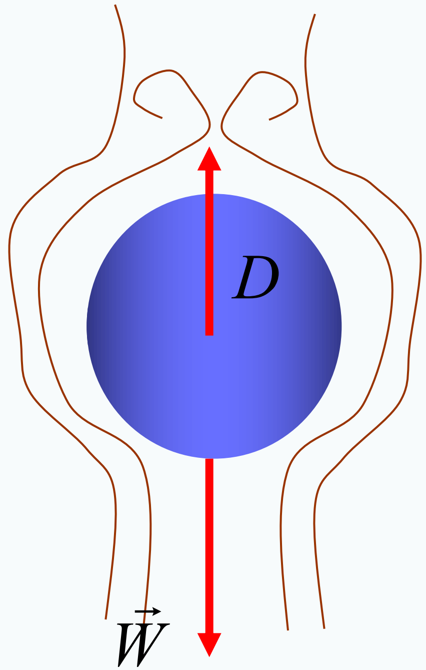
$$F_n \tan\theta_c - \mu_s F_n = 0$$

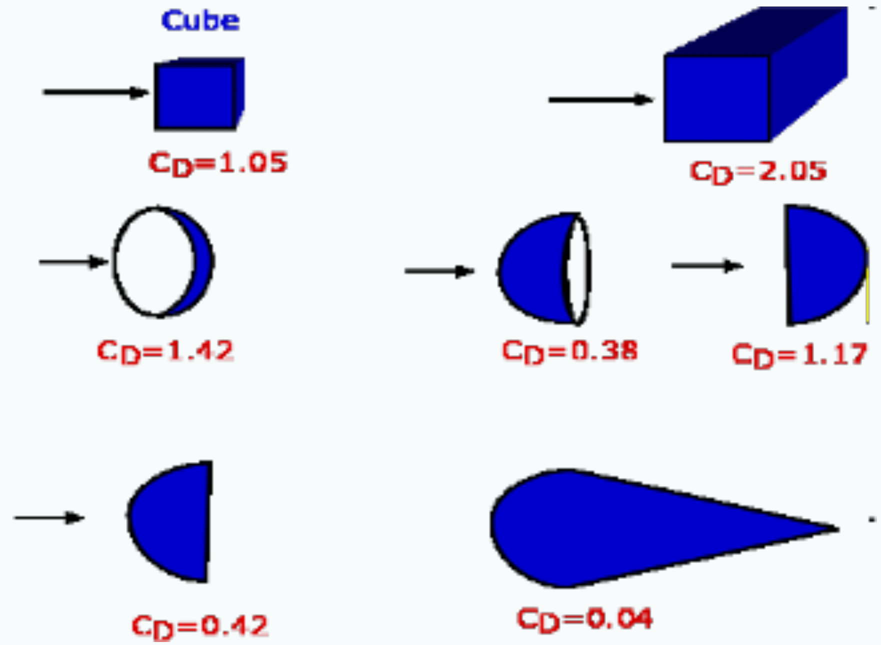


$$mg\sin\theta - f_k = ma_x$$

$$a_x = g(\sin\theta - \mu_k\cos\theta)$$

Drag forces





$$D = \frac{1}{2} A C_D \rho v^2$$

A – effective cross-section

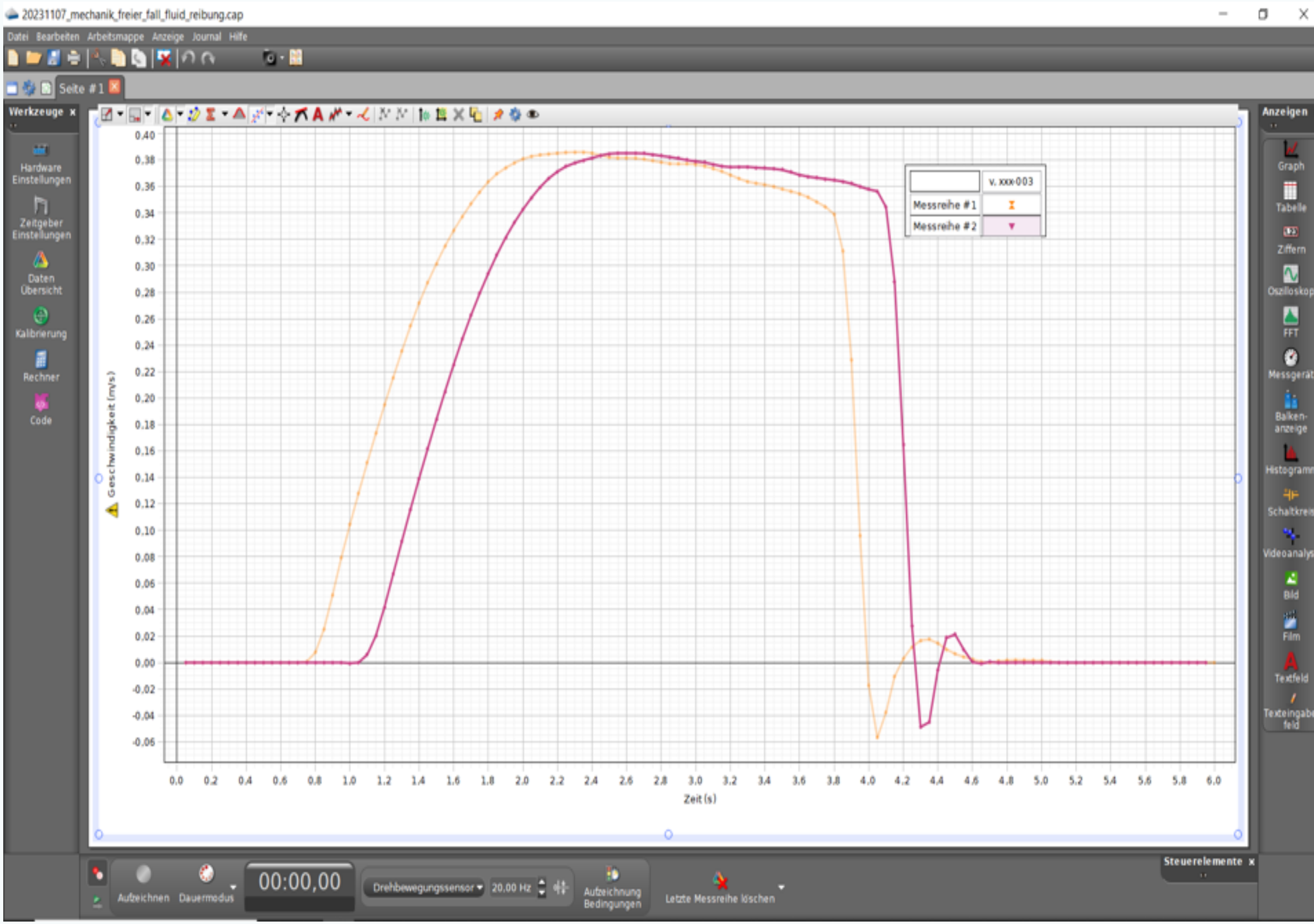
C_D – geometric shape factor

