Lecture 5

Applying Newton's Laws

Date: 2025.03.13

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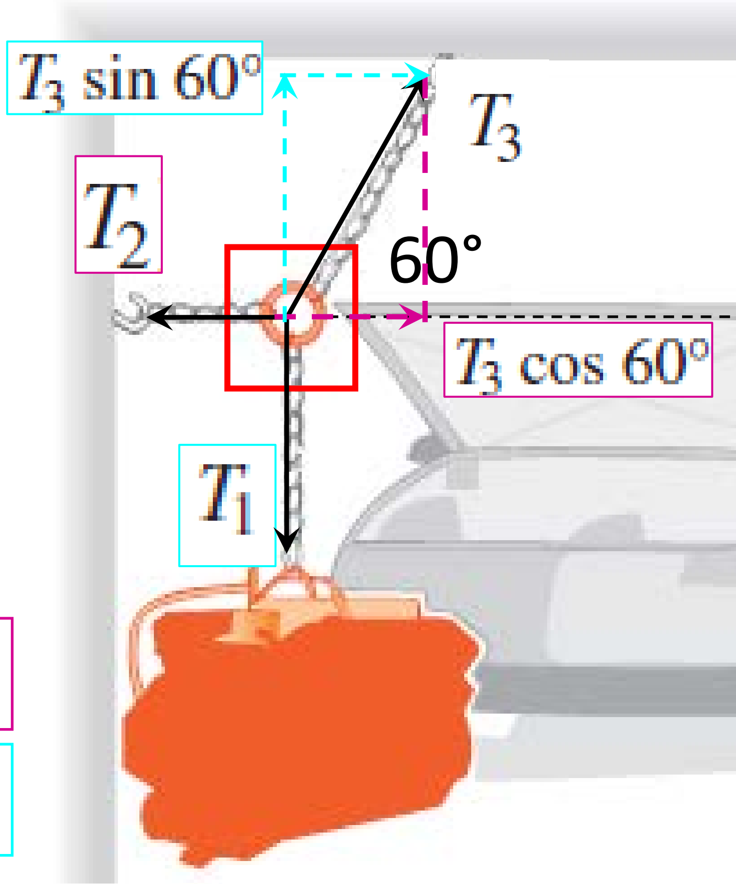
Example 5.3

In Fig. 5.3a, a car engine with weight w hangs from a chain that is linked at ring O to two other chains, one fastened to the ceiling and the other to the wall. Find expressions for the tension in each of the three chains in terms of w. The weights of the ring and chains are negligible compared with the weight of the engine.



Ring:	$\sum F_x = T_3 \cos 60° + (-T_2) = 0$	Newton's first law in x
Ring:	$\sum F_y = T_3 \sin 60° + (-T_1) = 0$	Newton's first law in y

$$T_3 = \frac{T_1}{\sin 60°} = \frac{w}{\sin 60°} = 1.2w \qquad T_2 = T_3 \cos 60° = w\frac{\cos 60°}{\sin 60°} = 0.58w$$

Newton’s Second Law

$$\sum \vec{F} = m\vec{a} \qquad \text{(Newton's second law, vector form)} \qquad (5.3)$$

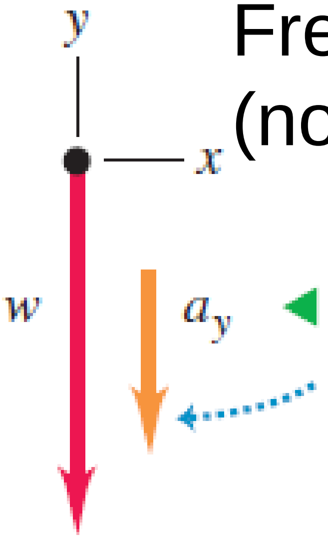
We most often use this relationship in component form:

$$\sum F_x = ma_x \qquad \sum F_y = ma_y \qquad \text{(Newton's second law, component form)} \qquad (5.4)$$

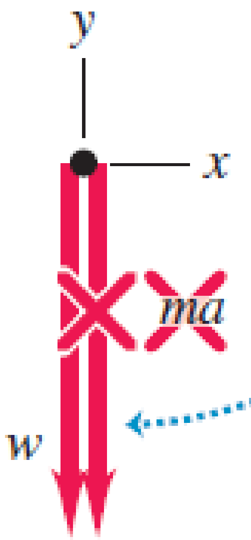
Free-body diagrams (non-equilibrium)

Example

Only the force of gravity acts on this falling fruit.

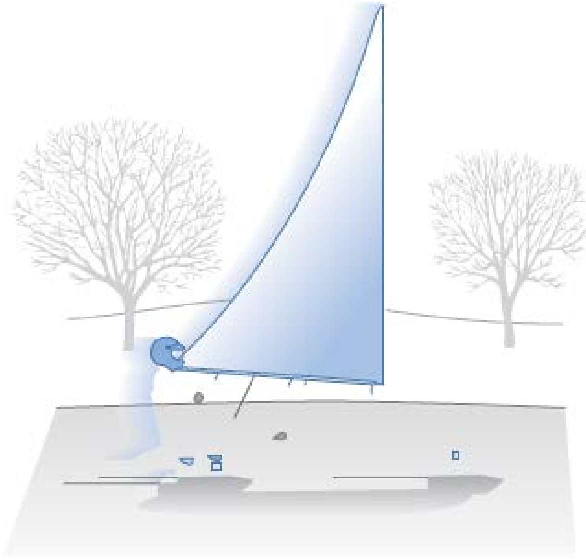


RIGHT!
You can safely draw the acceleration vector to one side of the diagram.

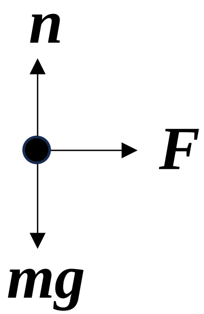


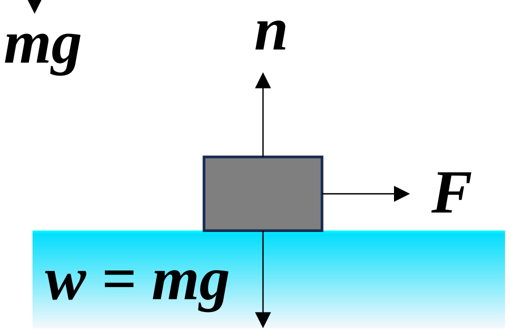
WRONG
This vector doesn’t belong in a free-body diagram because $m\vec{a}$ is *not* a force.

Example 5.7: acceleration in x



An iceboat is at rest on a frictionless horizontal surface (Fig. 5.7a). A wind is blowing along the direction of the runners so that 4.0 s after the iceboat is released, it is moving at 6.0 m/s (about 22 km/h, or 13 mi/h). What constant horizontal force F does the wind exert on the iceboat? The combined mass of iceboat and rider is 200 kg.





The forces acting on the iceboat and rider (considered as a unit) are the **weight *w***, the **normal force *n*** exerted by the surface, and **the horizontal force *F*** by the wind.

Recall the equations in kinematics. Which one shall we use?

$$v = v_0 + at$$

$$x = x_0 + v_0 t + \tfrac{1}{2} a t^2$$

$$\bar{v} = \frac{v_0 + v_1}{2}$$

$$v^2 = v_0^2 + 2a(x - x_0)$$

But wait! What is the acceleration?

Example 5.7: acceleration in *x*

Known quantities

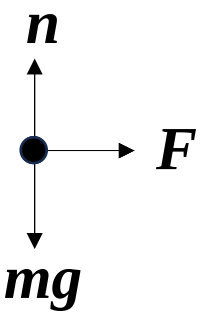
mass $m = 200\ \text{kg}$

initial and final x-velocities

$v_{0x} = 0$ and $v_x = 6.0\ \text{m/s}$

elapsed time $t = 4.0\ \text{s}$.

Unknown quantities



acceleration a_x

normal force n

horizontal force F

$\sum F_x = F =$

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$$\sum F_x = F = ma_x$$
$$\sum F_y = n + (-mg) = 0 \quad \text{so} \quad n = mg$$

$$a_x = \frac{v_x - v_{0x}}{t} = \frac{6.0\ \text{m/s} - 0\ \text{m/s}}{4.0\ \text{s}} = 1.5\ \text{m/s}^2$$
$$F = ma_x = (200\ \text{kg})(1.5\ \text{m/s}^2) = 300\ \text{kg}\cdot\text{m/s}^2$$

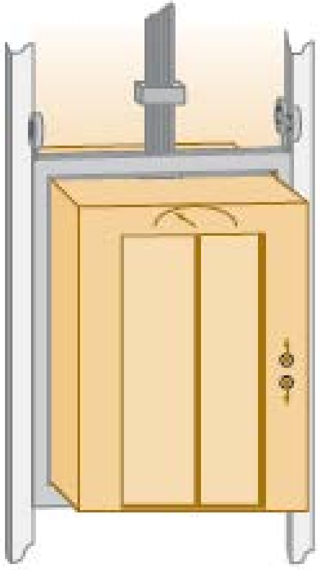
Since $1\ \text{kg}\cdot\text{m/s}^2 = 1\ \text{N}$, the final answer is

$$F_W = 300\ \text{N (about 67 lb)}$$

Example 5.8: acceleration in y

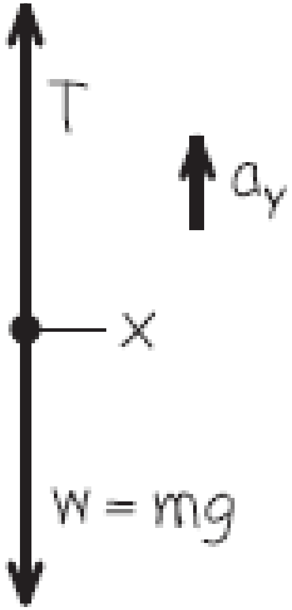
Example 5.8 Tension in an elevator cable

An elevator and its load have a combined mass of 800 kg (Fig. 5.9a). The elevator is initially moving downward at 10.0 m/s; it slows to a stop with constant acceleration in a distance of 25.0 m. What is the tension T in the supporting cable while the elevator is being brought to rest?



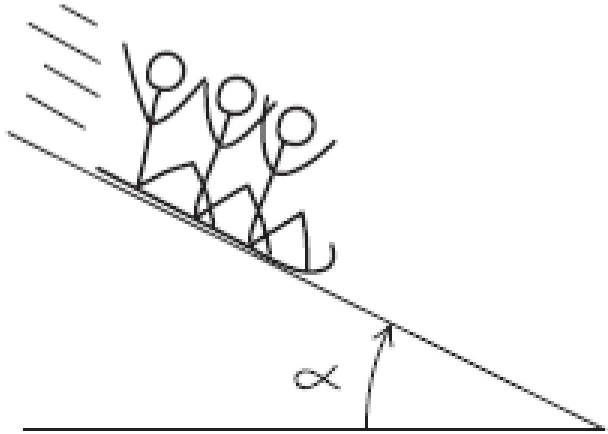
The only difference now is the acceleration direction is in y!

$$\sum F_y = T + (-w) = ma_y$$



Example 5.10: acceleration down a hill

A toboggan loaded with students (total weight w) slides down a snow-covered slope. The hill slopes at a constant angle α, and the toboggan is so well waxed that there is virtually no friction. What is its acceleration?

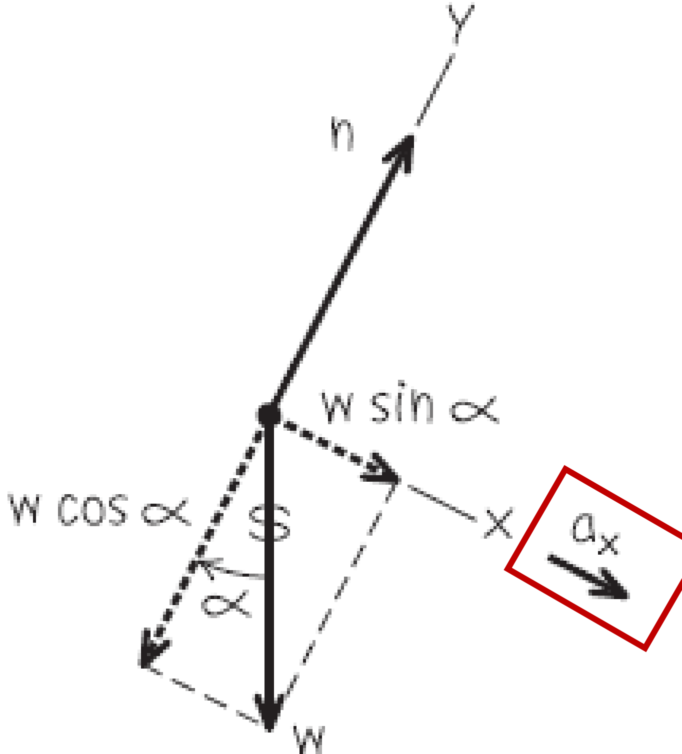


Acceleration is only in the direction downhill.

$$\sum F_y = n - w\cos\alpha = ma_y = 0$$

$$\sum F_x = w\sin\alpha = ma_x$$

$$\boxed{a_x = g\sin\alpha}$$



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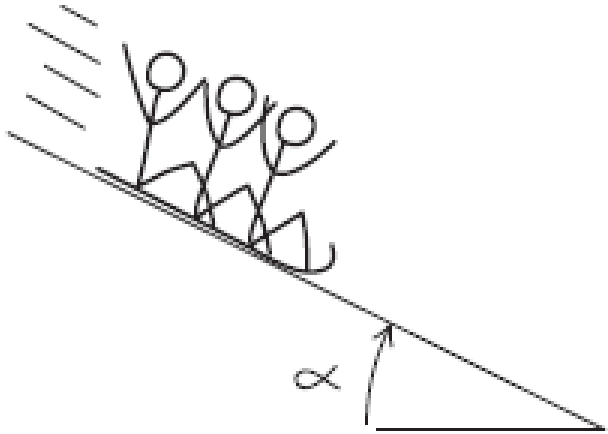
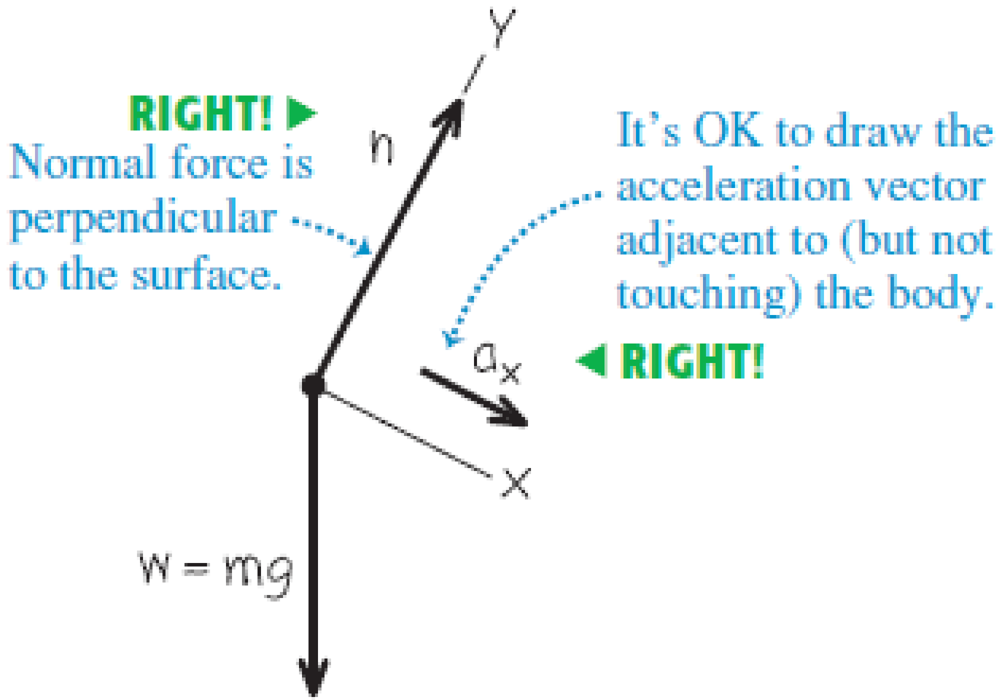
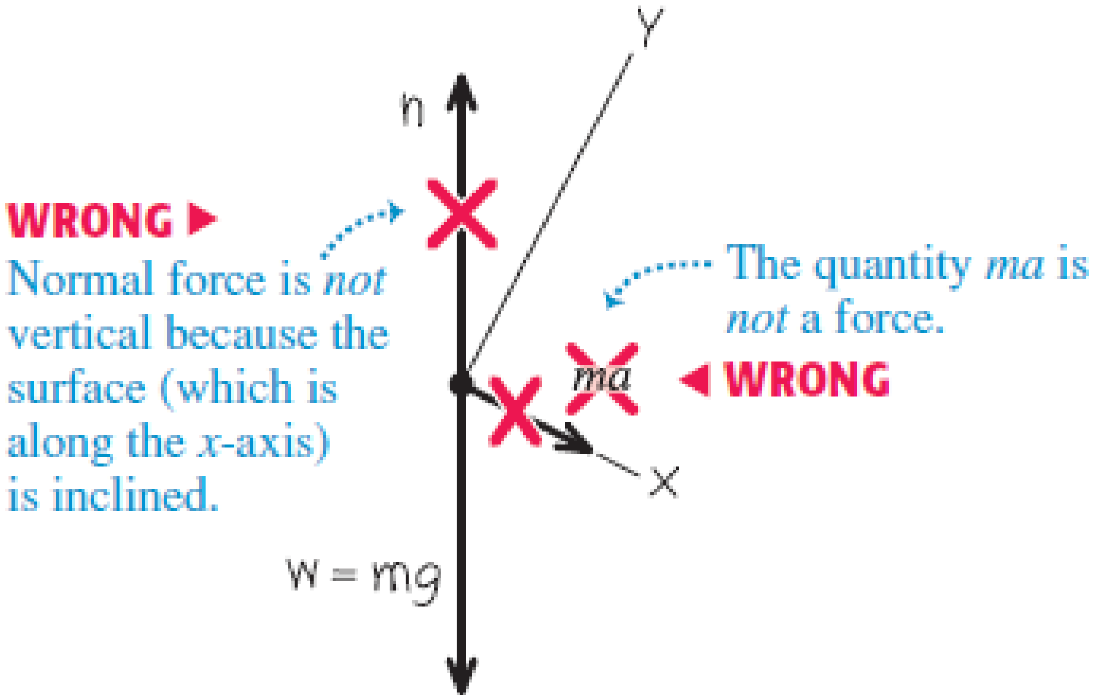


