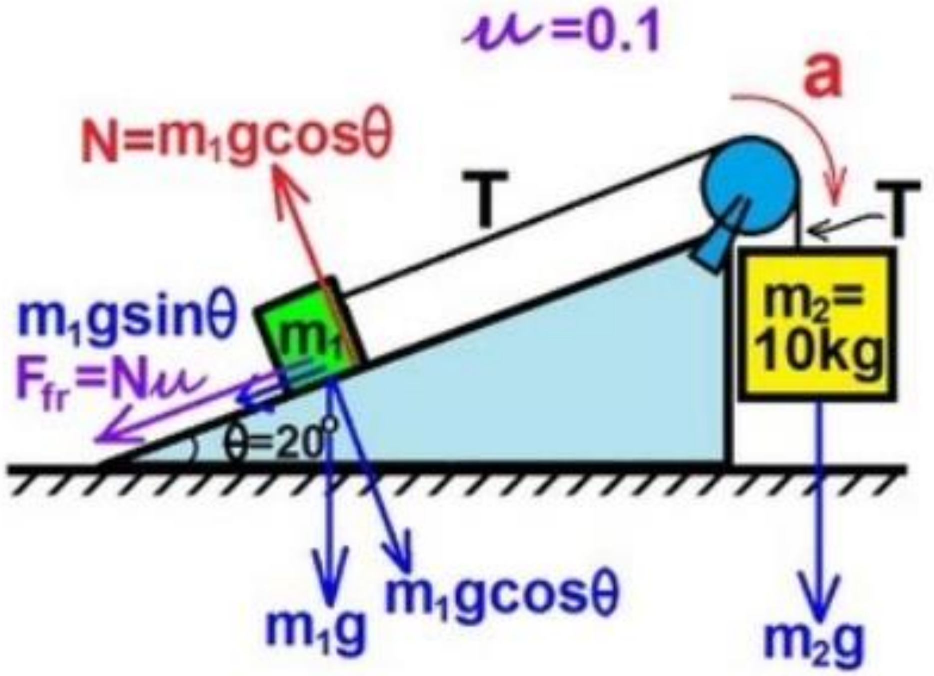
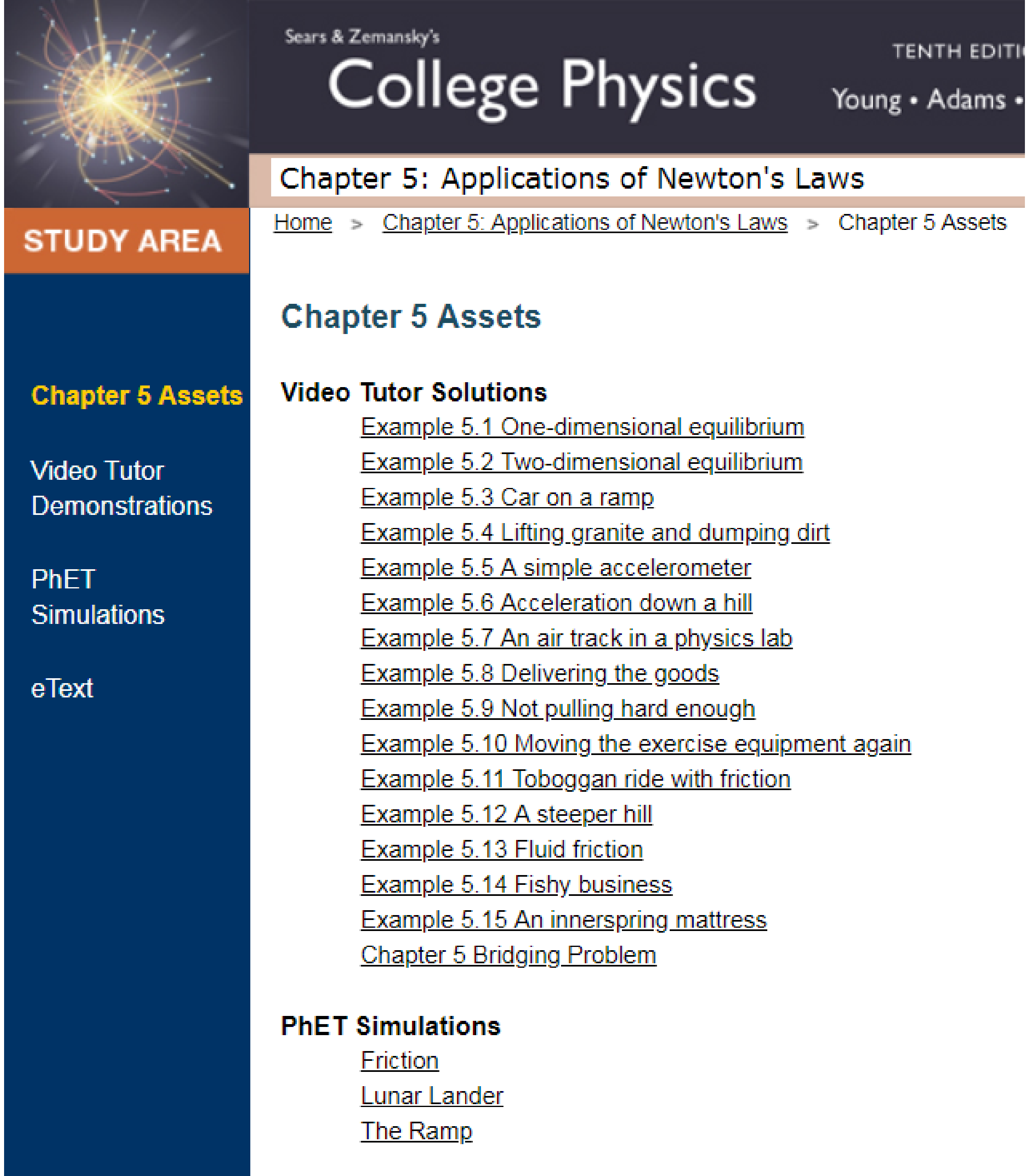
Applications of Newton's Laws
Chapter 5



Use the study area as we go through the slides

VTS Ex 5.1

PhET Friction



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STUDY AREA

Chapter 5: Applications of Newton's Laws

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- Friction
- Lunar Lander
- The Ramp

Goals for Chapter 5

- To draw free-body diagrams, showing forces on an individual object.
- To solve for unknown quantities using Newton's 2^{nd} law on an object or objects connected to one another.
- To relate the force of friction acting on an object to the normal force exerted on an object in 2^{nd} law problems.
- To use Hooke's law to relate the magnitude of the spring force exerted by a spring to the distance from the equilibrium position the spring has been stretched or compressed.

Newton's first law

Every object continues either at rest or in constant motion in a straight line,
unless it is forced to change that state by forces acting on it.