ρ - medium (fluid) density

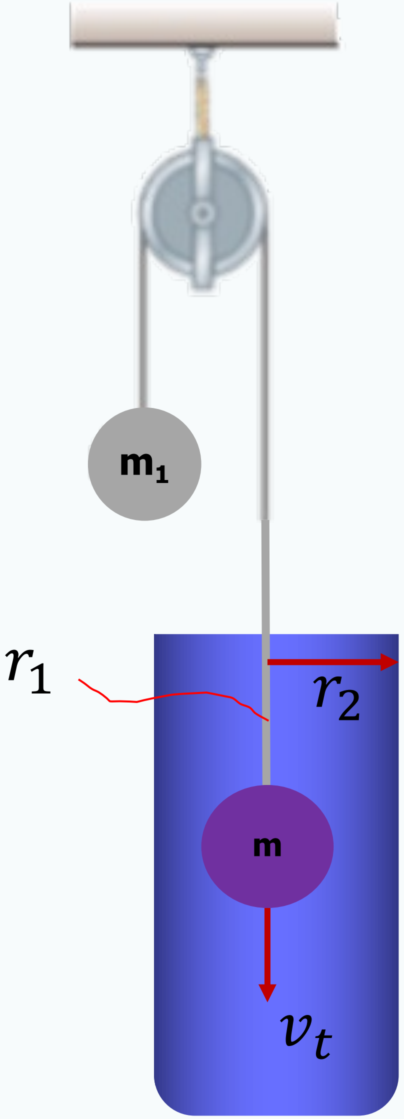
$$D - mg = ma$$

$$v_{terminal} = \sqrt{\frac{2mg}{A C_D \rho}}$$

Attwood machine in water



Attwood machine in water

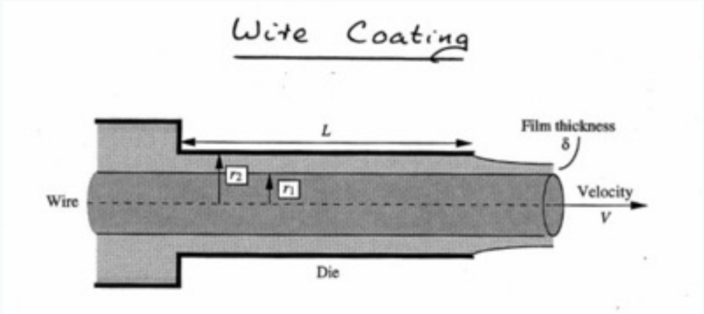


$$-mg + m_1 g + F_D + F_B = 0$$

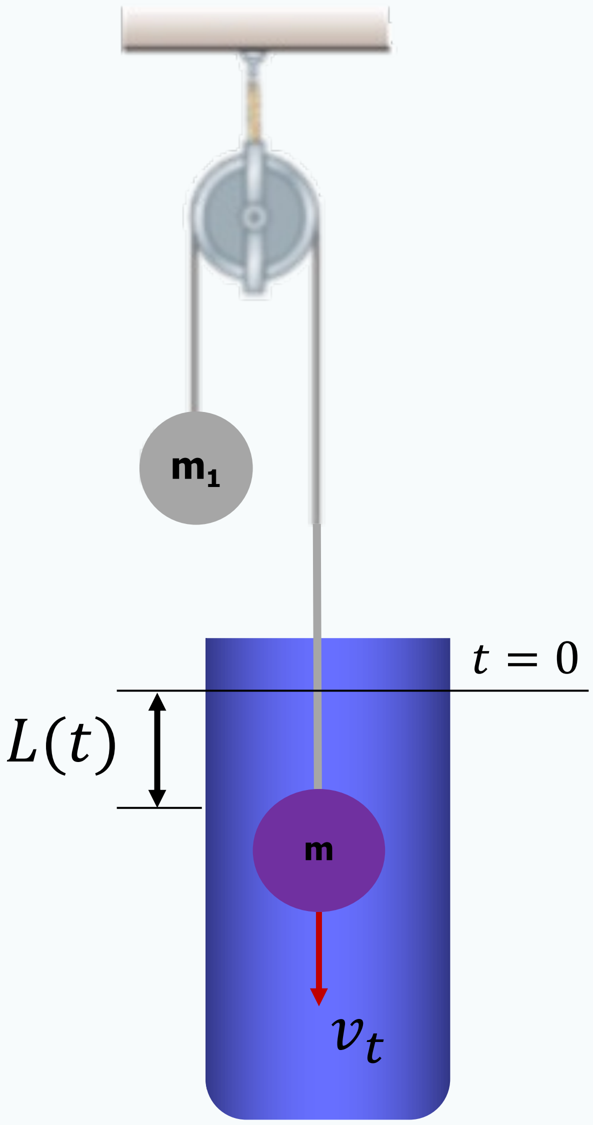
$$F_B = \rho_l V g \qquad F_D = 0.5 \rho_l C_d A v^2$$