Some remarks

(a) Correct free-body diagram for the sled



(b) Incorrect free-body diagram for the sled



$$a_x = g \sin \alpha$$

Start | Pause | Reset

|< Step | Step >|

Zoom in | Zoom out

Vector length

short — long

☑ Show free-body diagram

☑ Show components

☑ Show θ

t = 0 s

v = 0 m/s

a = 3.352 m/s²

Δx = 0 m

Initial velocity (m/s) 0

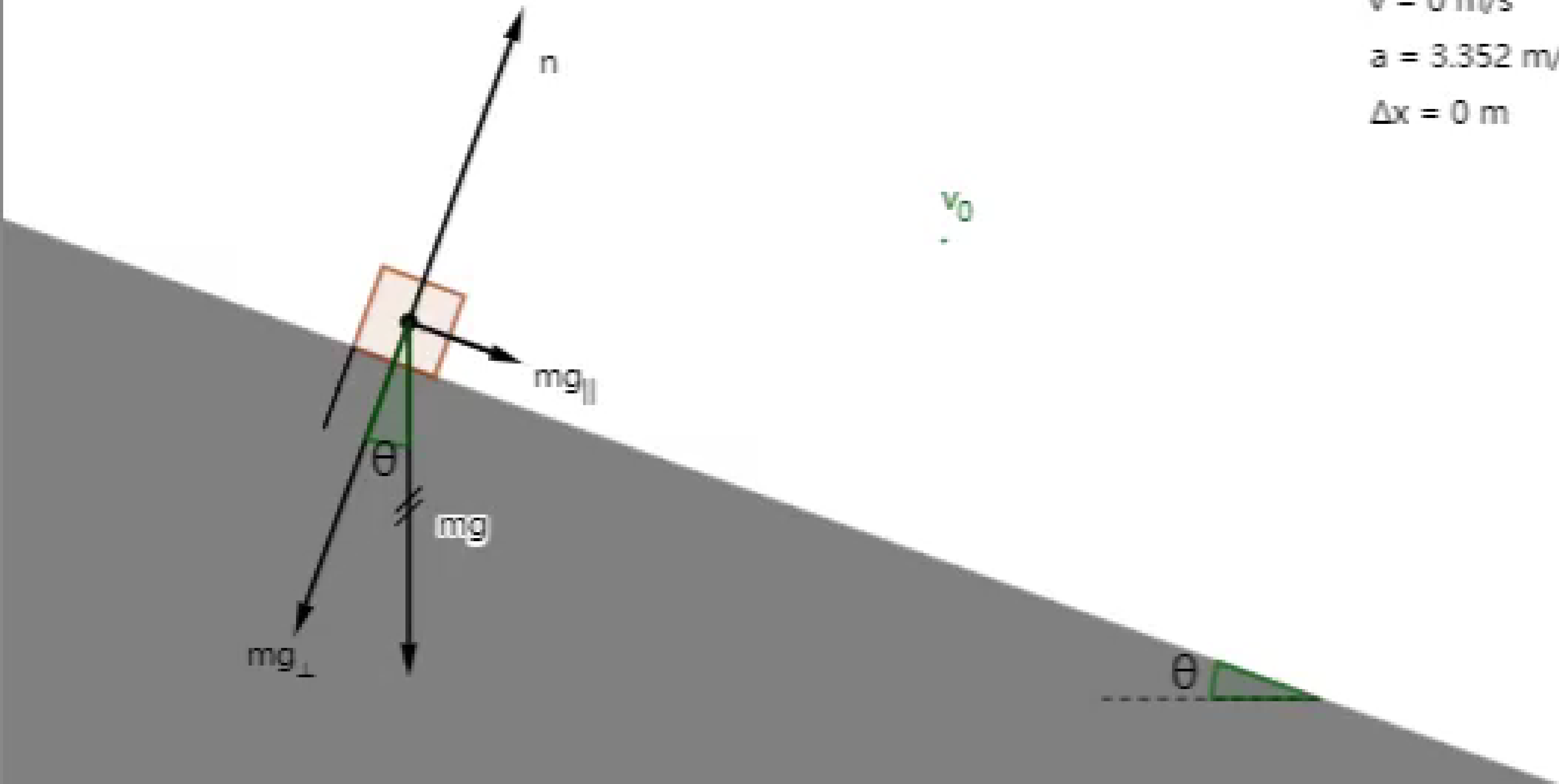
g (m/s²) 9.8

mass (kg) 3

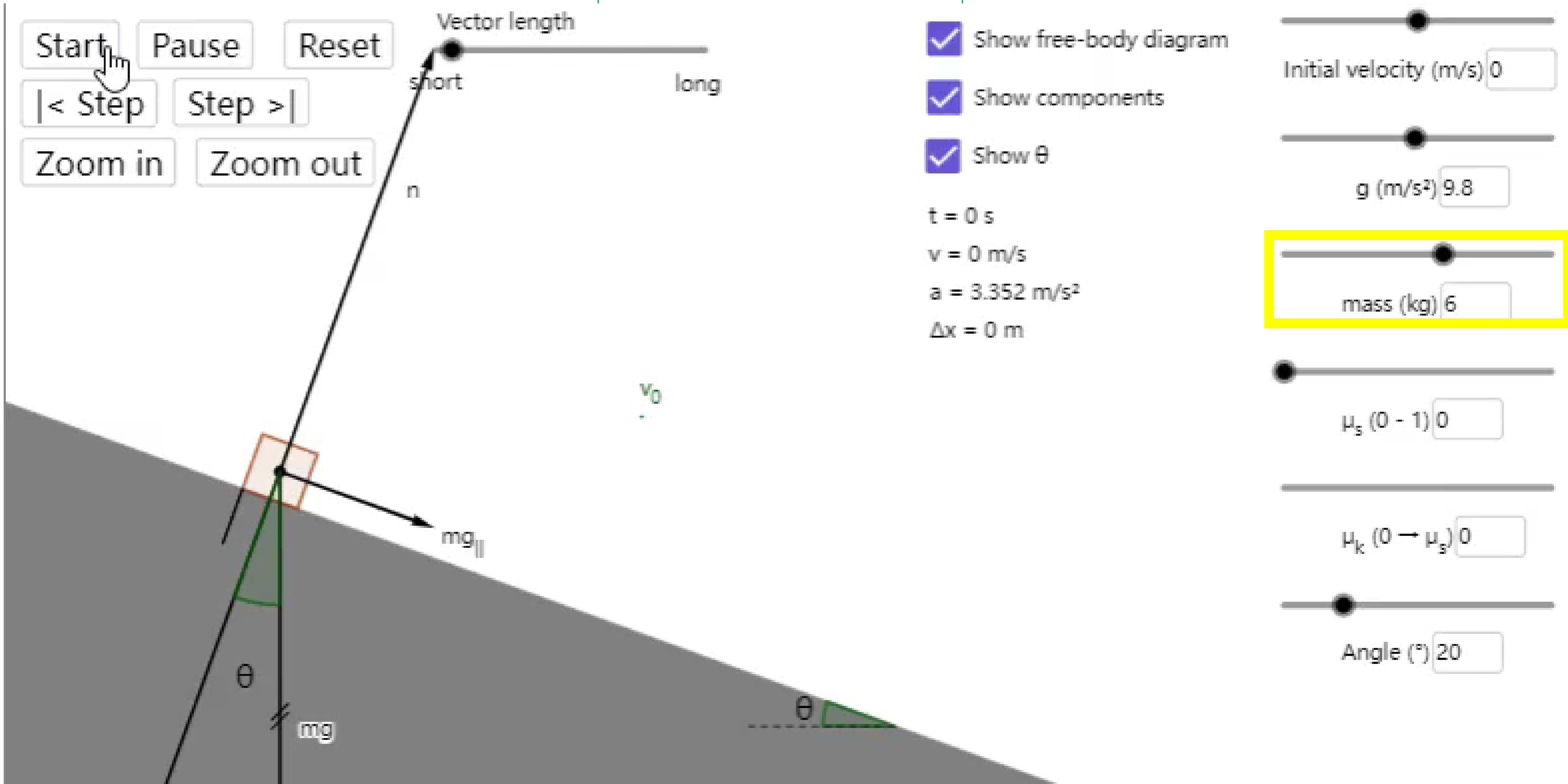
μ_s (0 - 1) 0

μ_k (0 → μ_s) 0

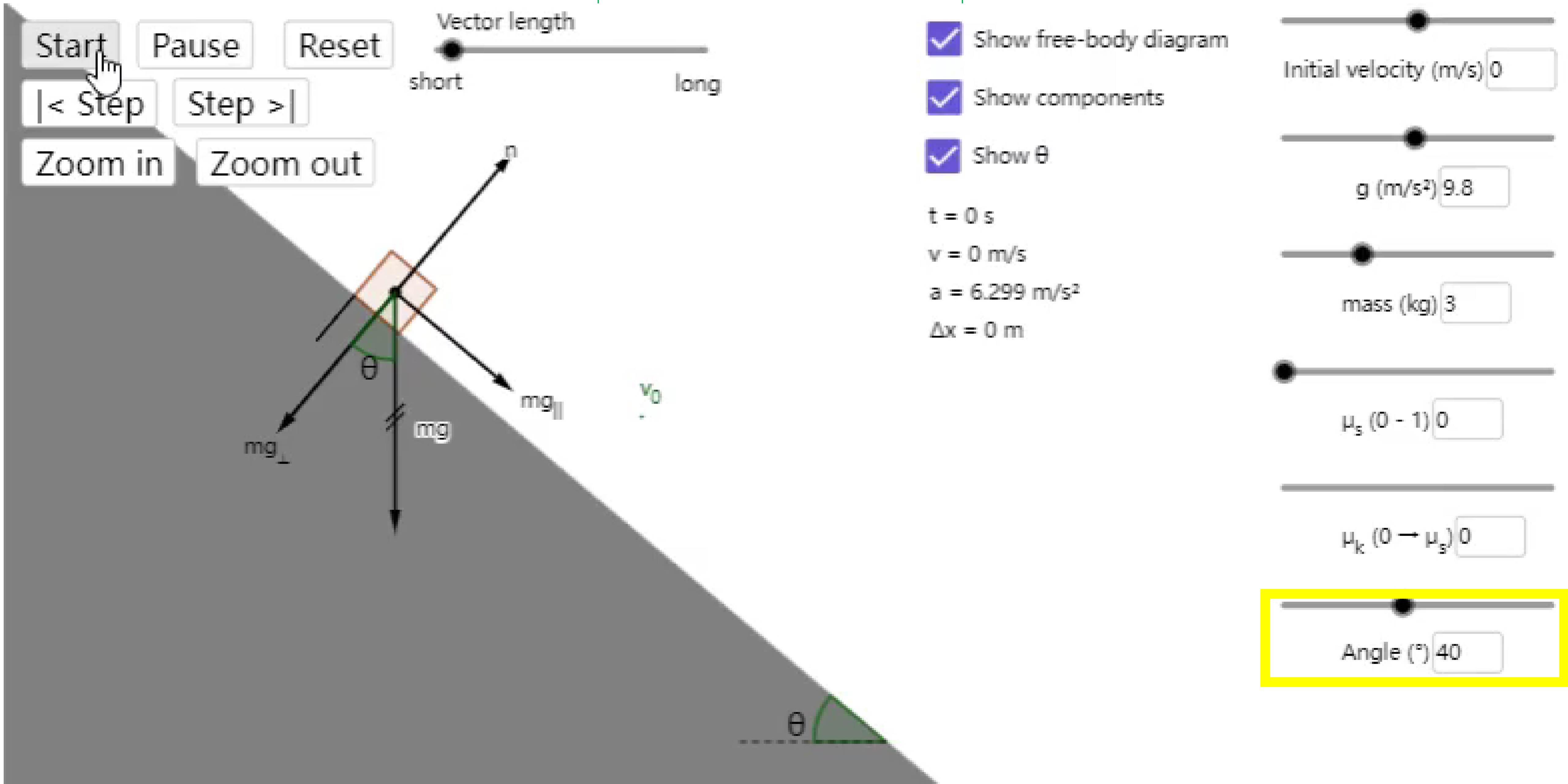
Angle (°) 20



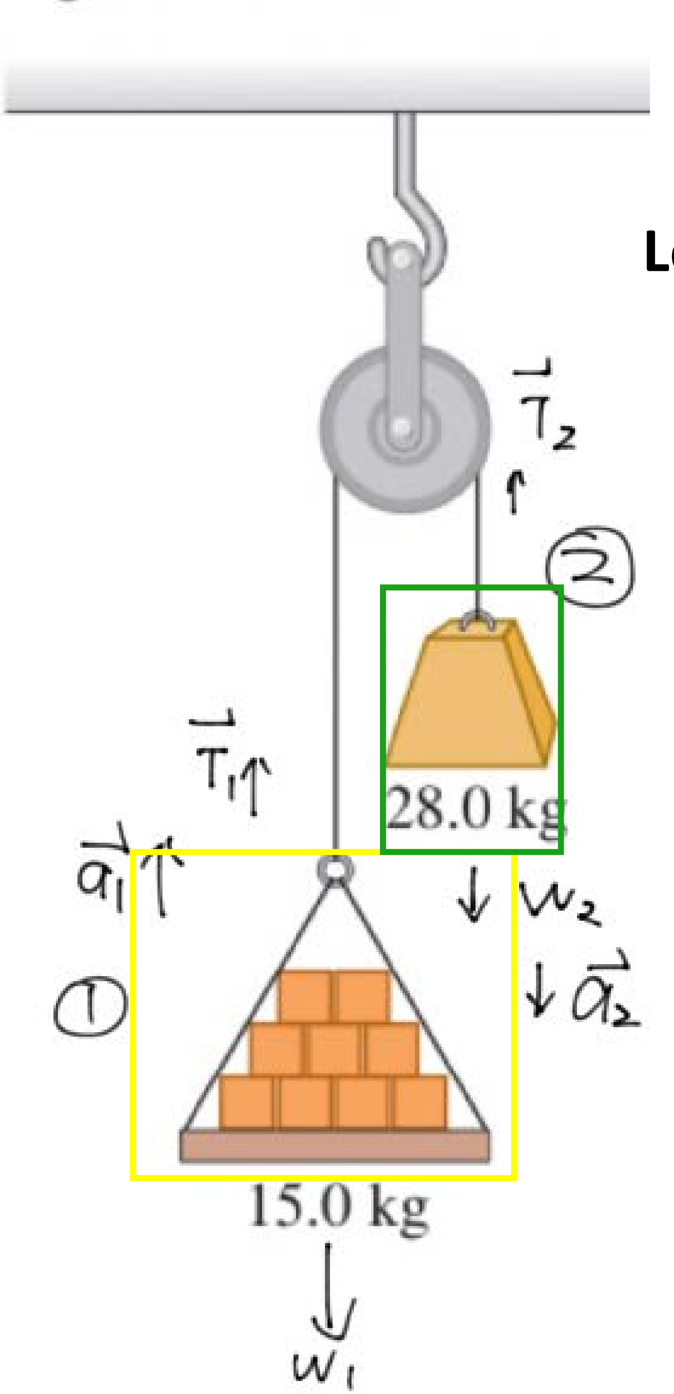
$$a_x = g \sin \alpha$$



$$a_x = g \sin \alpha$$



15.0-kg load of bricks hangs from one end of a rope that passes over a small, frictionless pulley. A 28.0-kg counterweight is suspended from the other end of the rope, as shown in Fig. E5.15. The system is released from rest. (a) Draw two free-body diagrams, one for the load of bricks and one for the counterweight. (b) What is the magnitude of the upward acceleration of the load of bricks? (c) What is the tension in the rope while the load is moving? How does the tension compare to the weight of the load of bricks? To the weight of the counterweight?