Newton's Second Law

- **The net force acting on an object is equal to its mass times its acceleration**

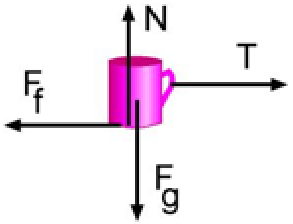
Vector form

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

Component form

$$\Sigma F_x = ma_x \qquad \Sigma F_y = ma_y$$

1. $\Sigma \vec{F} = 0$
2. $\Sigma \vec{F} = m\vec{a}$
3. $\vec{F}_{AB} = -\vec{F}_{BA}$



Newton's First Law: Vector form

$$\sum \vec{F} = 0 \qquad \vec{a} = 0$$

$$\Delta \vec{v} = 0$$

$$\vec{v} = \text{constant}$$

SUMMARY (also see page 121)

Newton's third law

- **For every action (force) there is a reaction (force) equal in magnitude and opposite in direction.**

$$\vec{F}_{AonB} = -\vec{F}_{BonA}$$
$$\vec{F}_{AB} = -\vec{F}_{BA}$$

- Forces always act in pairs (of action and reaction)

5.1 Equilibrium of a particle

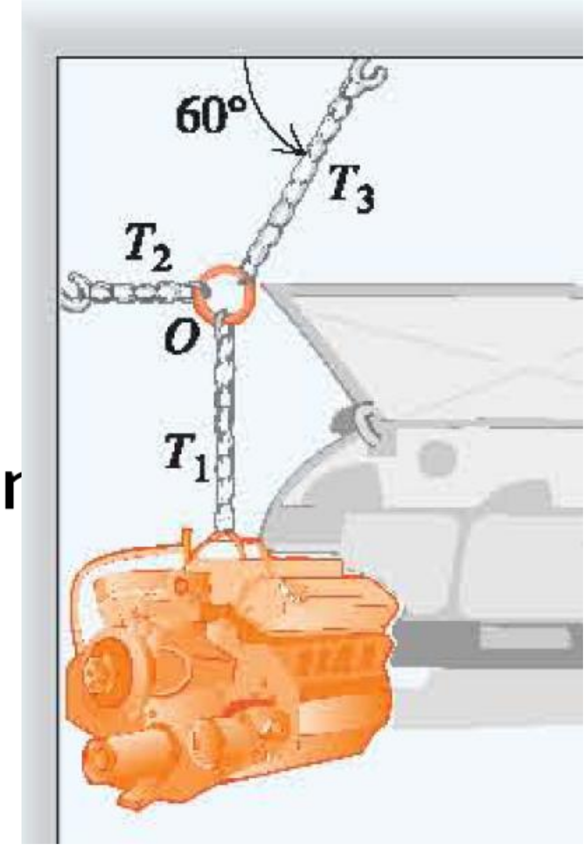
- A **particle** is in equilibrium if there is no net force acting on it.

$$\Sigma \vec{F} = 0$$

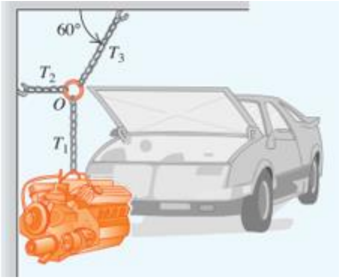
Example 5.2: 2D equilibrium > 1. $\Sigma\vec{F} = 0$

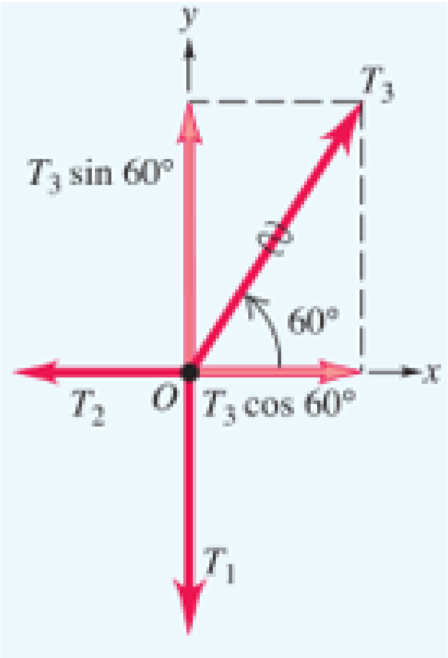
VTS Ex 5.2

A car engine with mass m = 224 kg kg hangs from a chain that is linked at point O to two other chains, one fastened to the ceiling and the other to the wall. Find the tension in each of the three chains, assuming that w is given and the weights of the chains themselves are negligible.



Ans = T1 = 2,195 N , T2 = 1,268 N , T3 = 2,535 N



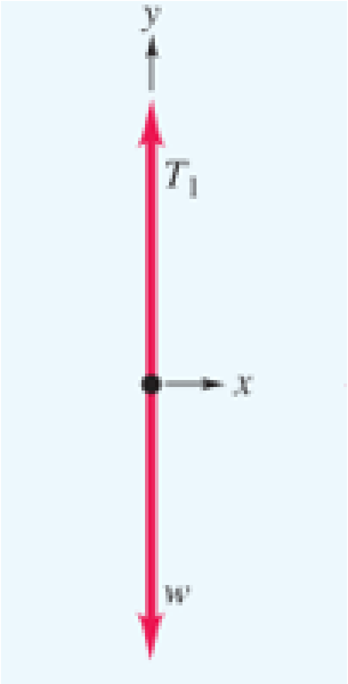


(c) Free-body diagram of ring O

Draw a free body diagram for the O ring. Since the net force is zero write two equations.

Realize you have 3 unknowns.
You need another equation from the free body diagram of the engine.

Solve the equations.



(b) Free-body diagram of engine

$$\sum F_x = 0 = T_3 \cos(60) - T_2$$

$$\sum F_y = 0 = T_3 \sin(60) - T_1$$

$$\sum F = 0 = T_1 - 224 \ x \ 9.8$$

Ans = T1 = 2,195 N , T2 = 1,268 N , T3 = 2,535 N

5.2 > 2 $\Sigma\vec{F} = m\vec{a}$

5.2 Applications of Newton's Second Law

We're now ready to discuss problems in **dynamics,** showing applications of Newton's second law to systems that are *not* in equilibrium. Here's a restatement of that law:

Newton's second law

An object's acceleration equals the vector sum of the forces acting on it, divided by its mass. In vector form, we rewrite this statement as

$$\Sigma\vec{F} = m\vec{a}. \tag{4.7}$$

However, we'll usually use this relation in its component form:

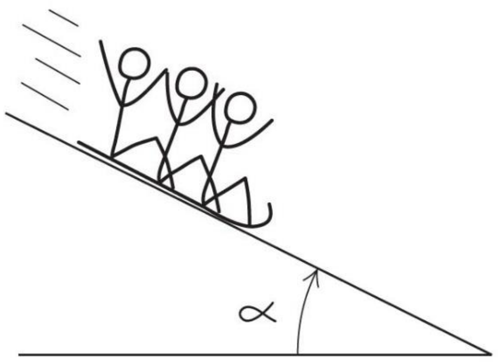
$$\Sigma F_x = ma_x, \qquad \Sigma F_y = ma_y. \tag{4.8}$$

Example 5.6: 2D acceleration

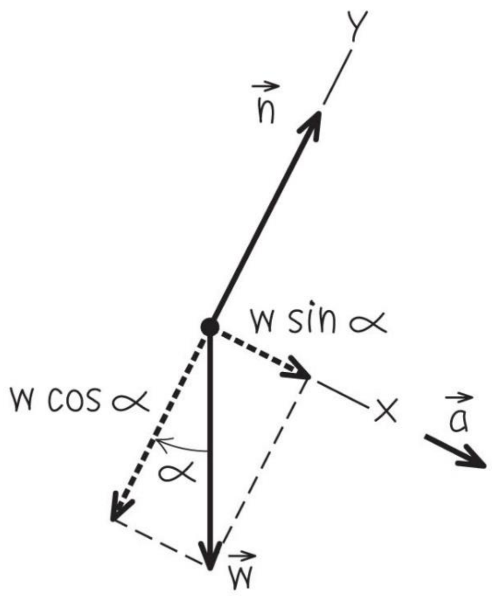
VTS Ex 5.6

- A toboggan loaded with vacationing students (total weight w) slides down a long, snow-covered slope. The hill slopes at a constant angle α, and the toboggan is so well waxed that there is virtually no friction at all. Find the toboggan's acceleration and the magnitude n of the normal force the hill exerts on the toboggan.