$$v_t = \frac{\sqrt{2\rho_l C_d A g (m - m_1 - \rho_l V)}}{\rho_l C_d a}$$

$$F_{th} = ma \qquad F_{wire} = \frac{2\pi\eta L v}{\ln(r_2/r_1)}$$



Attwood machine in water



$$v_t = \frac{\sqrt{2\rho_l C_d A g (m - m_1 - \rho_l V)}}{\rho_l C_d a}$$

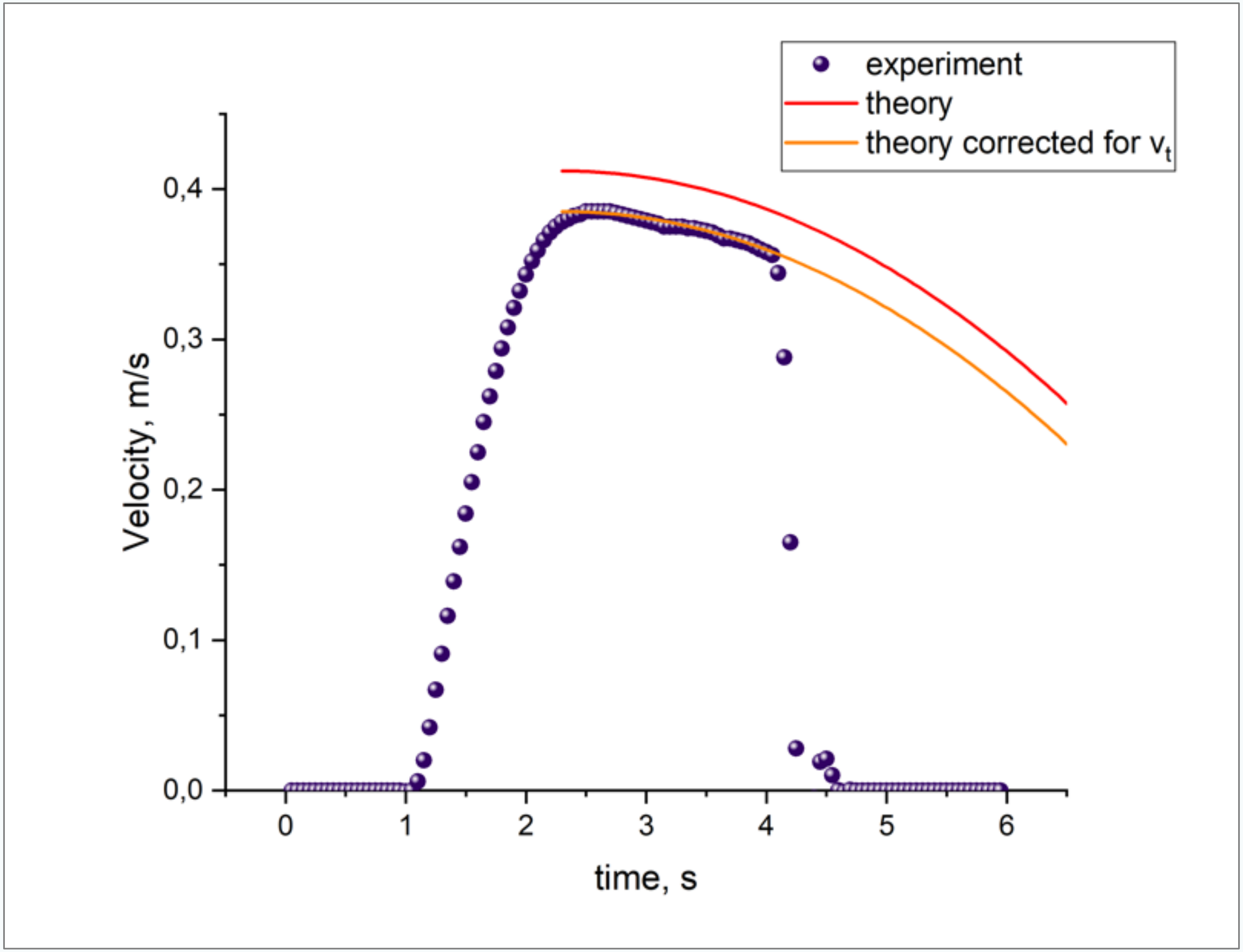
$$F_{th} = ma \qquad F_{th} = \frac{2\pi\eta L v}{\ln(r_2/r_1)}$$