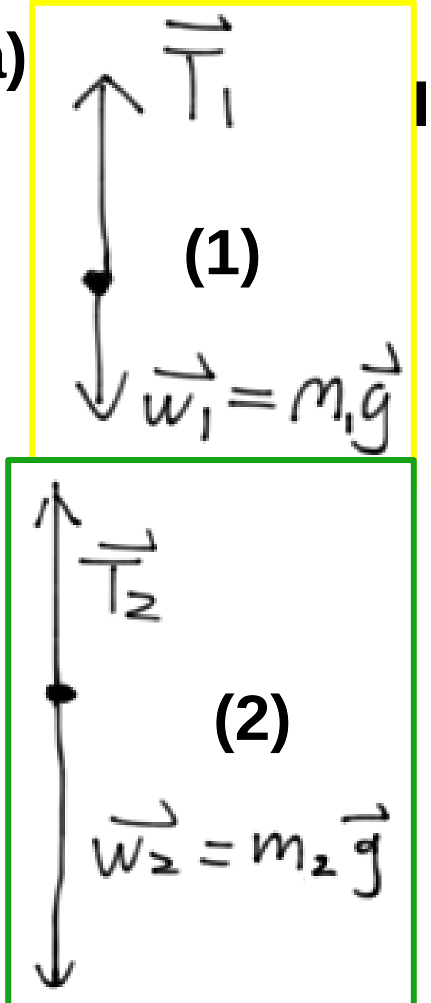
Implied Constraints:

I. $|\vec{T}_1| = |\vec{T}_2|$

Length of the cable is constant

II. $|\vec{a}_1| = |\vec{a}_2|$

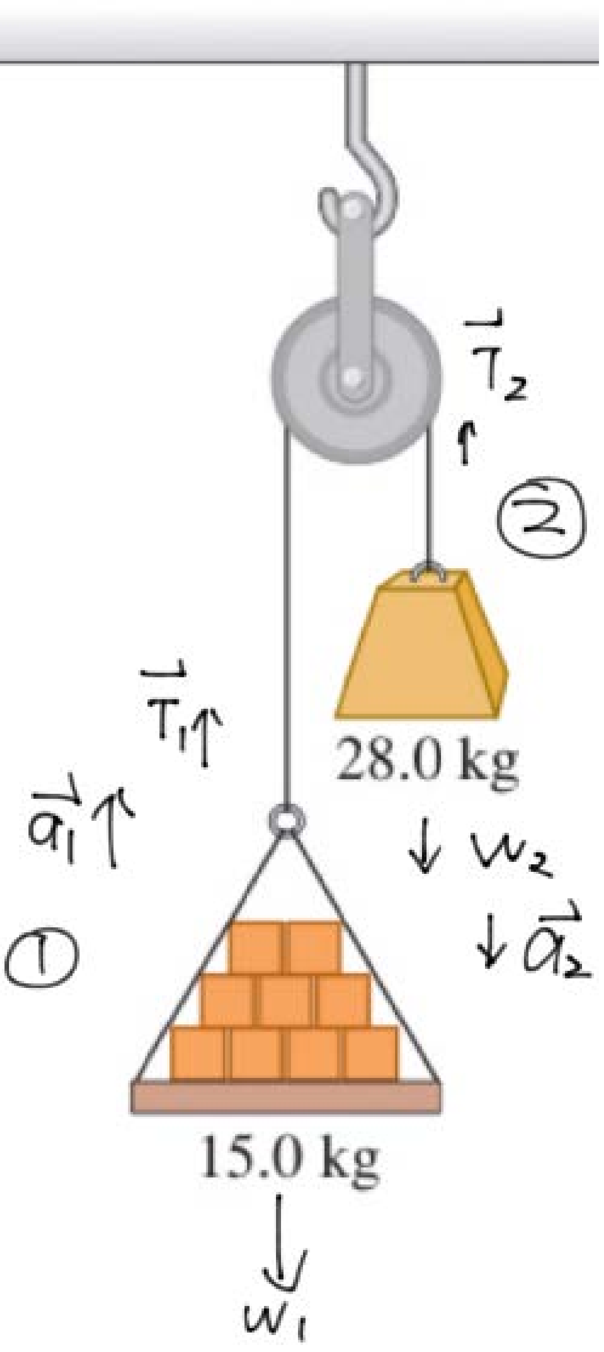
(a)



Intuition

$\Sigma\vec{F}\uparrow$

$\Sigma\vec{F}\downarrow$



(b) To calculate the acceleration, we use Newton's second law $F = ma$

$\vec{T}_1$ (1) $\Sigma \vec{F} \uparrow$ $\vec{w}_1 = m_1 \vec{g}$

$\vec{T}_2$ (2) $\Sigma \vec{F} \downarrow$ $\vec{w}_2 = m_2 \vec{g}$

$$T_1 - m_1 g = m_1 a \quad (1)$$

$$m_2 g - T_2 = m_2 a \quad (2)$$

$$\boxed{T = T_1 = T_2}$$

T, a unknown

① + ②

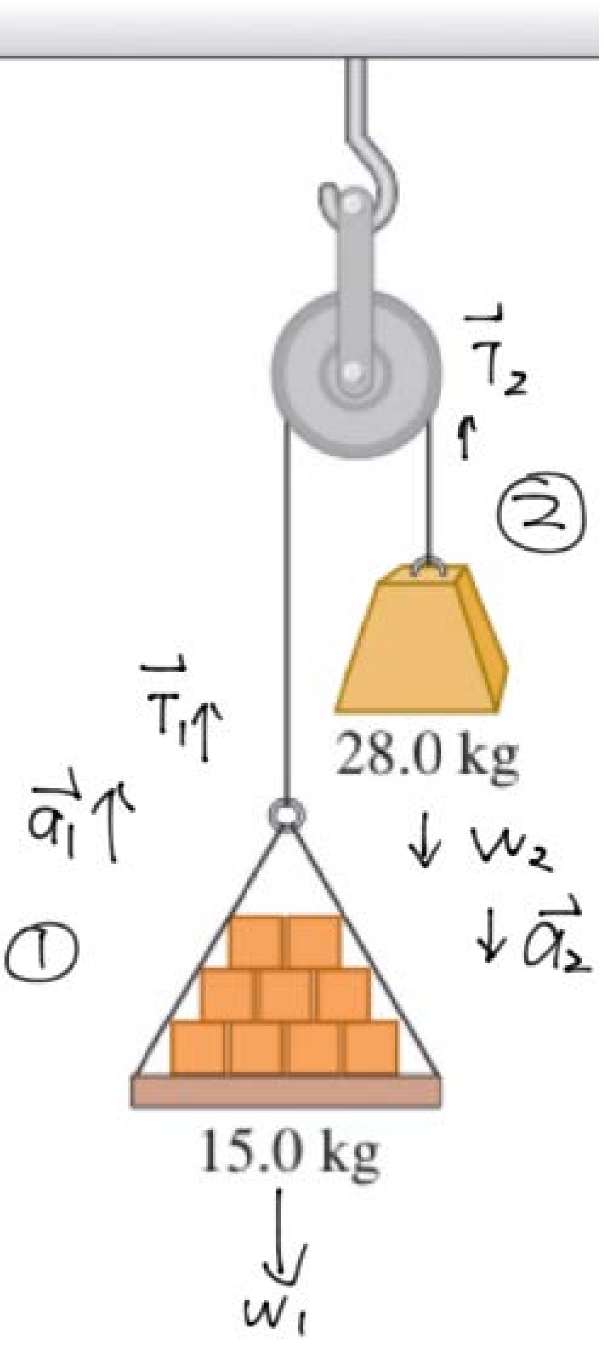
$$(T - m_1 g) + (m_2 g - T) = m_1 a + m_2 a$$

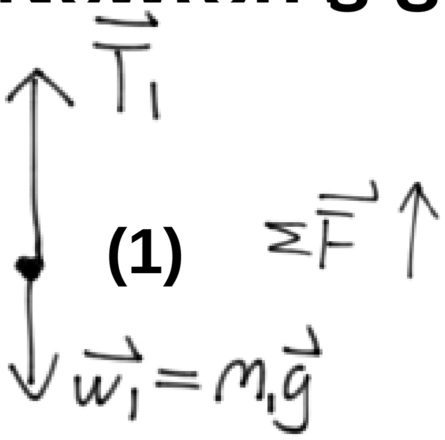
$$(m_2 - m_1) g = (m_1 + m_2) a$$

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

$$a = \frac{28 - 15}{28 + 15} \cdot 9.8\ m/s^2 = 2.96\ m/s^2$$

(b) To calculate the acceleration, we use Newton's second law $F = ma$

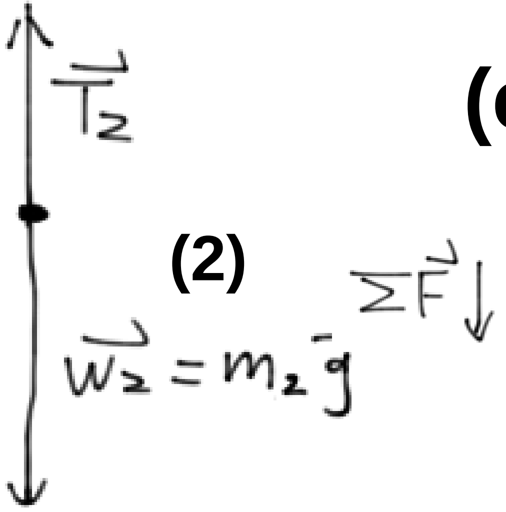




$\hat{i} \uparrow$

$$\vec{a}_1 = 2.96\ m/s^2\ \hat{i}$$

$$\vec{a}_2 = -2.96\ m/s^2\ \hat{i}$$



(c) Calculate the tension T

Recall $T_1 - m_1 g = m_1 a$

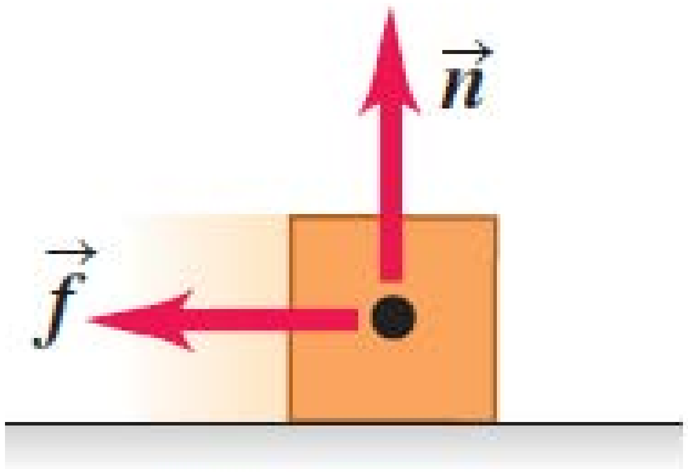
$$T = m_1 g + m_1 a \quad \text{from ①}$$

$$= 15\ kg\ (9.8 + 2.96)\ m/s^2$$

$$= 191.0\ N$$

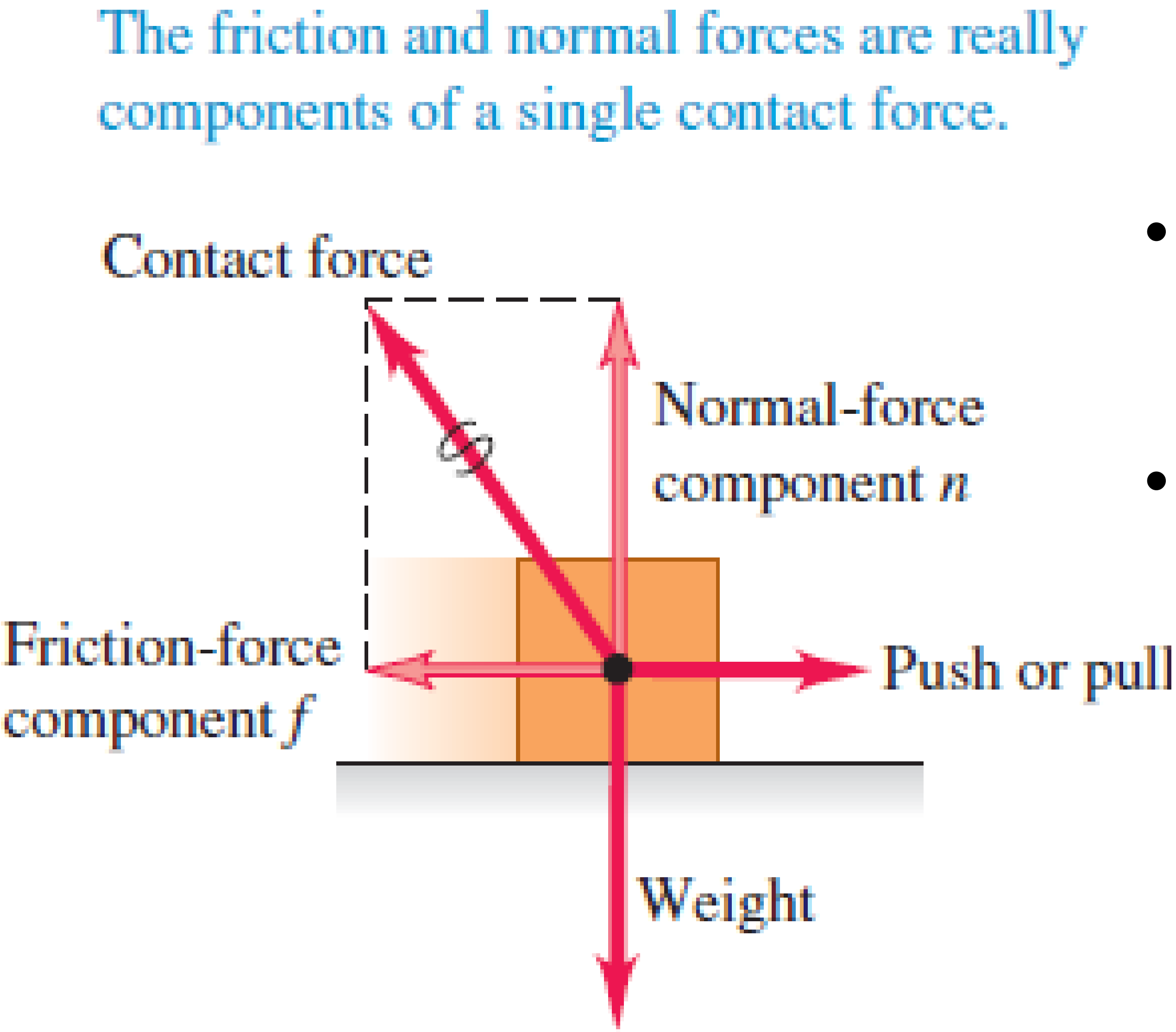
Recall Frictional Forces

(b) **Friction force $\vec{f}$:** In addition to the normal force, a surface may exert a frictional force on an object, directed parallel to the surface.