$$2\ \Sigma \vec{F} = m\vec{a}$$



(**a**) The situation



(**b**) Free-body diagram for toboggan

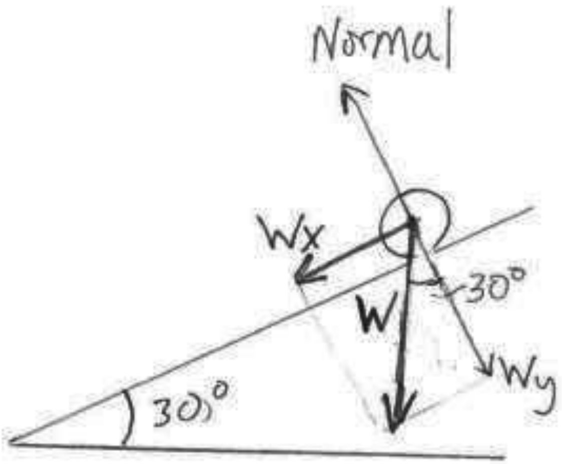
$$\left.\begin{aligned} &\sum F_x = ma_x, \quad && (mg)\sin\alpha = ma_x \\ &\sum F_y = 0, && n + (-mg\cos\alpha) = 0 \end{aligned}\right\} \quad a_x = g\sin\alpha$$

INCLINED PLANE

A 2.0 kg ball is on a frictionless ramp that is 30° above the horizontal. Find the acceleration of the ball

SOH
CAH
TOA

$W = mg$



$W_x = W \sin 30°$
$W_y = W \cos 30°$

The force causing the ball to roll is Wx

Wy is equal + opposite to the Normal

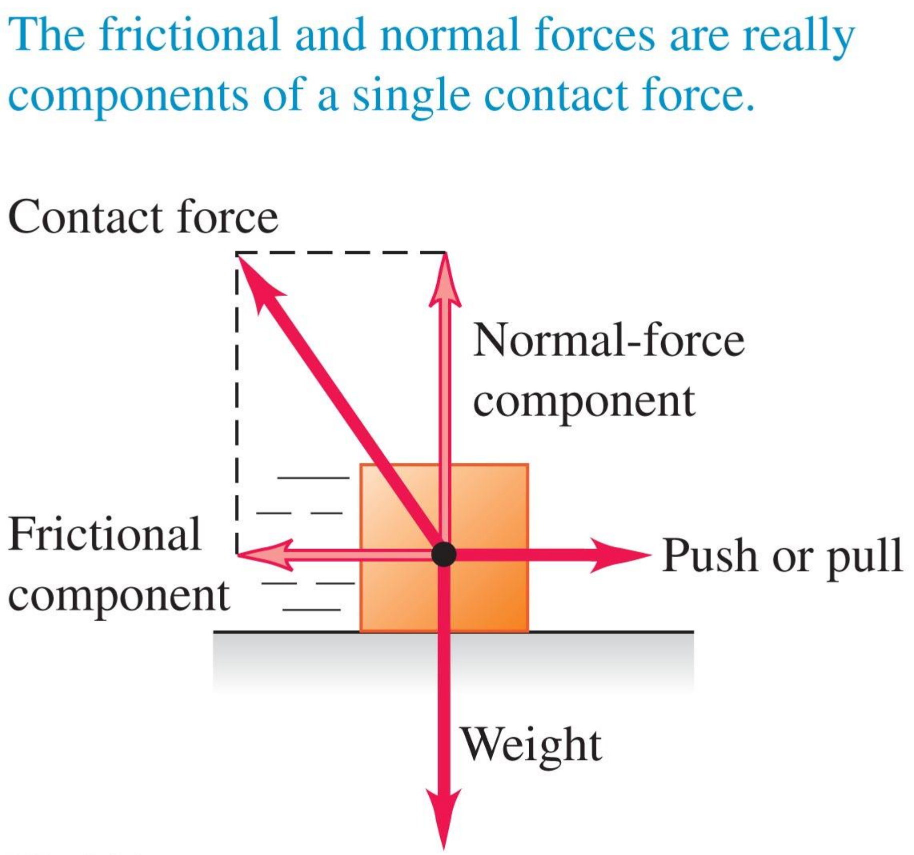
so

$W_x = m\,a$

$a = \frac{W_x}{m} = \frac{(2.0)(9.8)\sin(30°)}{2.0} = 4.9 \text{ m/s}^2$

Contact Force and Friction

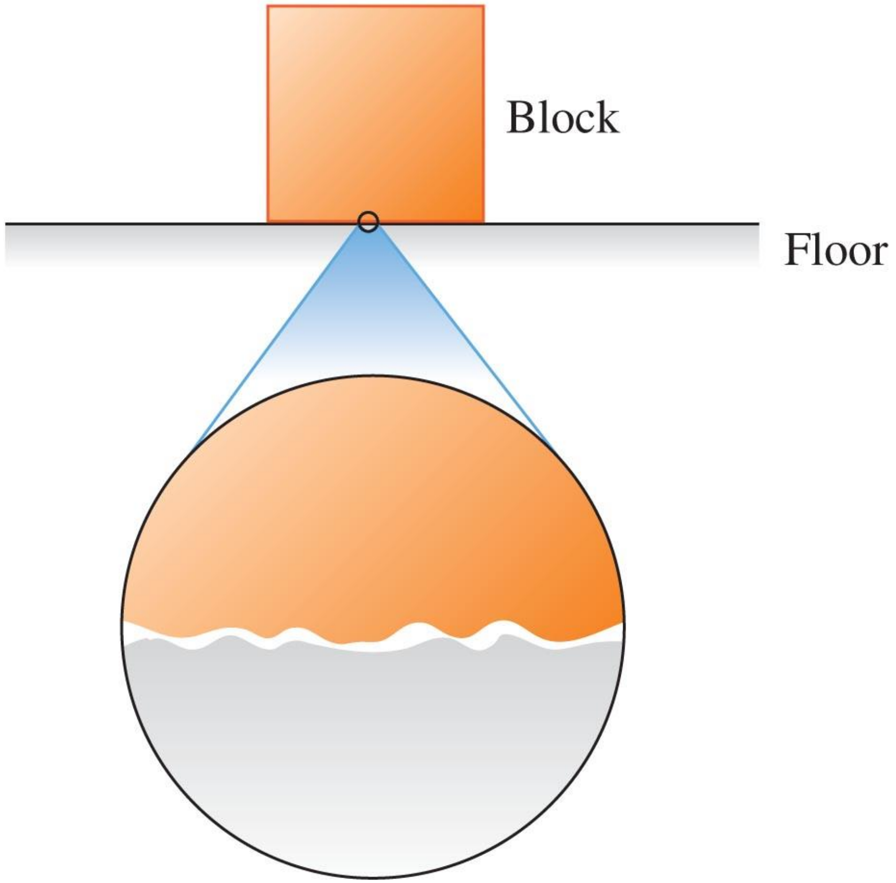
- We need to re-examine problems we formerly did as "ideal."
- We need to be able to find frictional forces given the mass of the object and the nature of the surfaces in contact with each other.



- There are two regions of friction:
  1) when an object is sliding with respect to a surface → *kinetic-friction* force
  2) when there is no relative motion → *static-friction* force

The Microscopic View of Friction

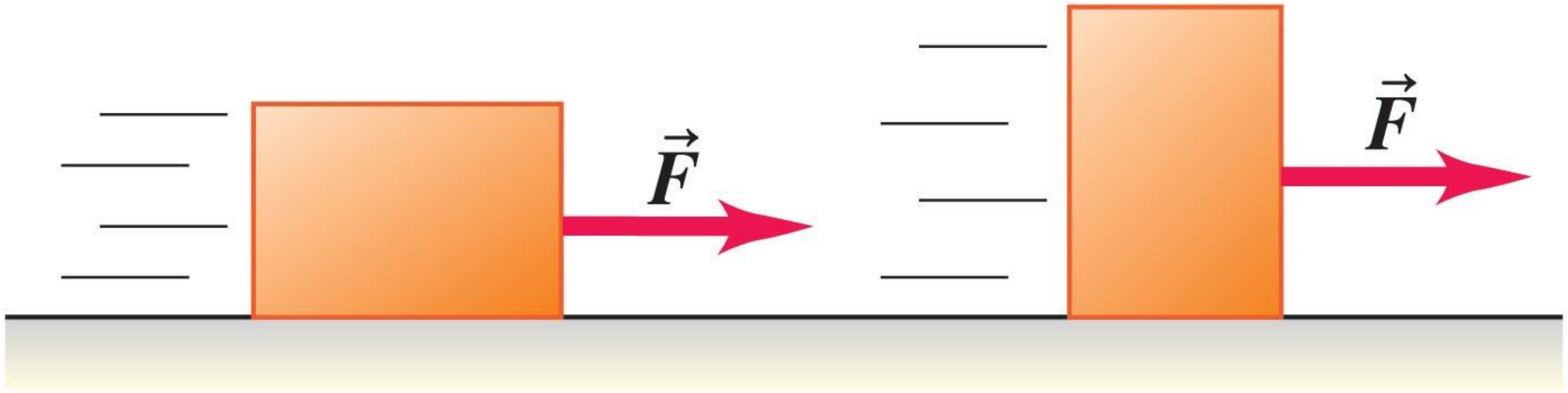
- A surface will always have imperfections, your perception of them depends on the magnification.
- The coefficient of friction (μ) will reveal how much force is involved.