$$\frac{dv_{in}}{dt} \approx \frac{2\pi\eta(v_t t)v_t}{m\ln(r_2/r_1)}$$

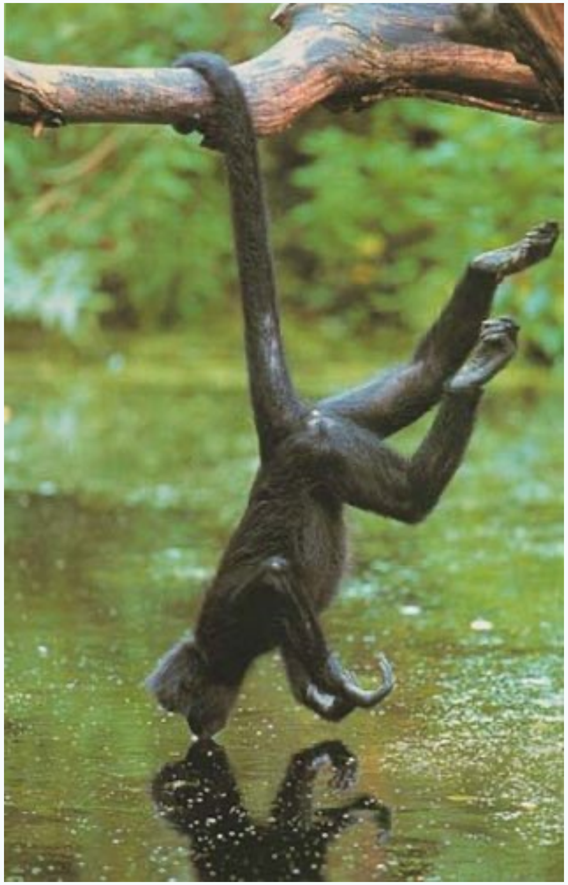
$$v_{in} = \frac{2\pi\eta(m - m_1 - \rho_l V)g t^2}{\rho_l C_d m \ln(r_2/r_1)}$$