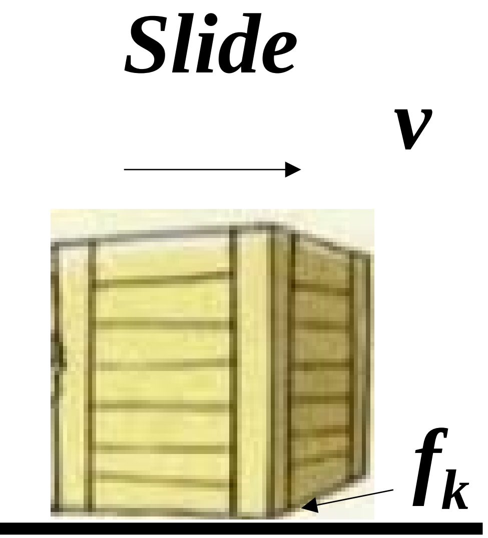
Direction counters the direction of the (tendency of) motion relative to the surface

Normal and Frictional Forces



- The perpendicular component vector is the normal force, denoted by ***n***
- The vector parallel to the surface is the **friction force,** denoted by ***f***

Kinetic Friction



kinetic friction force $\vec{f}_k$

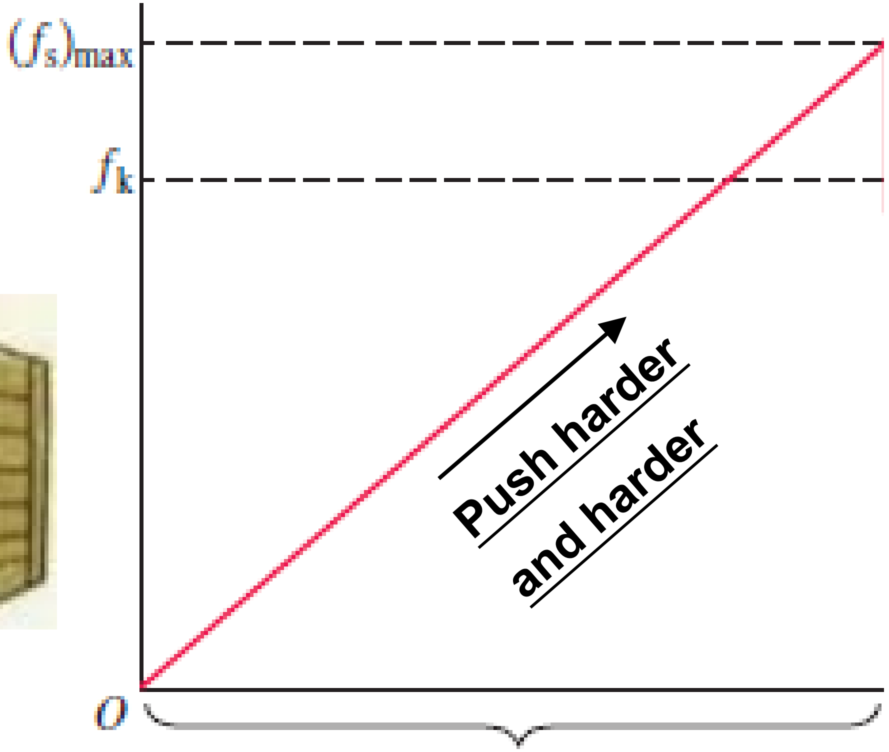
$$f_k = \mu_k n \qquad \text{(magnitude of kinetic friction force)}$$

where μ_k (pronounced "mu-sub-k") is a constant called the **coefficient of kinetic friction.** The more slippery the surface, the smaller this coefficient. Because it is a quotient of two force magnitudes, μ_k is a pure number without units.

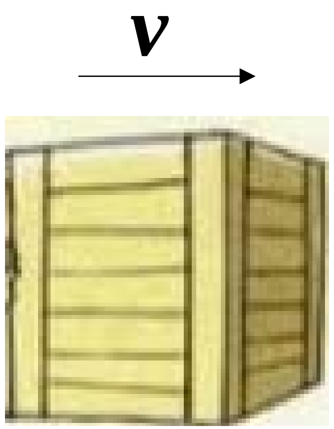
CAUTION **Friction and normal forces are always perpendicular** Remember that Eq. (5.5) is *not* a vector equation because $\vec{f}_k$ and $\vec{n}$ are always perpendicular. Rather, it is a scalar relationship between the magnitudes of the two forces.

Kinetic and Static Friction

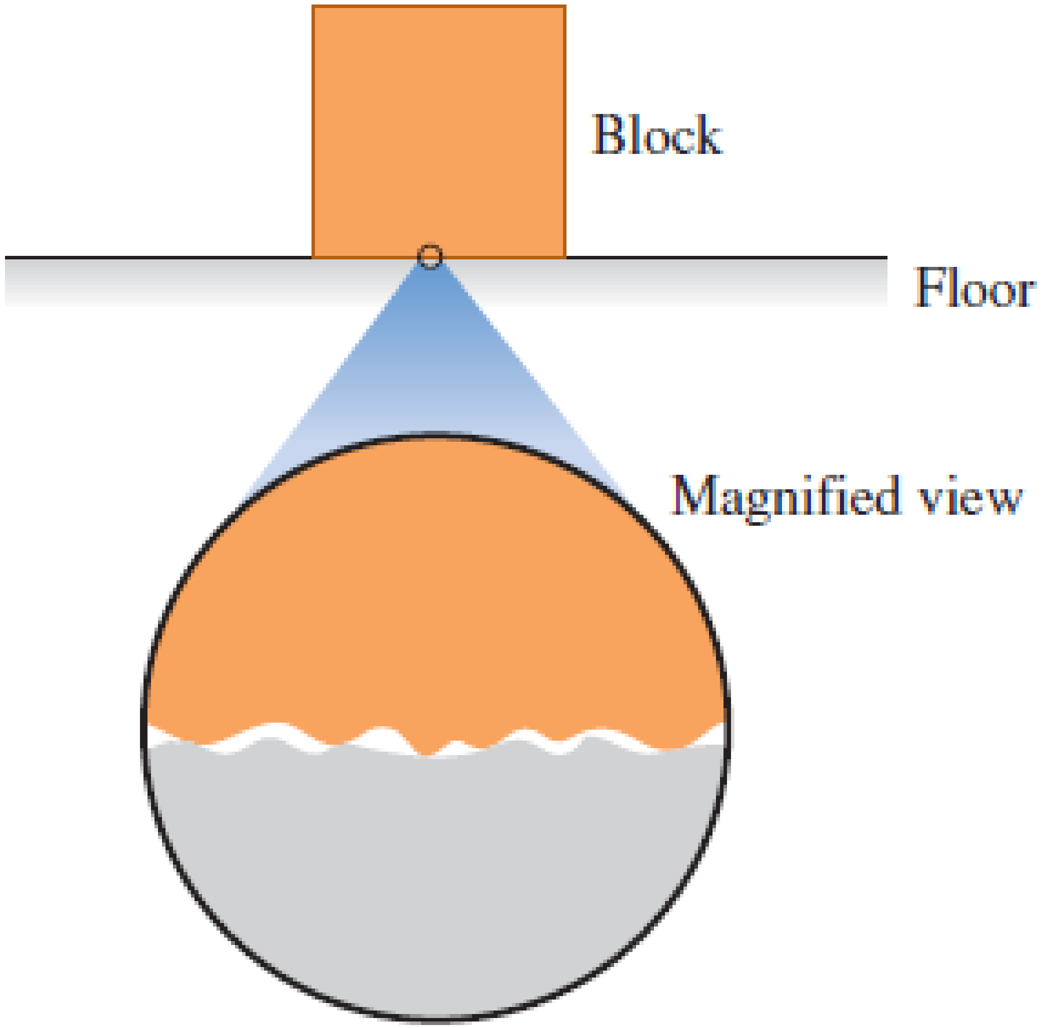
When you try to slide a heavy box of books across the floor, the box doesn't move at all unless you push with a certain minimum force. Then the box starts moving, and you can usually keep it moving with less force than you needed to get it started.



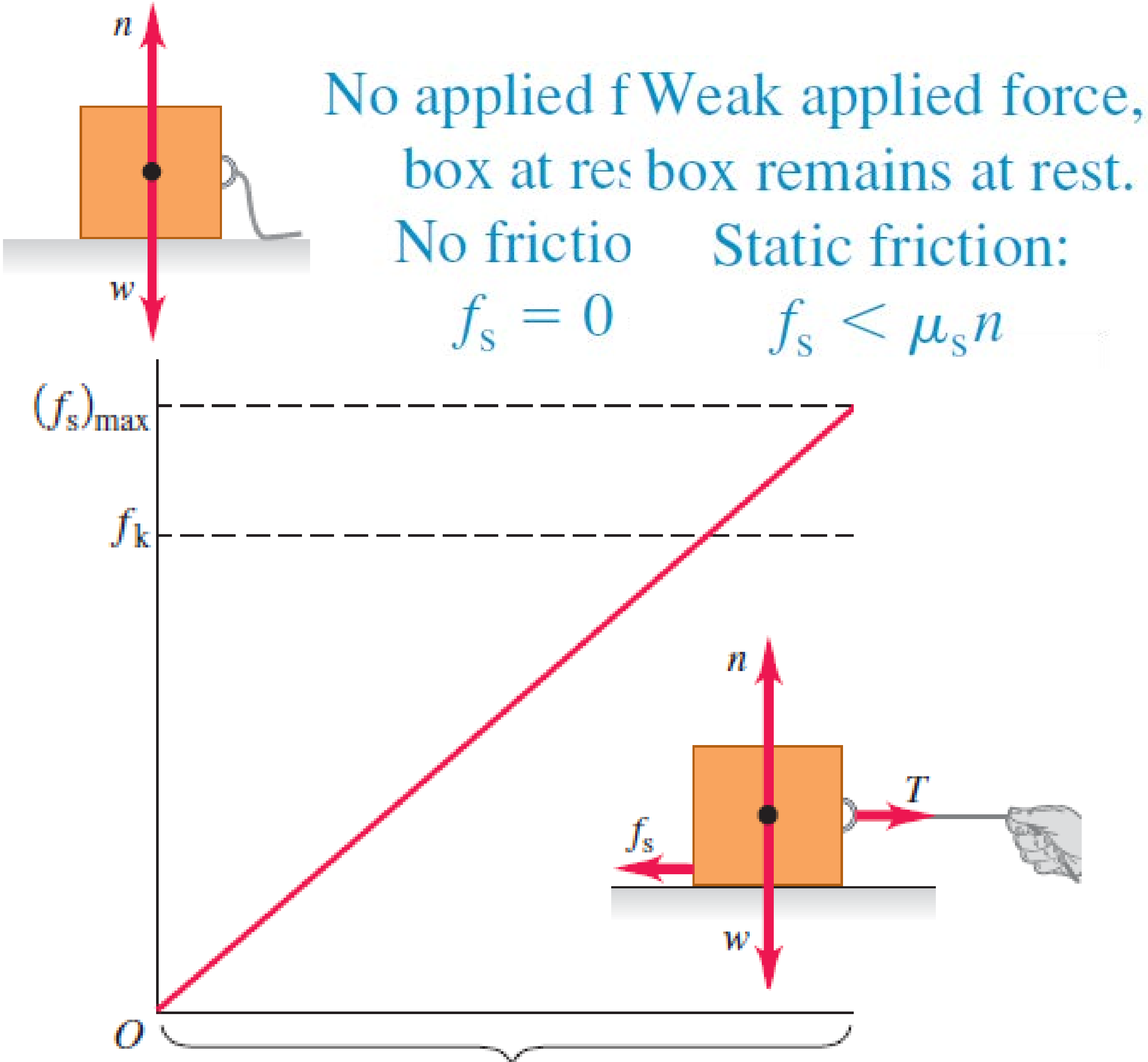
Box at rest; static friction
equals applied force.