On a microscopic level, even smooth surfaces are rough; they tend to catch and cling.

No Dependence on Surface Area

- The normal force determines friction.



$$f_s \le \mu_s n \quad \rightarrow \text{no relative movement}$$

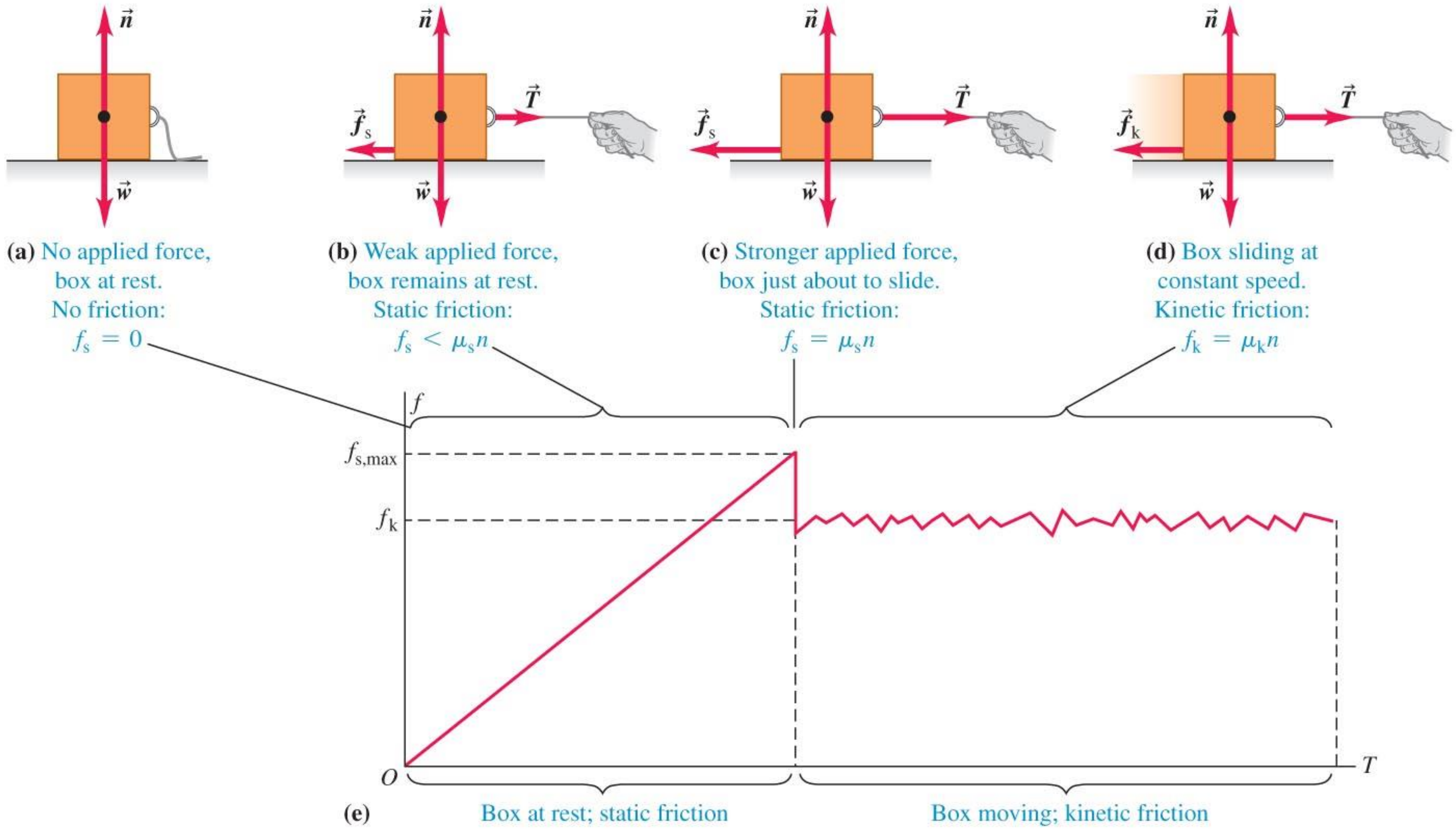
$$f_{s,\text{max}} = \mu_s n \quad \rightarrow \text{interface "breaks loose"}$$

$$f_k = \mu_k n \quad \rightarrow \text{sliding with friction}$$

$$\mu_k \le \mu_s$$

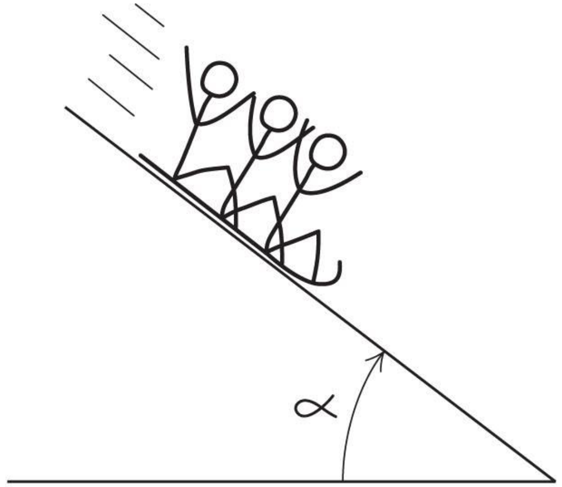
Friction Changes as Forces Change –

- Forces from static friction increase as force increases while forces from kinetic friction are *relatively* constant.