$$\boxed{v_m \approx v_t - v_{in}}$$

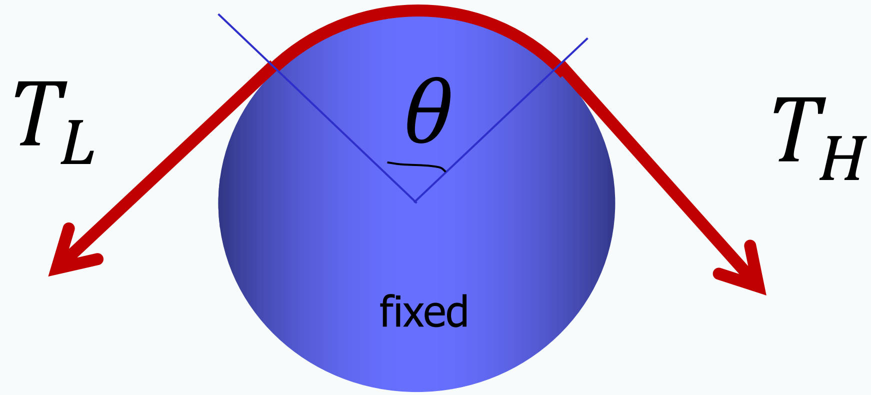
Attwood machine in water



Capstan equation

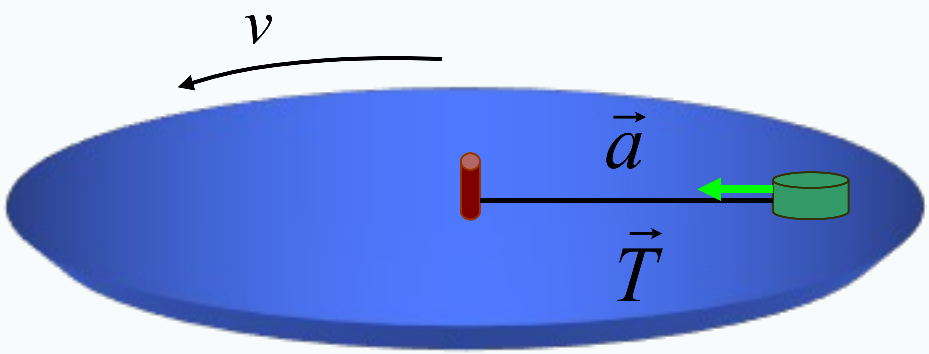


$$T_{Load} = T_{Hold}\, e^{\mu_s \theta}$$