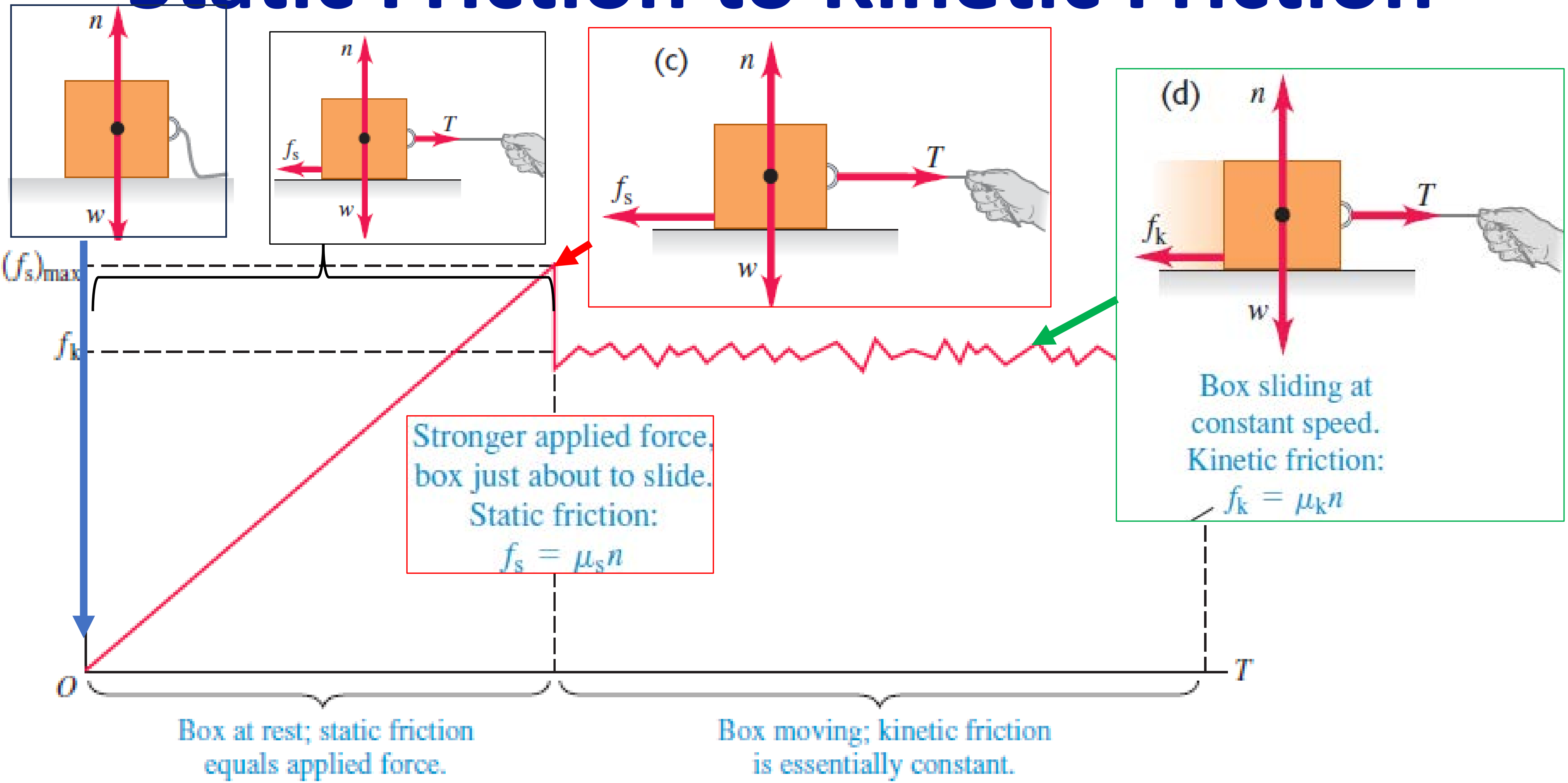
Static Friction



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

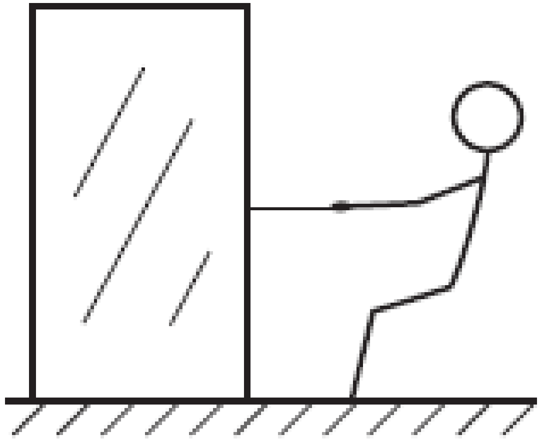


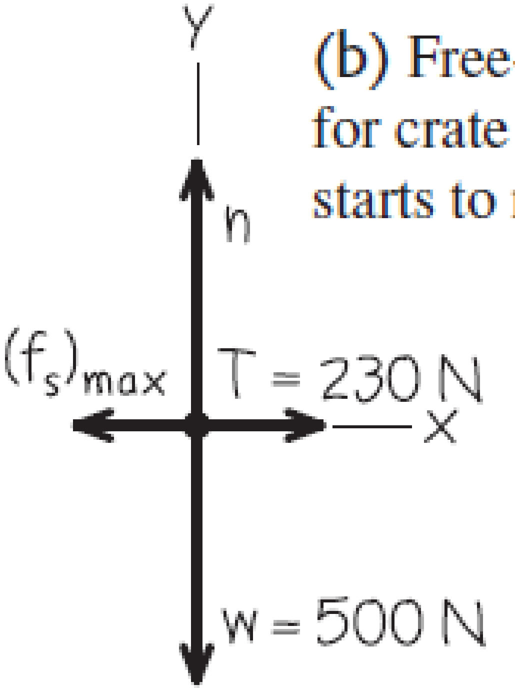
Static Friction to Kinetic Friction



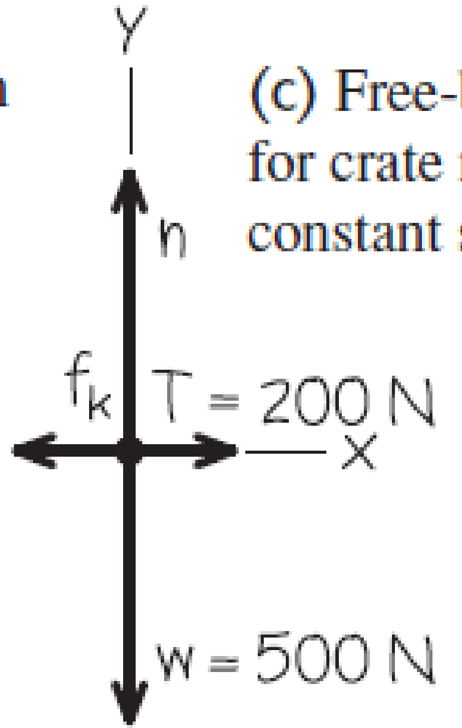
Example 5.13

You want to move a 500-N crate across a level floor. To start the crate moving, you have to pull with a 230-N horizontal force. Once the crate "breaks loose" and starts to move, you can keep it moving at constant velocity with only 200 N. What are the coefficients of static and kinetic friction?





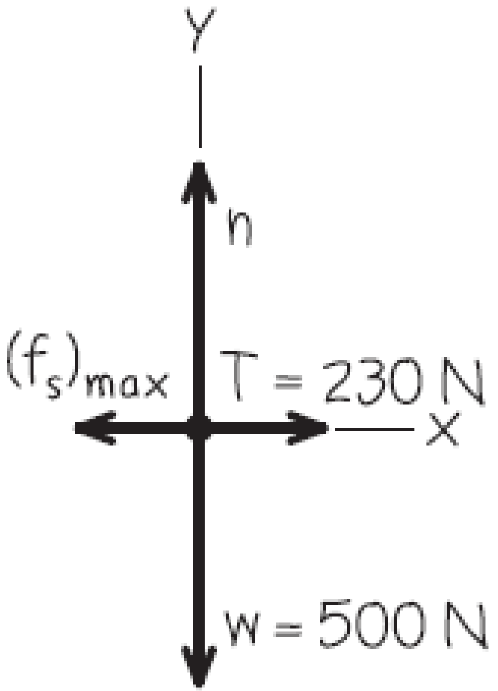
(b) Free-body diagram for crate just before it starts to move



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

Example 5.13 Static

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



EXECUTE: Just before the crate starts to move (Fig. 5.20b), we have from Eqs. (5.2)

$$\sum F_x = T + (-(f_s)_{max}) = 0 \quad \text{so} \quad (f_s)_{max} = T = 230\text{ N}$$

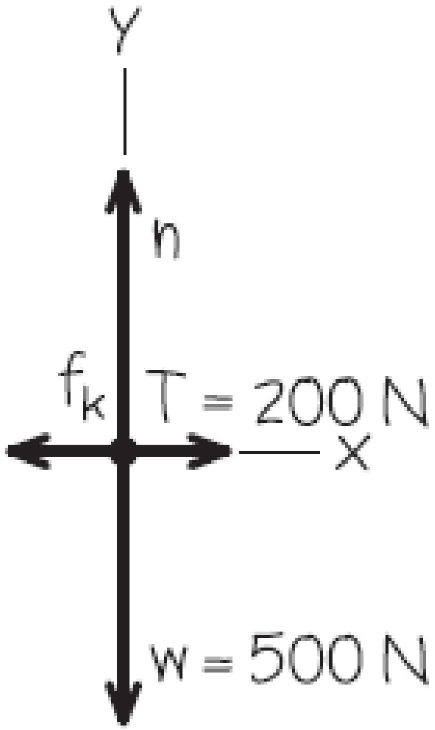
$$\sum F_y = n + (-w) = 0 \quad \text{so} \quad n = w = 500\text{ N}$$

Now we solve Eq. (5.6), $(f_s)_{max} = \mu_s n$, for the value of μ_s:

$$\mu_s = \frac{(f_s)_{max}}{n} = \frac{230\text{ N}}{500\text{ N}} = 0.46$$

Example 5.13 Kinetic

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



After the crate starts to move (Fig. 5.20c) we have

$$\sum F_x = T + (-f_k) = 0 \quad \text{so} \quad f_k = T = 200\text{ N}$$

Only holds for constant velocity!

$$\sum F_y = n + (-w) = 0 \quad \text{so} \quad n = w = 500\text{ N}$$

Using $f_k = \mu_k n$ from Eq. (5.5), we find

$$\mu_k = \frac{f_k}{n} = \frac{200\text{ N}}{500\text{ N}} = 0.40$$

Example 5.14

In Example 5.13, what is the friction force if the crate is at rest on the surface and a horizontal force of 50 N is applied to it?

Note: Static friction can be less than the maximum!

$$f_s \leq \mu_s n \qquad \text{(magnitude of static friction force)}$$

The applied force is less than the maximum force of static friction 230 N (given in the previous problem)

The system is the in equilibrium and follow Newton's *first* law, not the second.

EXECUTE: From the equilibrium conditions, Eqs. (5.2), we have

$$\sum F_x = T + (-f_s) = 0 \quad \text{so} \quad f_s = T = 50\text{ N}$$

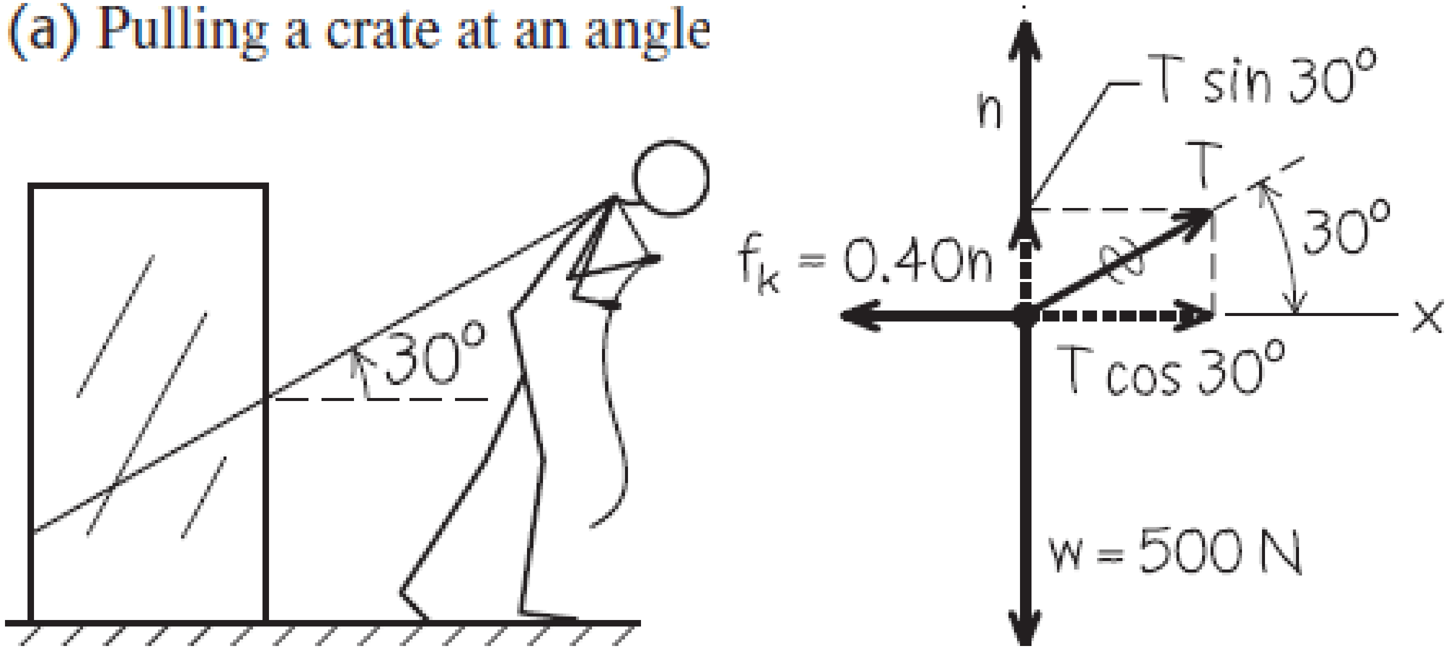
Example 5.15

In Example 5.13, suppose you move the crate by pulling upward on the rope at an angle of 30° above the horizontal. How hard must you pull to keep it moving with constant velocity? Assume that $\mu_k = 0.40$.

$$T\cos 30° = \mu_k(w - T\sin 30°)$$

$$T = \frac{\mu_k w}{\cos 30° + \mu_k \sin 30°} = 188\text{ N}$$

(a) Pulling a crate at an angle

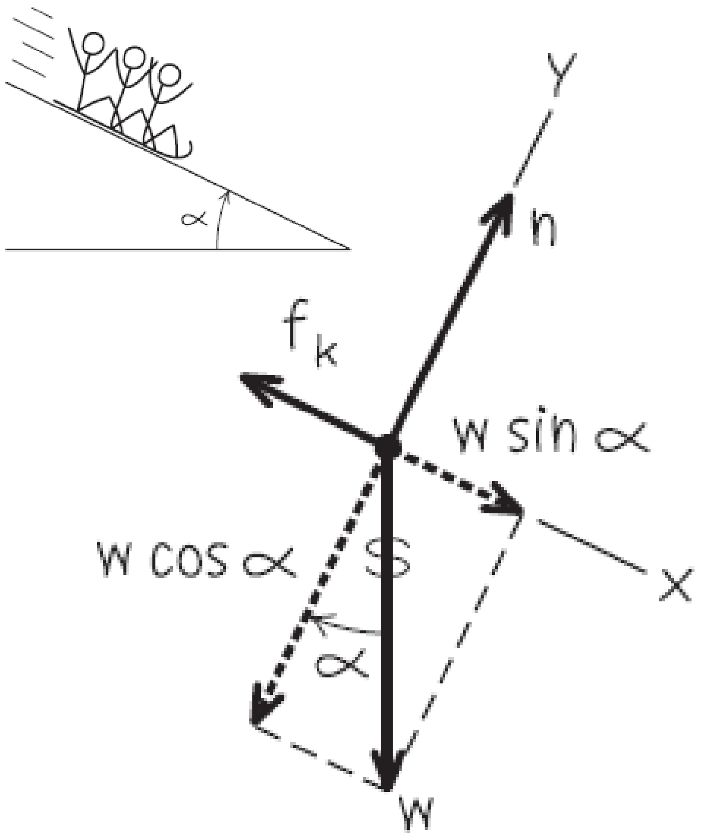


Used to require 200 N if T is along x. Reduced normal force makes the dragging easier!

What is the optimal angle?

Example 5.16

Let's go back to the toboggan we studied in Example 5.10. The wax has worn off, so there is now a nonzero coefficient of kinetic friction μ_k. The slope has just the right angle to make the toboggan slide with constant velocity. Find this angle in terms of w and μ_k.



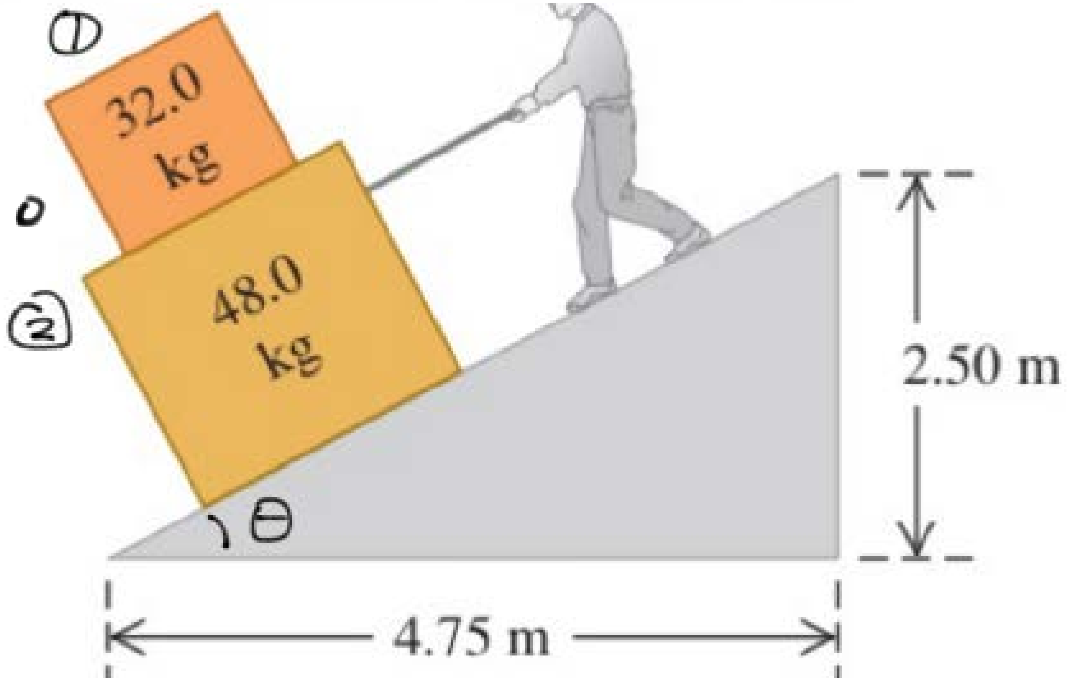
EXECUTE: The equilibrium conditions are

$$\sum F_x = w \sin \alpha + (-f_k) = w \sin \alpha - \mu_k n = 0$$
$$\sum F_y = n + (-w \cos \alpha) = 0$$

$$\mu_k n = w \sin \alpha \quad \text{and} \quad n = w \cos \alpha$$

$$\mu_k = \frac{\sin \alpha}{\cos \alpha} = \tan \alpha \quad \text{so} \quad \alpha = \arctan \mu_k$$

5.31 •• You are lowering two boxes, one on top of the other, down the ramp shown in Fig. E5.31 by pulling on a rope parallel to the surface of the ramp. Both boxes move together at a constant speed of 15.0 cm/s. The coefficient of kinetic friction between the ramp and the lower box is 0.444, and the coefficient of static friction between the two boxes is 0.800. (a) What force do you need to exert to accomplish this? (b) What are the magnitude and direction of the friction force on the upper box?



$$\tan\theta = \frac{2.5\,m}{4.75\,m} = 0.5263 \Rightarrow \theta = 27.76^{\circ}$$

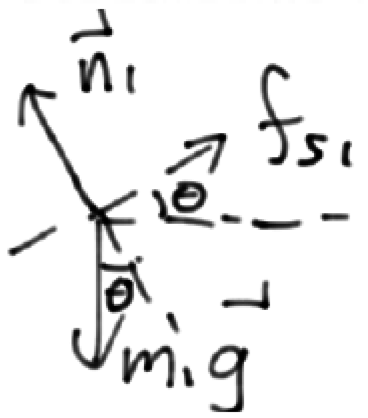
$$\sin\theta = 0.466 \qquad \cos\theta = 0.885$$

the surface of the ramp. Both boxes move together at a constant speed of 15.0 cm/s. The coefficient of kinetic friction between the ramp and the lower box is 0.444, and the coefficient of static friction between the two boxes is 0.800. (a) What force do you need to exert to accomplish this? (b) What are the magnitude and direction of the friction force on the upper box?