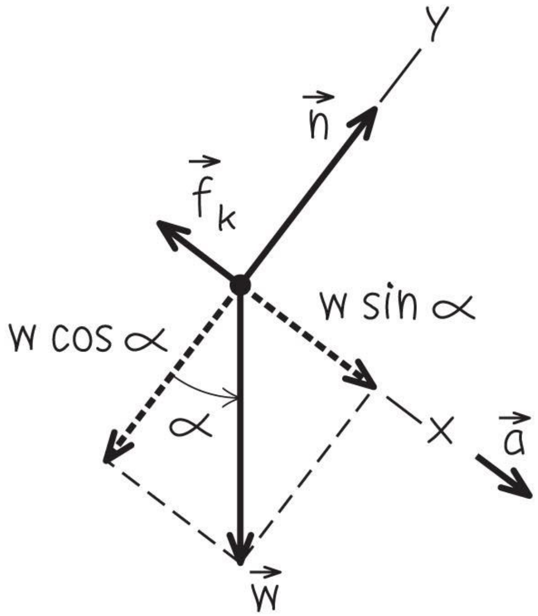


A Toboggan on a Steep Hill with

VTS Ex 5.11



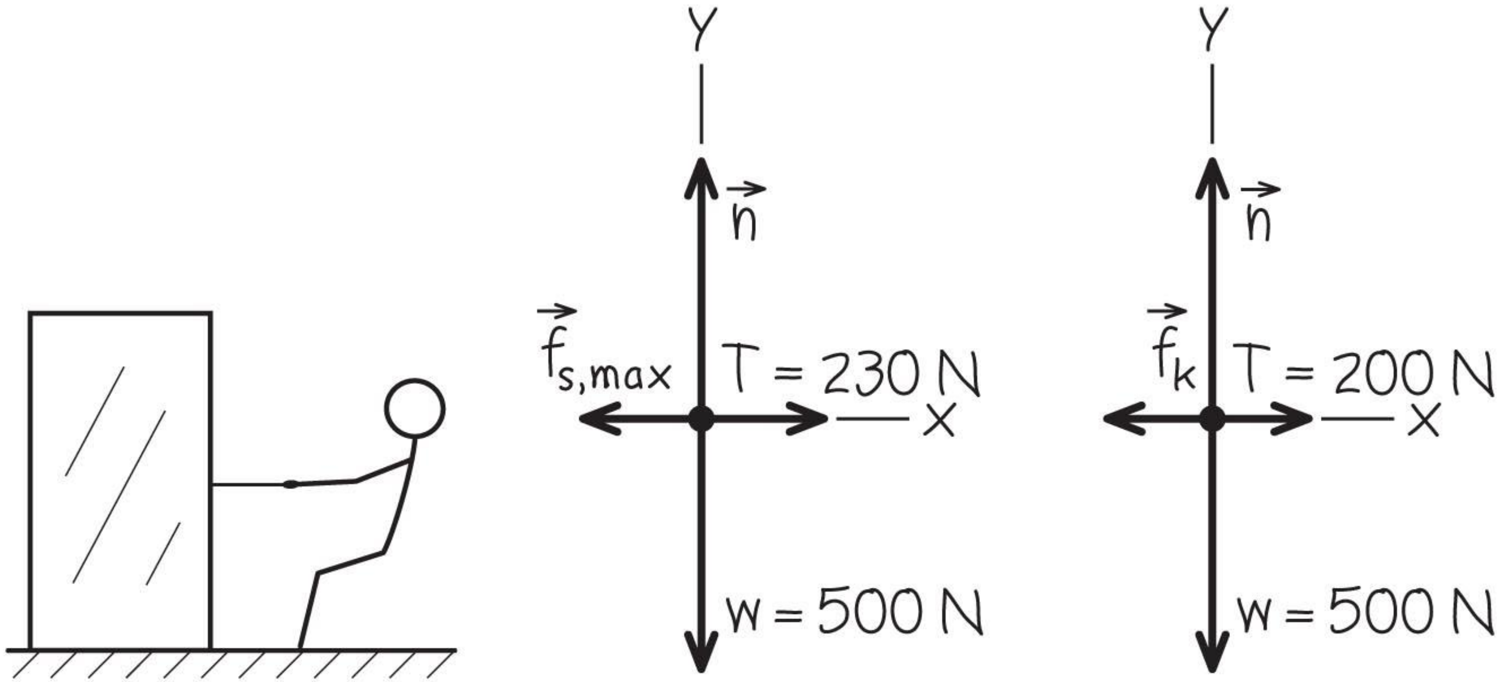
(a) The situation



(b) Free-body diagram for toboggan

$$\left.\begin{aligned}\sum F_x = 0, &\quad (mg)\sin\alpha + (-f_k) = (mg)\sin\alpha + (-\mu_k n) = 0 \\ \sum F_y = 0, &\quad n + (-mg\cos\alpha) = 0\end{aligned}\right\} \quad \mu_k = \frac{\sin\alpha}{\cos\alpha} = \tan\alpha$$

VTS Ex 5.8



(a) Pulling a crate

(b) Free-body diagram for crate just before it starts to move

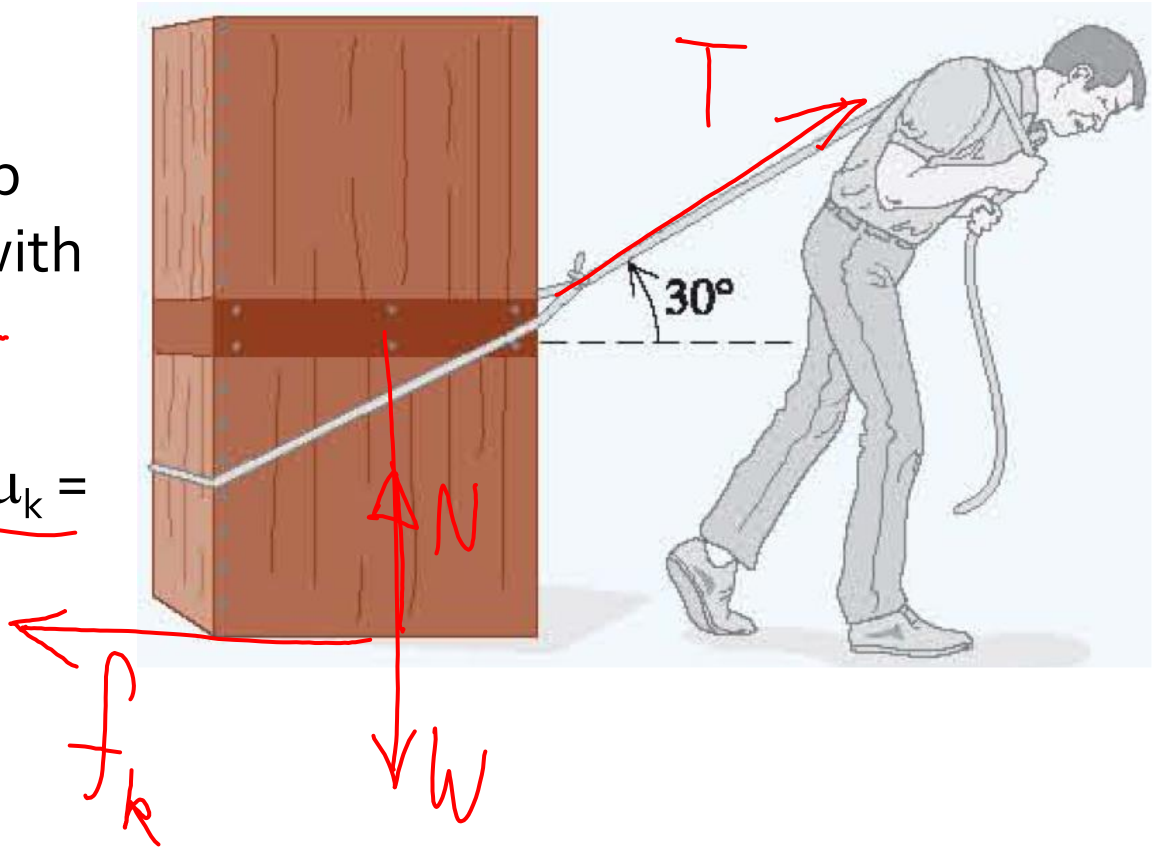
(c) Free-body diagram for crate moving at constant speed