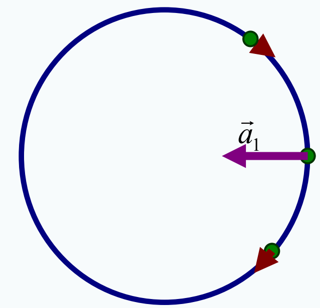


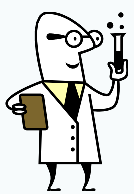
Euler-Eytelwein

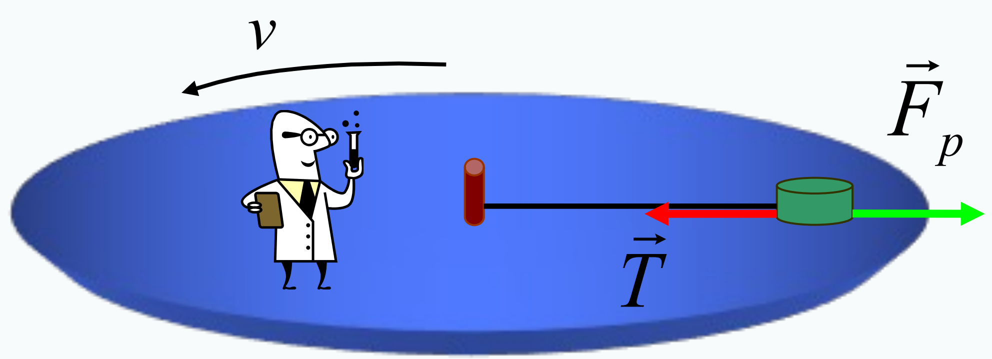
Centrifugal force



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