$\sin\theta = 0.466 \quad \cos\theta = 0.885$

$\tan\theta = \frac{2.5\,m}{4.75\,m} = 0.5263$

①

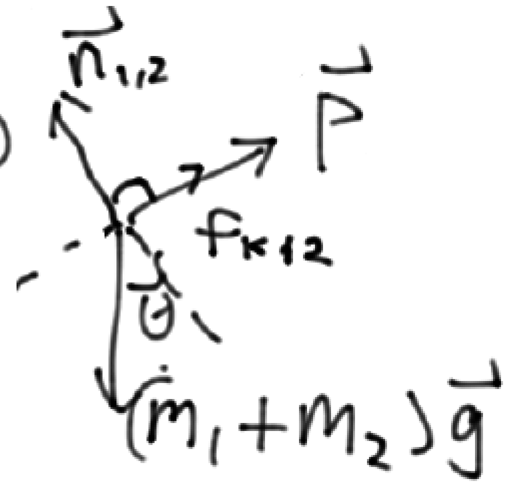


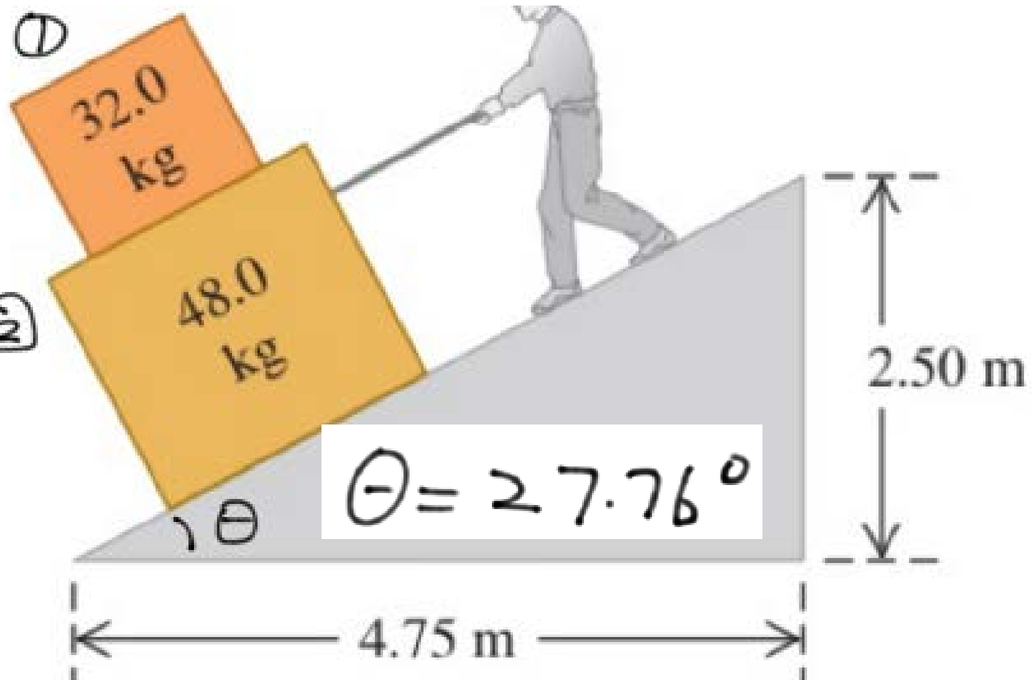
$m_1 = 32.0\ kg$

$m_2 = 48.0\ kg$

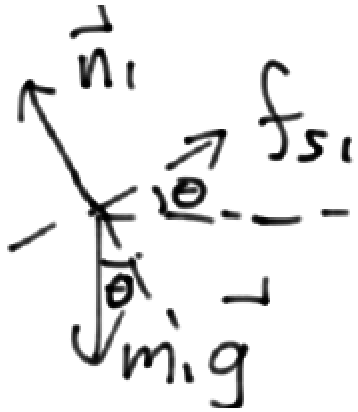
①② moving together.

①+②

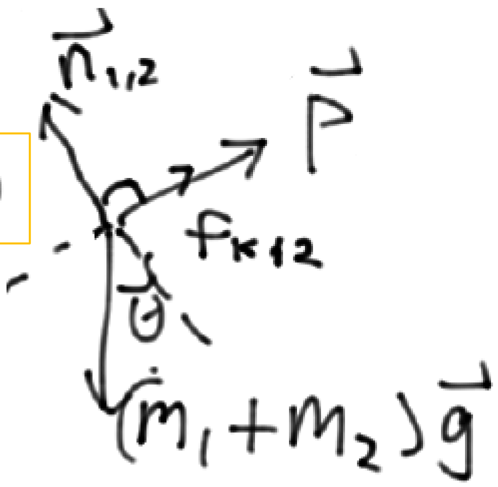




①

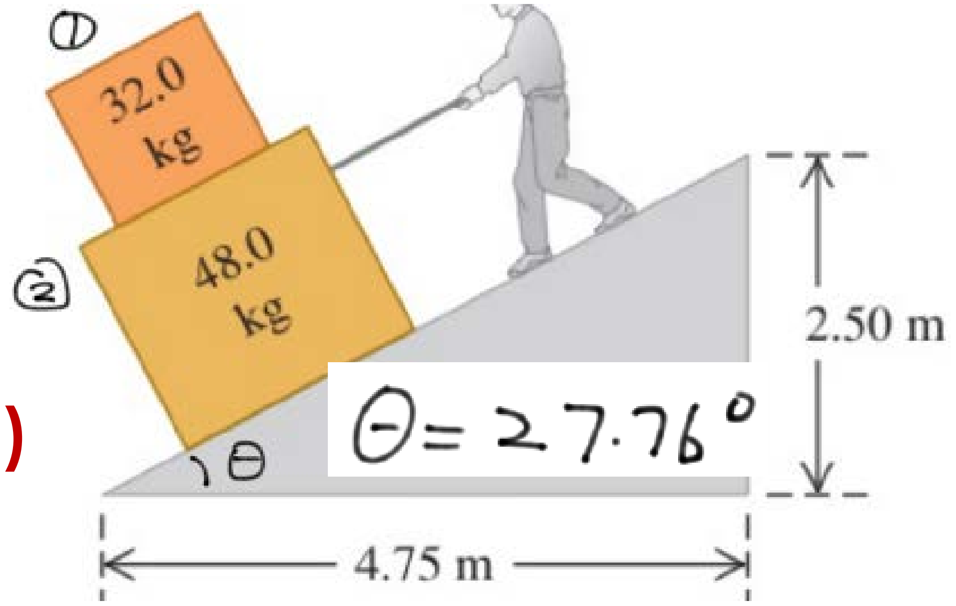


①+②



$\sin\theta = 0.466 \quad \cos\theta = 0.885$

$\tan\theta = \dfrac{2.5\,m}{4.75\,m} = 0.5263$



$m_1 = 32.0\,kg$

$m_2 = 48.0\,kg$

Along x $\quad P + \boxed{f_{k12}} = (m_1+m_2)g\cdot\sin\theta \qquad$ **(1)**

Along y $\quad n_{12} = (m_1+m_2)\cdot\cos\theta\, g \qquad$ **(2)**

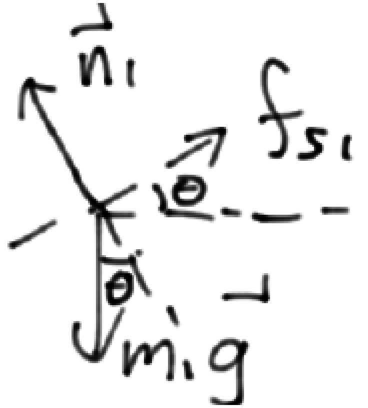
which are unknown? what is missing?

$\boxed{f_{k12}} = \mu_k \cdot n_{12} \qquad$ **(3)** $\quad \mu_k = 0.444$

Plug f_{k12} in ①

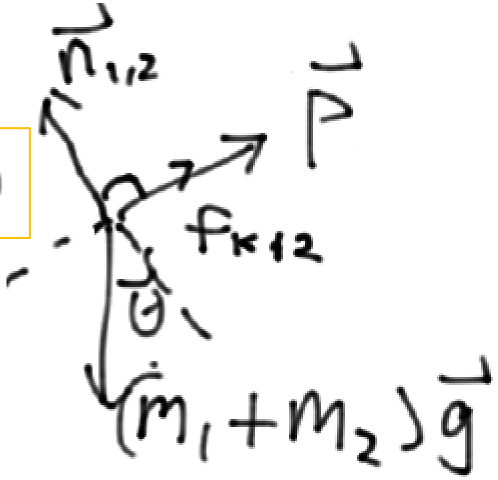
②+③: $\boxed{= \mu_k(m_1+m_2)\cos\theta\, g}$ $\quad P = (m_1+m_2)g\sin\theta - (m_1+m_2)g\cdot\mu_k\cdot\cos\theta$

①



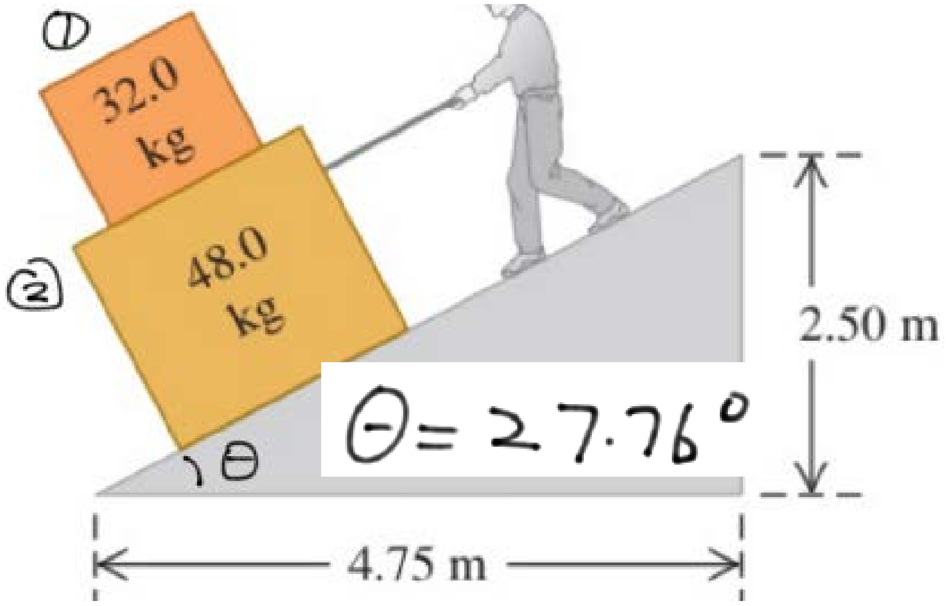
$m_1 = 32.0\,kg$
$m_2 = 48.0\,kg$

$\boxed{①+②}$



$\sin\theta = 0.466 \quad \cos\theta = 0.885$

$\tan\theta = \frac{2.5m}{4.75m} = 0.5263$



Plug f_{k12} in ①

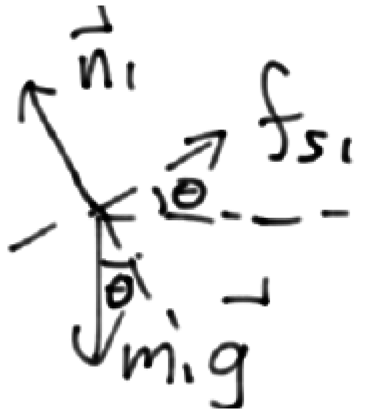
$$P = (m_1+m_2)g\sin\theta - \overbrace{(m_1+m_2)g\cdot\mu_k\cdot\cos\theta}^{f_{k12}}$$