Example 5.10: Kinetic friction

VTS Ex 5.10

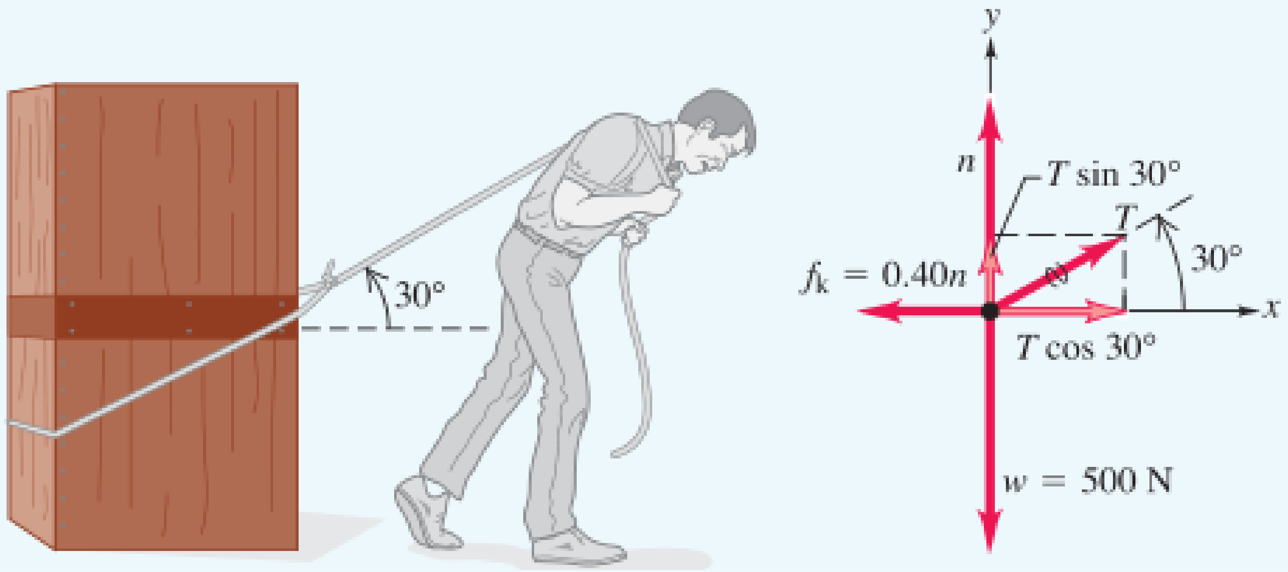
- You try to move a crate full of exercise equipment by pulling upward on the rope at an angle of 30° above the horizontal.

How hard do you have to pull to keep the crate moving with constant velocity? The weight of the crate is 500 N and μ_k = 0.40 for this crate.



Ans T=188N

$_2\ \Sigma\vec{F} = m\vec{a}$



SOLVE The crate is moving with constant velocity, so it is still in equilibrium. Applying $\Sigma\vec{F} = 0$ in component form, we find that

$$\Sigma F_x = T\cos 30° + (-f_k) = T\cos 30° - 0.40n = 0,$$
$$\Sigma F_y = T\sin 30° + n + (-500\text{ N}) = 0.$$

Solve

These are two simultaneous equations for the two unknown quantities T and n. To solve them, we can eliminate one unknown and solve for the other. There are many ways to do this. Here is one way: Rearrange the second equation to the form

$$n = 500\ \mathrm{N} - T\sin 30°.$$

Then substitute this expression for n back into the first equation:

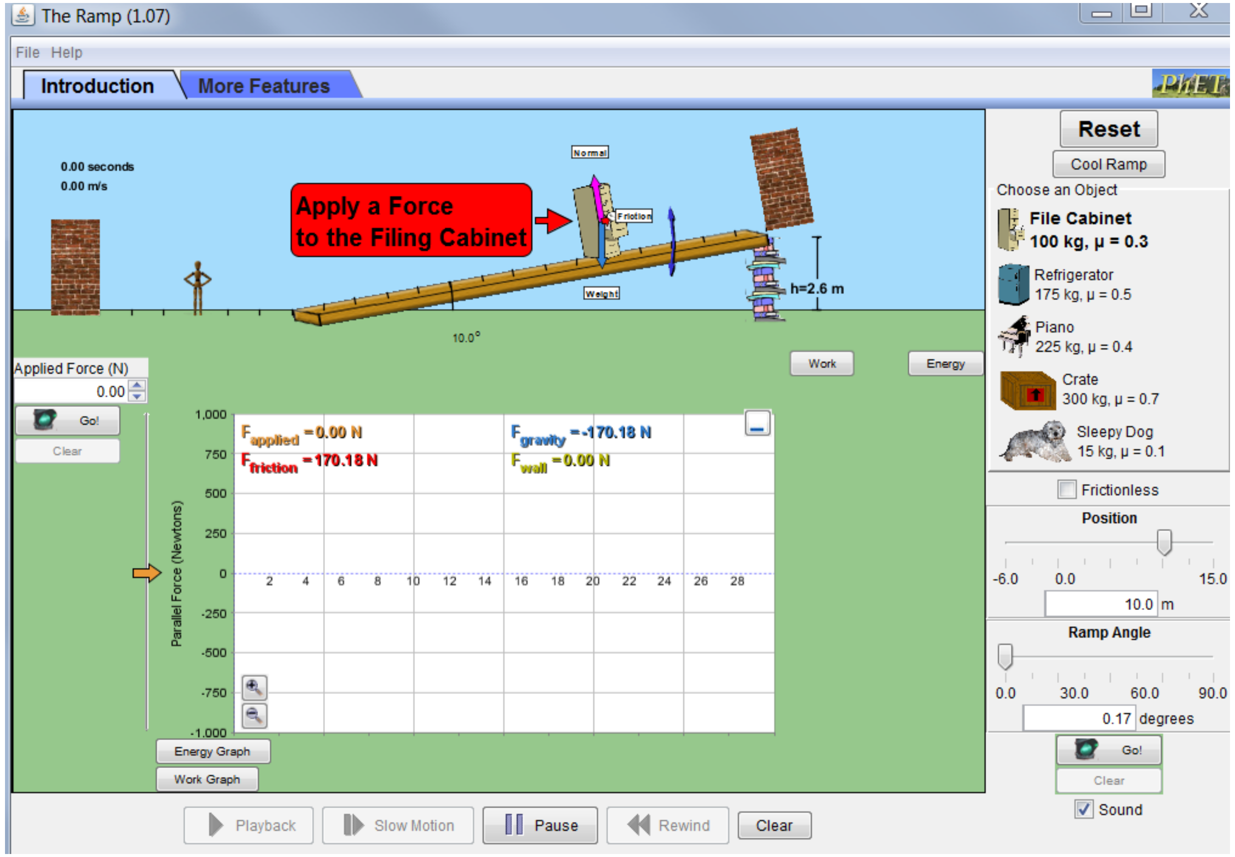
$$T\cos 30° - 0.40(500\ \mathrm{N} - T\sin 30°) = 0.$$

Finally, solve this equation for T, and then substitute the result back into either of the original equations to obtain n. The results are

$$T = 188\ \mathrm{N}, \qquad n = 406\ \mathrm{N}.$$

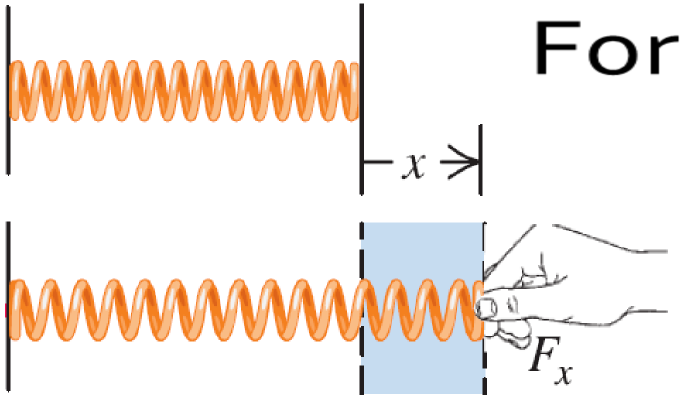
PhET The ramp

http://phet.colorado.edu/en/simulation/the-ramp



http://phet.colorado.edu/en/simulation/forces-1d
http://phet.colorado.edu/en/simulation/friction
http://phet.colorado.edu/en/simulation/lunar-lander