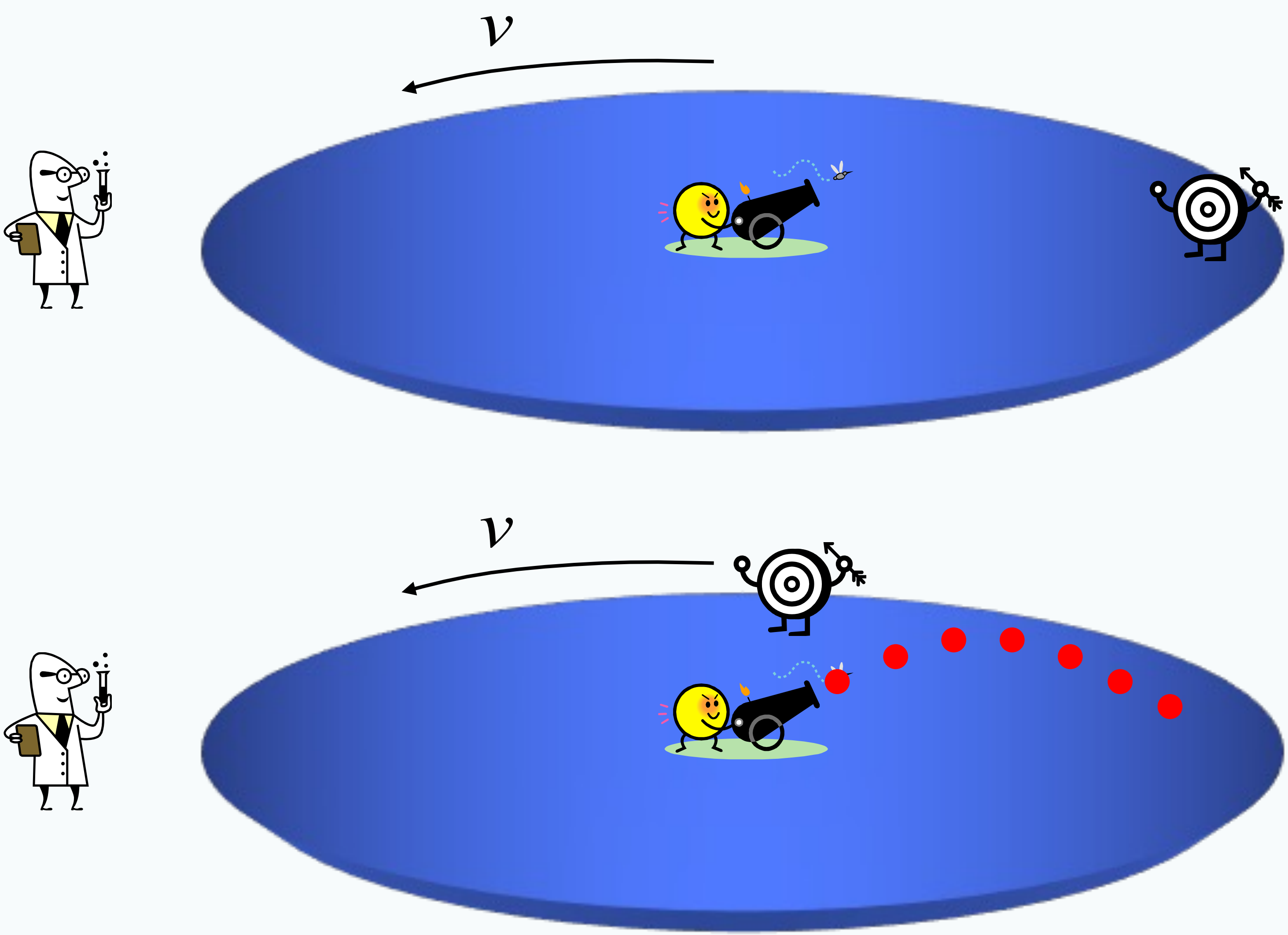




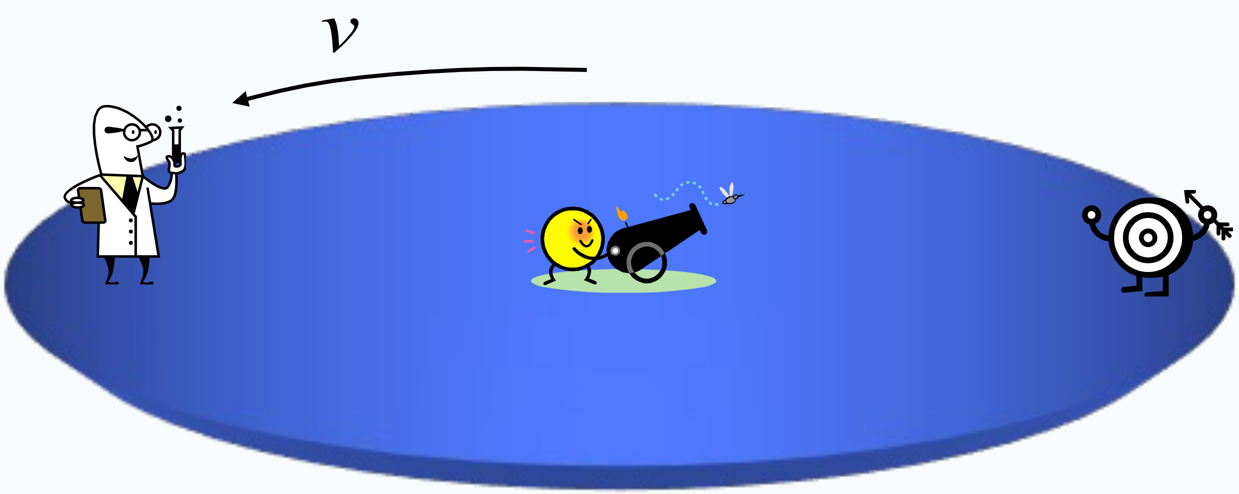


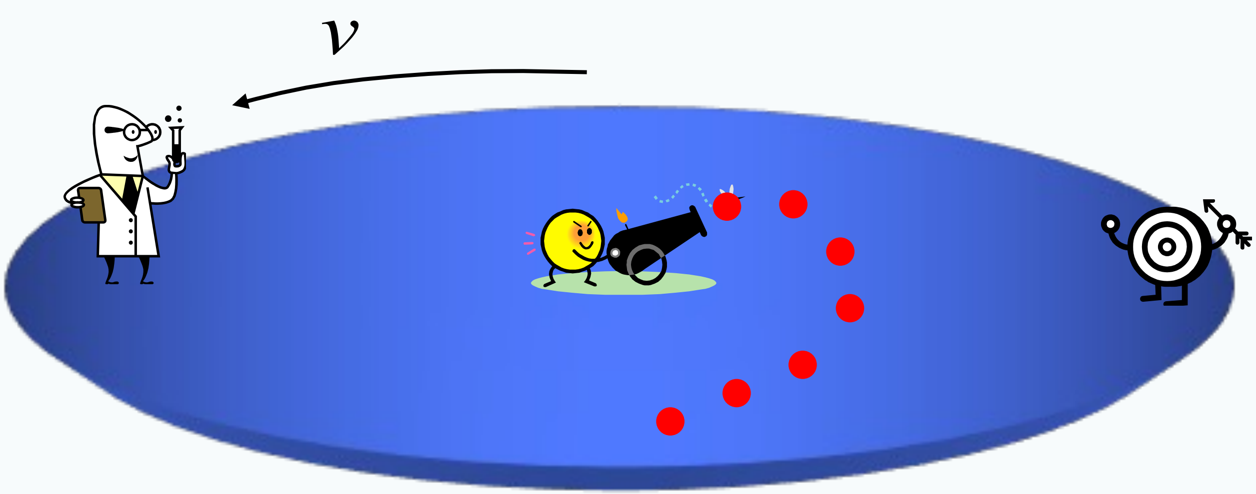
$$\vec{F}_p = \frac{mv^2}{r}\hat{\mathrm{r}}$$