$$= (m_1+m_2)g\,(\sin\theta - \mu_k\cdot\cos\theta)$$

$$= 80.0kg\cdot 9.8m/s^2\,(0.466 - 0.444\times 0.885)$$

$$= 57.3\ N$$

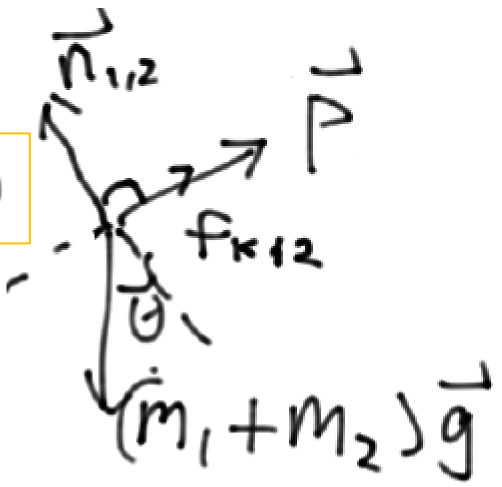
①



$m_1 = 32.0\ kg$

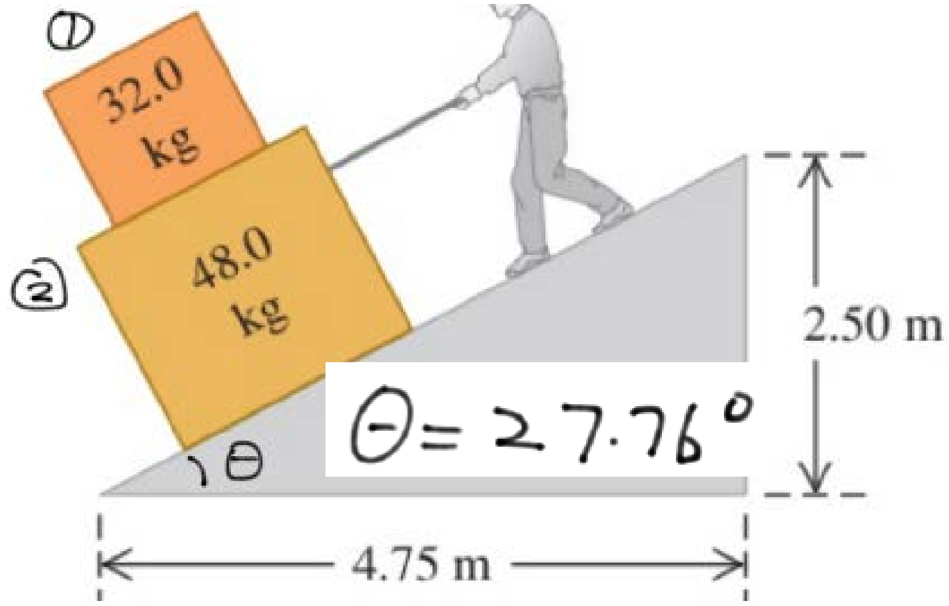
$m_2 = 48.0\ kg$

$\boxed{①+②}$



$\sin\theta = 0.466 \quad \cos\theta = 0.885$

$\tan\theta = \frac{2.5m}{4.75m} = 0.5263$



①+② moving together so between them, there is STATIC Friction

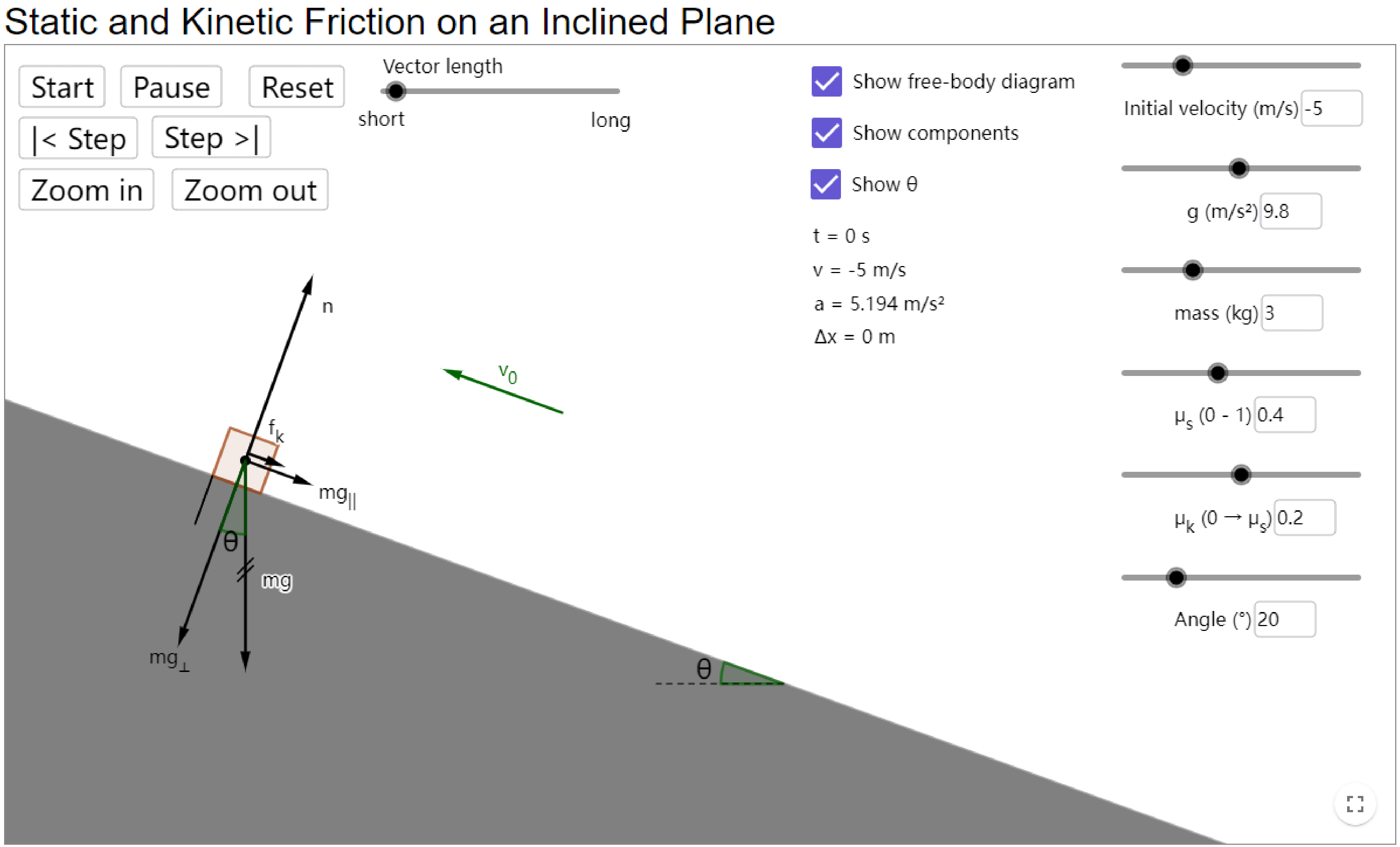
$n_1 = m_1 g \cdot \cos\theta$

$f_{s1} = m_1 g \cdot \sin\theta$ so

$f_{s1} = 32.0\ kg \cdot 9.8\ m/s^2 \cdot 0.466$

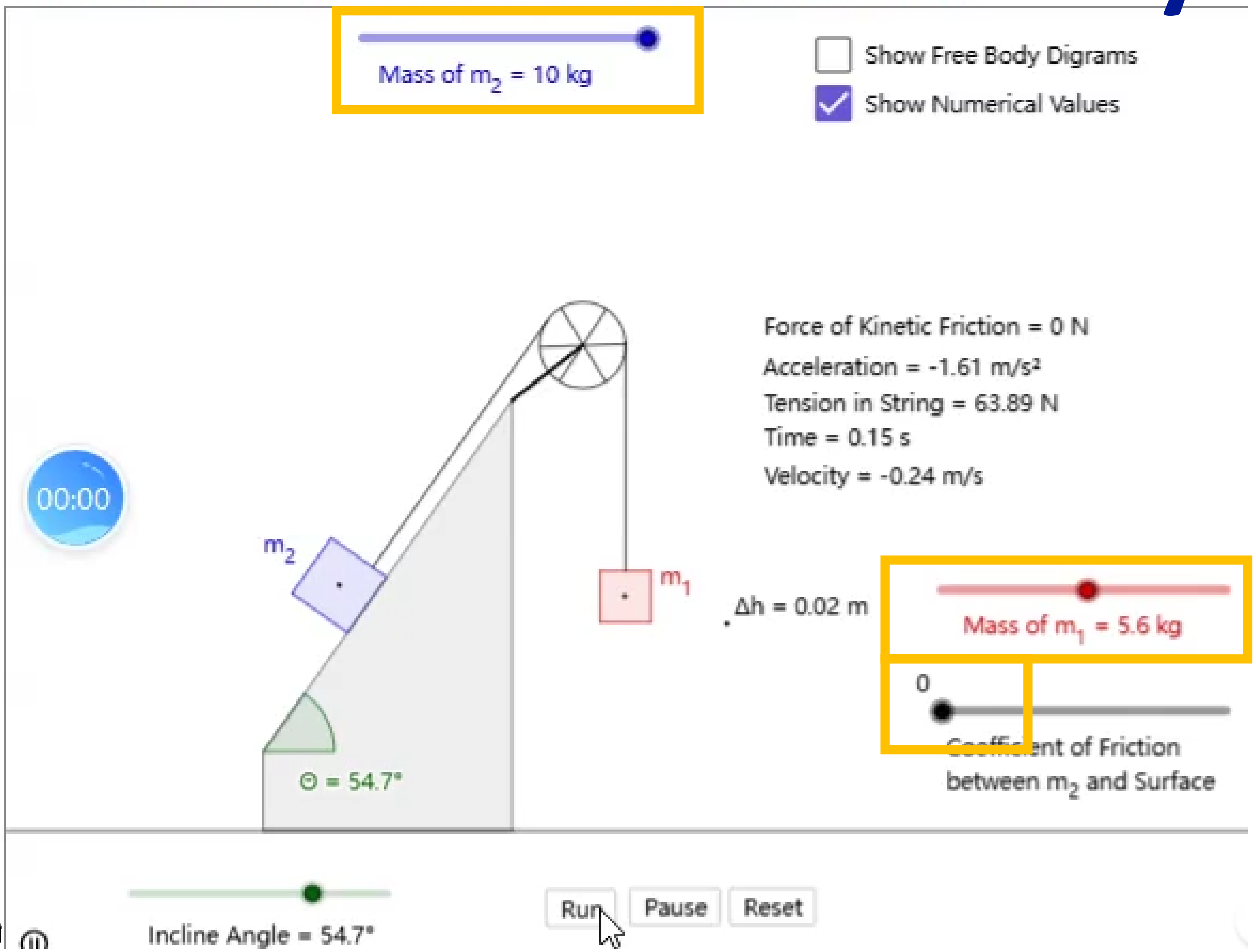
$= 146.1\ N$

Demonstration with O-Physics



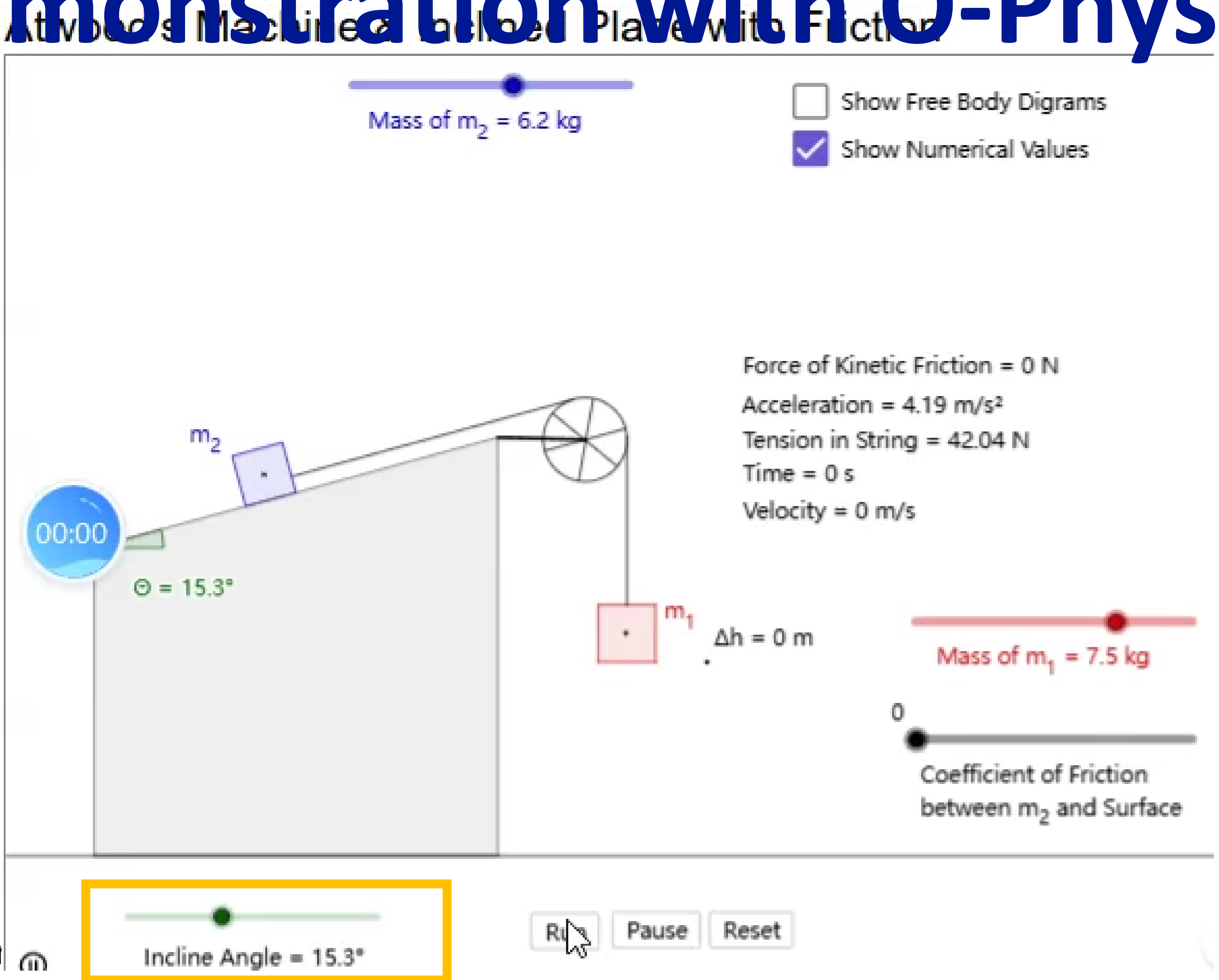
https://ophysics.com/f2.html

Demonstration with O-Physics



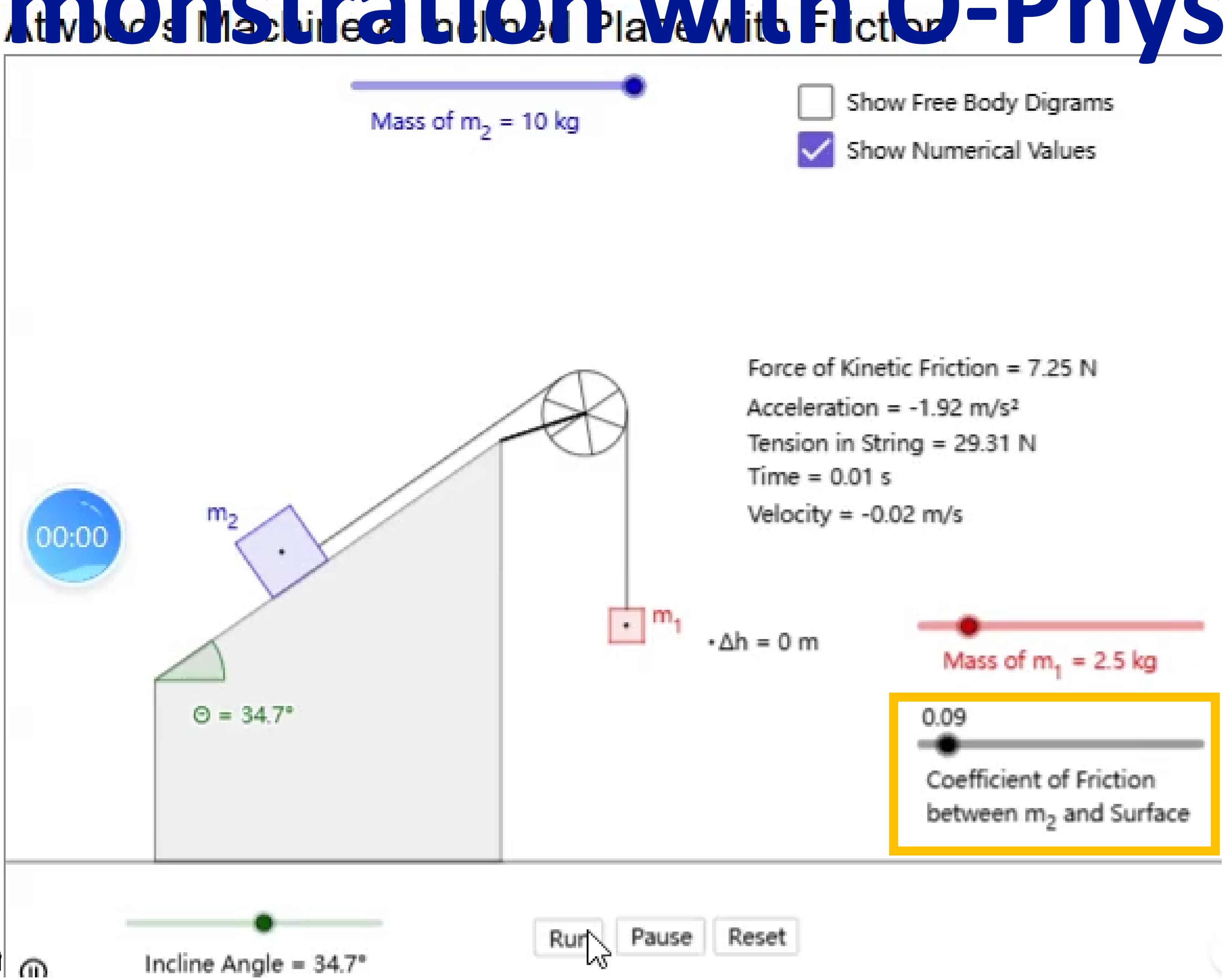
https://ophysics.cor

Demonstration with O-Physics



https://ophysics.com

Demonstration with O-Physics

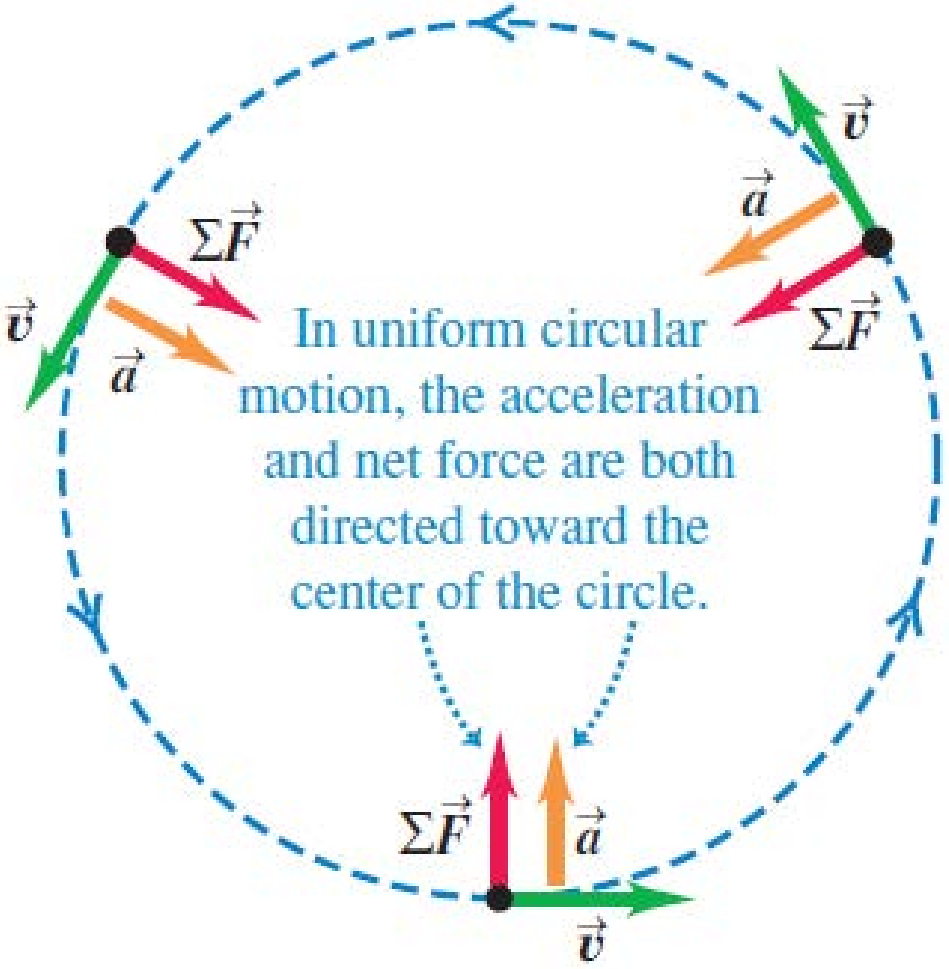


https://ophysics.cor

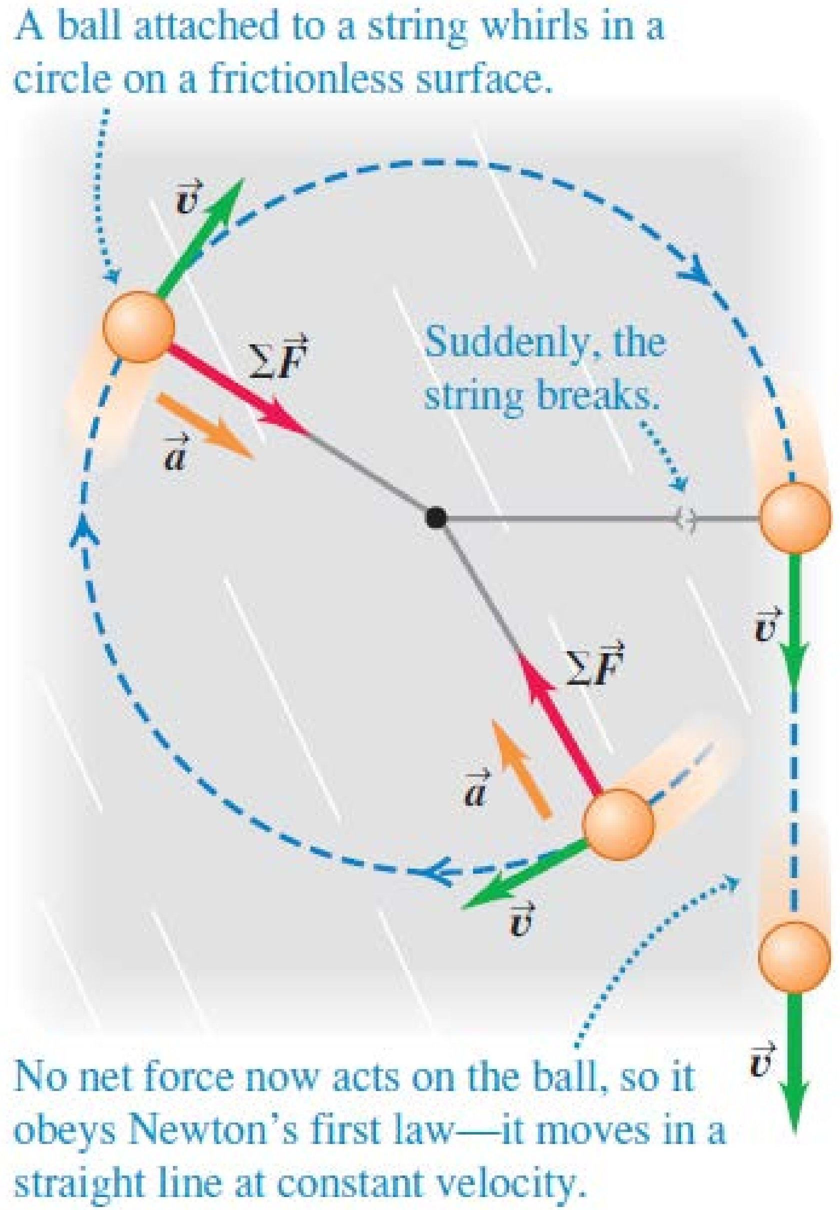
Rolling Friction

It's a lot easier to move a loaded filing cabinet across a horizontal floor using a cart with wheels than to slide it. How much easier? We can define a **coefficient of rolling friction** μ_r, which is the horizontal force needed for constant speed on a flat surface divided by the upward normal force exerted by the surface. Transportation engineers call μ_r the *tractive resistance*. Typical values of μ_r are 0.002 to 0.003 for steel wheels on steel rails and 0.01 to 0.02 for rubber tires on concrete. These values show one reason railroad trains are generally much more fuel efficient than highway trucks.