Hooke's Law 5.4 Elastic forces

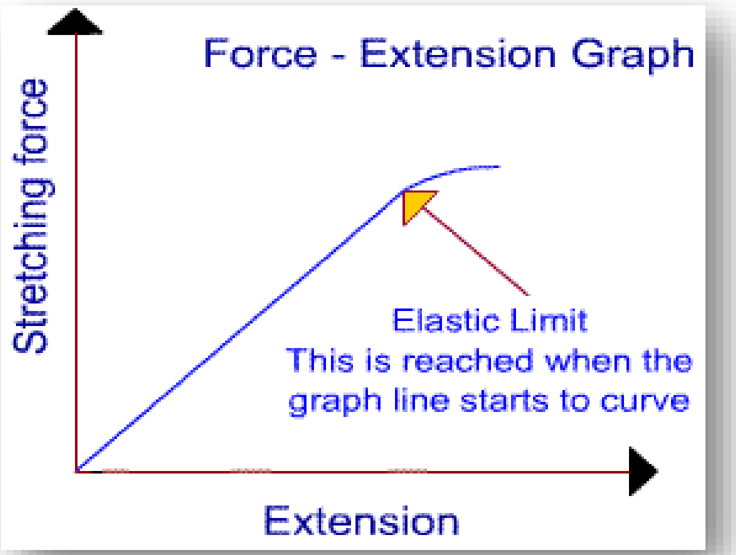


For an elastic spring, the applied force F is proportional to the extension/compression x.

$$\boldsymbol{F} \propto \boldsymbol{x}$$

$$\boldsymbol{F} = \boldsymbol{kx}$$

Where $\boldsymbol{k}$ is the *spring constant*

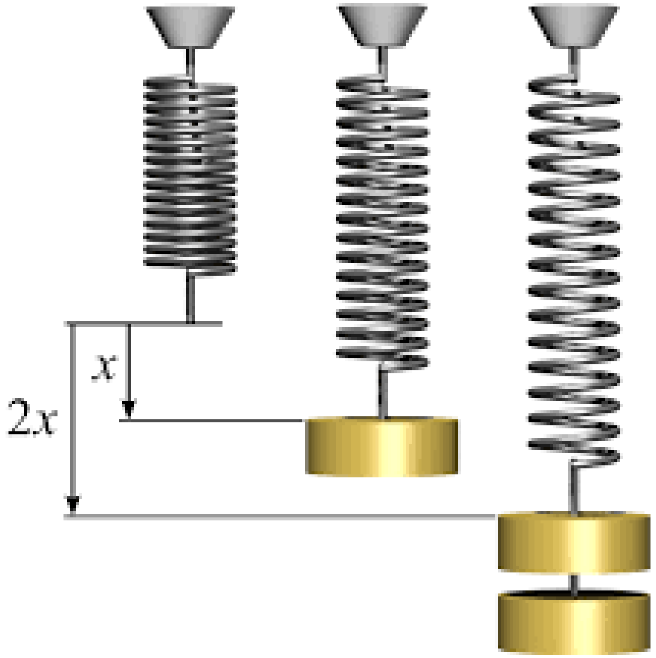


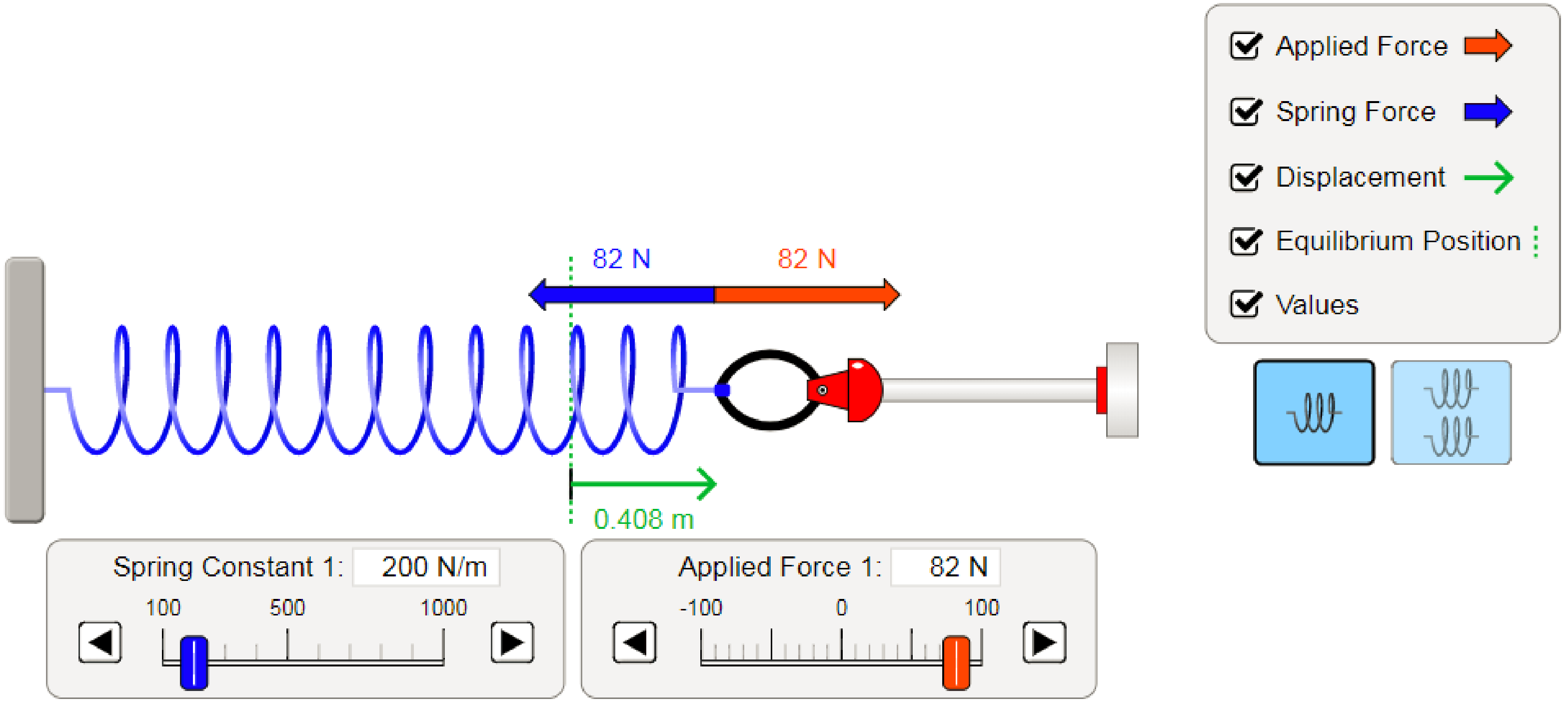
k is also sometimes called the force constant

$$F = kx$$

F α x

F α k





https://phet.colorado.edu/sims/html/hookes-law/latest/hookes-law_en.html

EXAMPLE 5.14 **Fishy business**

A spring balance used to weigh fish is built with a spring that stretches 1.00 cm when a 12.0 N weight is placed in the pan. When the 12.0 N weight is replaced with a 1.50 kg fish, what distance does the spring stretch?