Coriolis force

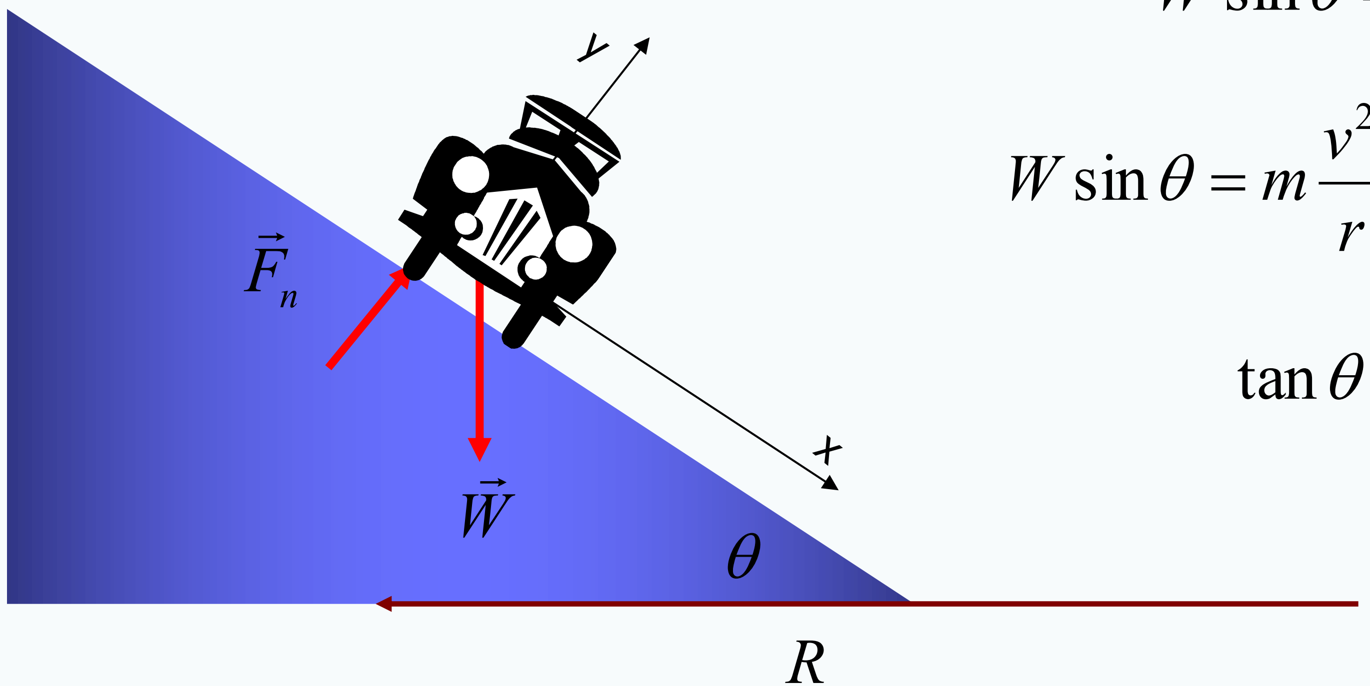


Coriolis force





Inclined surface



$$W \sin\theta = ma_x$$

$$W \sin\theta = m\frac{v^2}{r}\cos\theta$$

$$\tan\theta = \frac{v^2}{rg}$$

What is the minimal angle θ at which a car moving with a velocity of $v = 60$ km/h still can pass a curved (of radius R = 30 m) road covered with ice?

To remember!

- **To solve the problem, identify the <u>object</u> of interest and all <u>forces</u> acting on, find a convenient coordinate system, and finally apply the Newton's second low in the component form.**
- **Two bodies in contact may exert <u>frictional forces</u> on each other.**
- **A fluid surrounding moving objects may exert <u>drag forces</u>.**
- **There are <u>pseudo-forces</u> (centrifugal).**