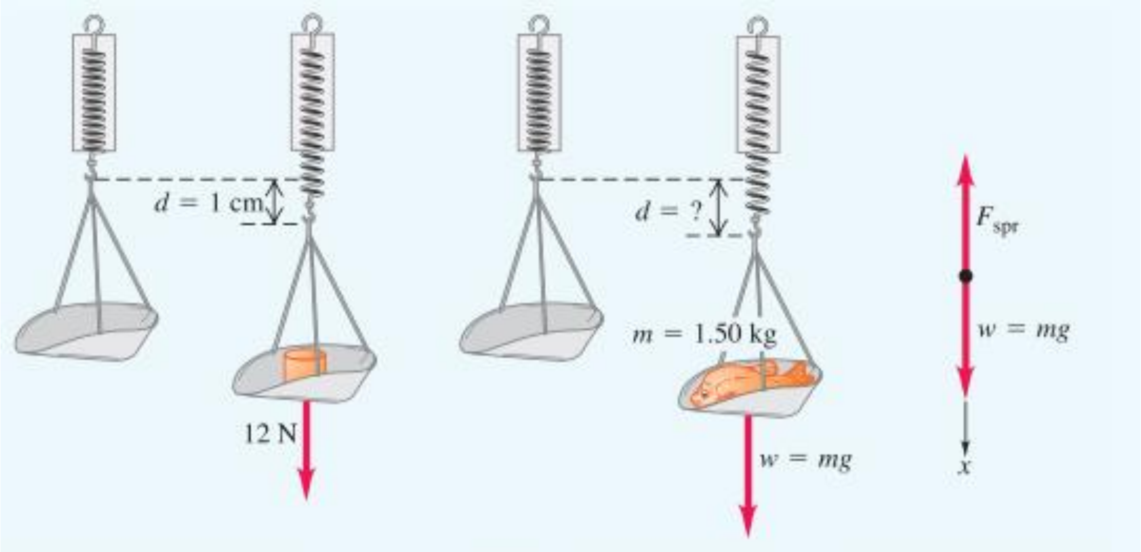
VTS Ex 5.14

$F_{sp} = 12N$

$x = 1cm = 1 \times 10^{-2} m$

$|F| = k|x|$ magnitude as vectors use direction

$k = \frac{12}{1 \times 10^{-2}} = 1200 \ N/m$



(a) The scale stretched by a known weight

(b) The scale stretched by a known mass

(c) Free-body diagram for the fish

$\Sigma F = 0$

$= F_{sp} - W$

$0 = Kx - 14.7$

$x = \frac{14.7}{K} = \frac{14.7}{1200}$

$= 0.0123 \ m$

$= 1.23 \ cm$

$F_{sp} = kx$

$W = mg$

$= 1.50 (9.8)$

$= 14.7 N$

An *elastic* problem

- A light spring having a force constant of 125 N/m is used to pull a 9.50 kg sled on a horizontal frictionless ice rink. The sled has an acceleration of 2.00 m/ s^2.
- By how much does the spring stretch if it pulls on the sled horizontally.

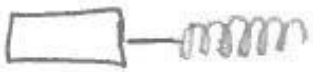
- 2 $\Sigma\vec{F} = m\vec{a}$ $\boldsymbol{F = kx}$

Ans x=0.152m

$a = 2.00\ m/s^2$ →

what is x?

$k = 125\ N/m$



9.50 kg

First find Force

$F = ma$

$= 9.50\ (2)$

$= 19\ N$

Then Find x

$F = kx$

$x = \frac{F}{k} = \frac{19}{125}$

$= 0.152\ m$

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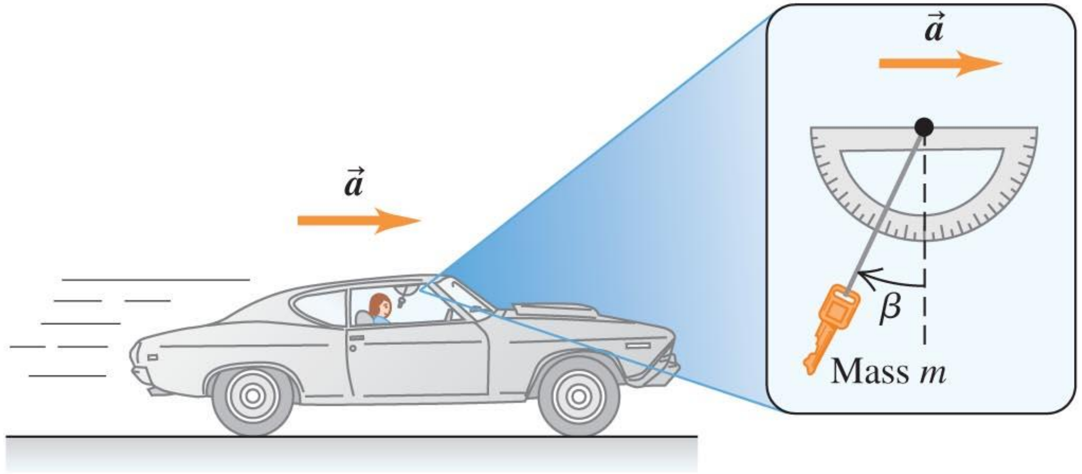
Appendix

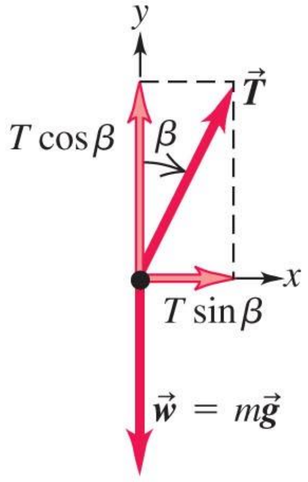
Extra information

- This experiment works in your car, a bus, or even an amusement park ride!

VTS Ex 5.5



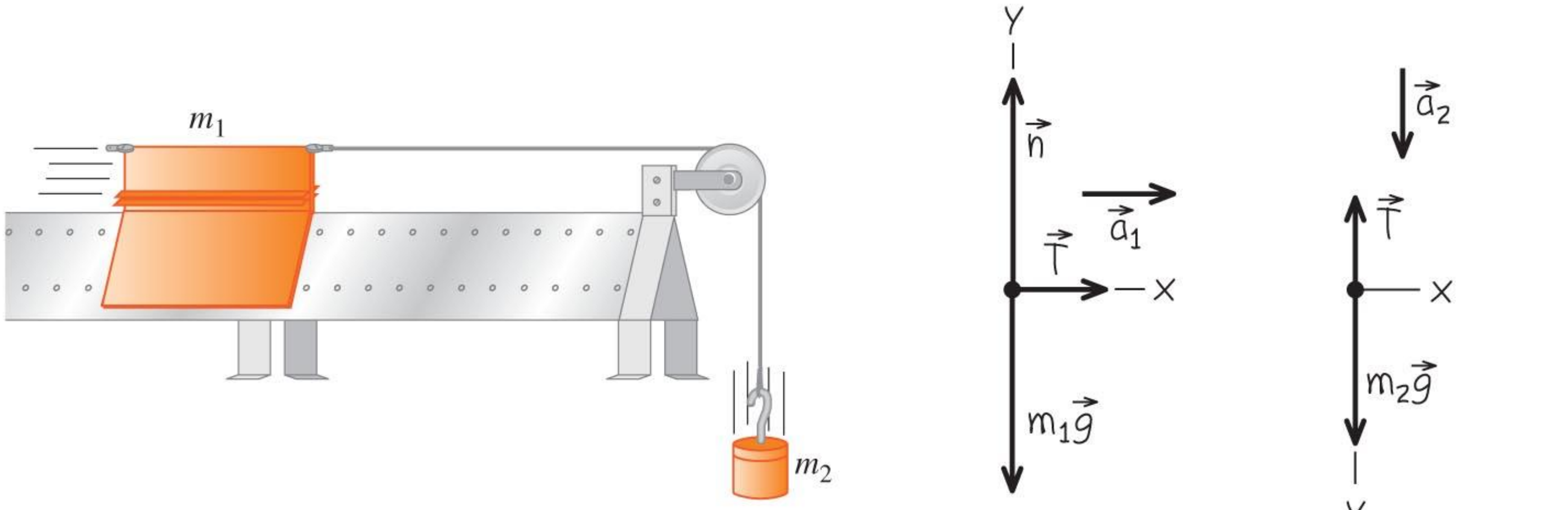
(a) Low-tech accelerometer



(b) Free-body diagram for the key

$$\left.\begin{array}{ll}\sum F_x = ma_x, & T \sin\beta = ma_x \\ \sum F_y = 0, & T\cos\beta + (-mg) = 0\end{array}\right\} \quad a_x = g\tan\beta$$

- This problem involves two interactive systems in a common lab experiment.



(a) Apparatus

(b) Free-body diagram for glider

(c) Free-body diagram for weight

VTS Ex 5.7

From Glider free-body diagram:

$$\sum F_x = m_1 a_x, \quad T = m_1 a_x$$

$$\sum F_y = 0, \quad n + (-m_1 g) = 0$$

From Weight free-body diagram:

$$\sum F_y = m_2 a_y, \quad \mathrm{m}_2\mathrm{g} + (-T) = m_2 a_y$$

Here, $a_{x\_Glider} = a_{y\_Weight} = a_{system}$

5.5 Forces in Nature