Dynamics of Circular Motion



$$a_{\mathrm{rad}} = \frac{v^2}{R} \qquad \text{(uniform circular motion)}$$



Dynamics of Circular Motion

We can also express the centripetal acceleration a_{rad} in terms of the *period* T, the time for one revolution:

$$T = \frac{2\pi R}{v} \qquad (5.15)$$

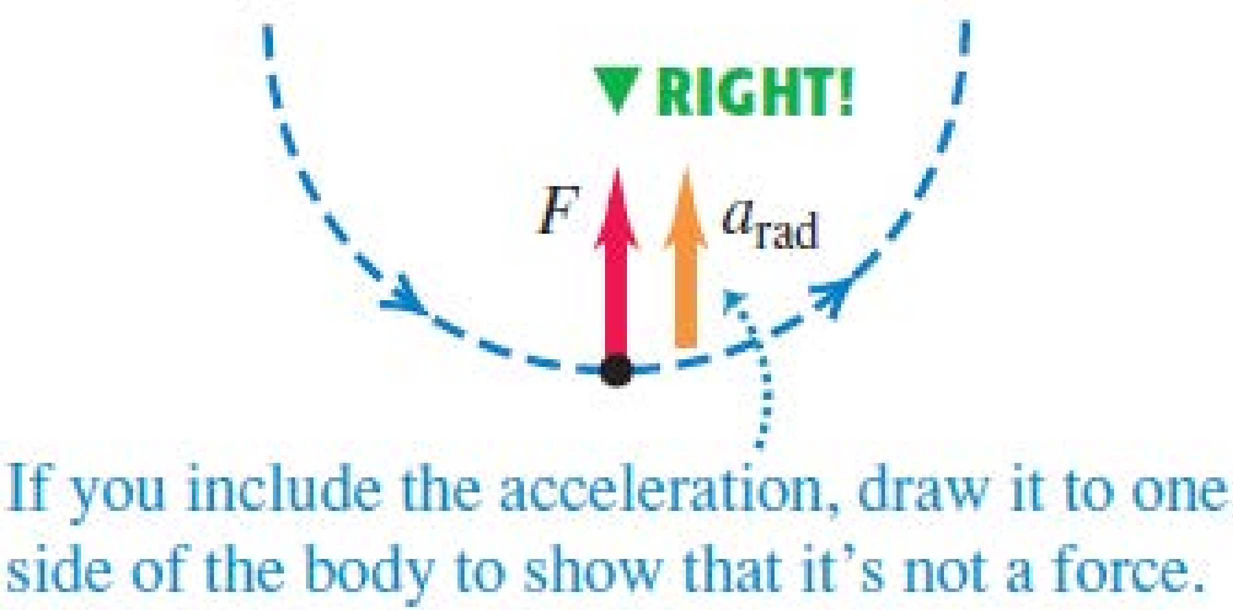
In terms of the period, a_{rad} is

$$a_{rad} = \frac{4\pi^2 R}{T^2} \qquad \text{(uniform circular motion)} \qquad (5.16)$$

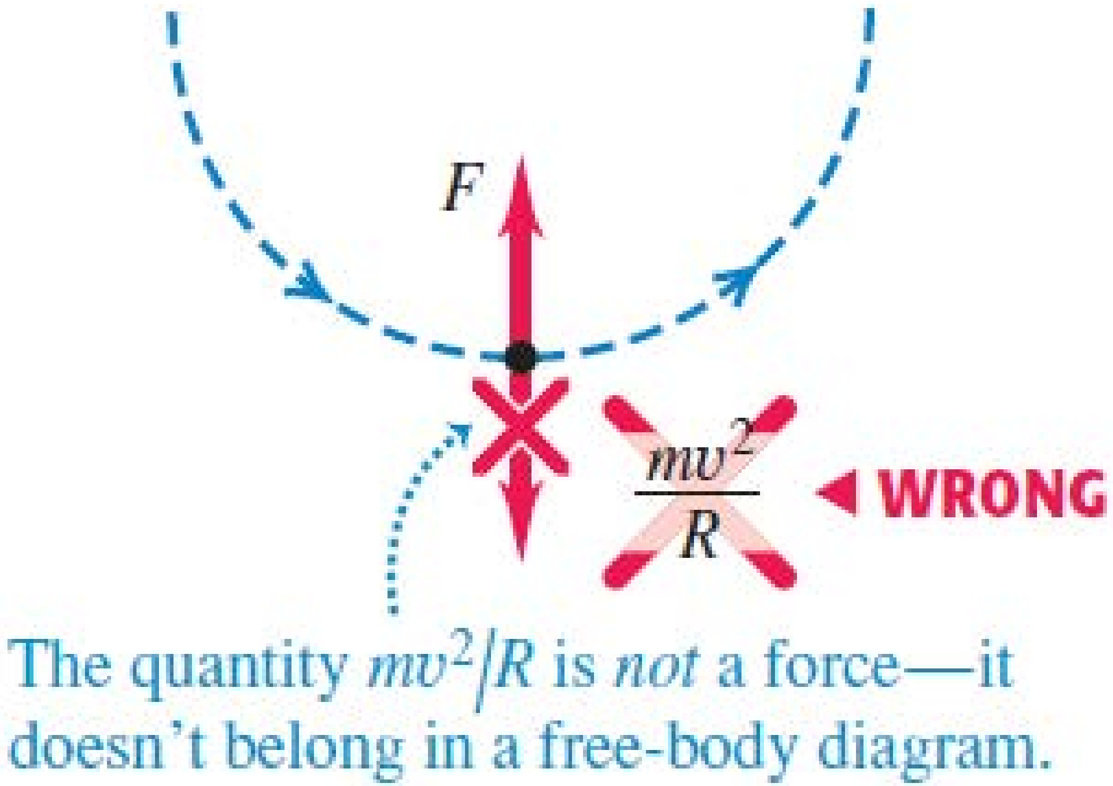
Dynamics of Circular Motion

$$F_{\text{net}} = ma_{\text{rad}} = m\frac{v^2}{R} \qquad \text{(uniform circular motion)}$$

(a) Correct free-body diagram



(b) Incorrect free-body diagram



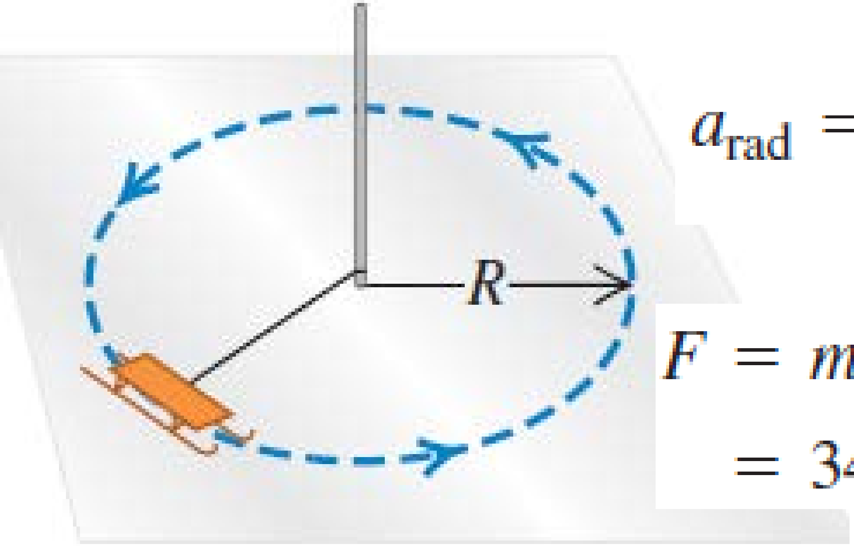
Force in uniform circular motion

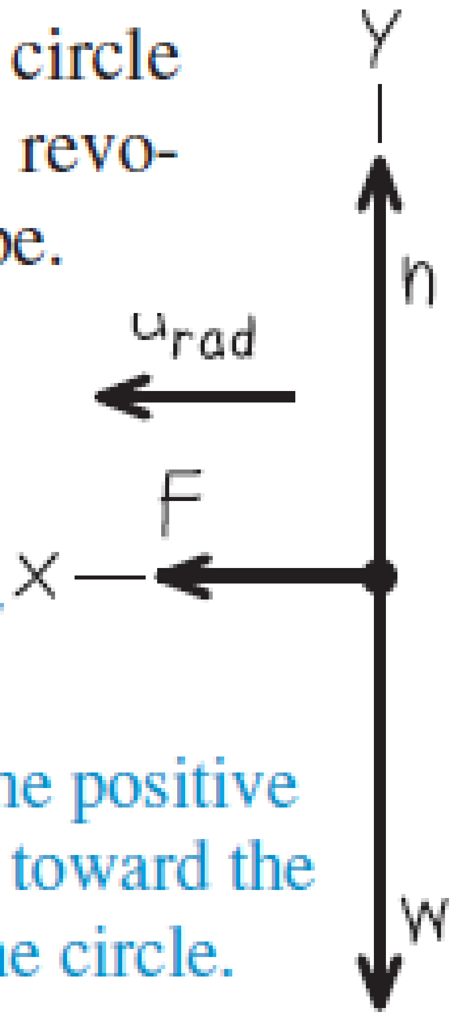
A sled with a mass of 25.0 kg rests on a horizontal sheet of essentially frictionless ice. It is attached by a 5.00-m rope to a post set in the ice. Once given a push, the sled revolves uniformly in a circle around the post (Fig. 5.31a). If the sled makes five complete revolutions every minute, find the force F exerted on it by the rope.

$$\sum F_x = F = ma_{\text{rad}}$$

$$a_{\text{rad}} = \frac{4\pi^2 R}{T^2} = \frac{4\pi^2(5.00\text{ m})}{(12.0\text{ s})^2} = 1.37\text{ m/s}^2$$

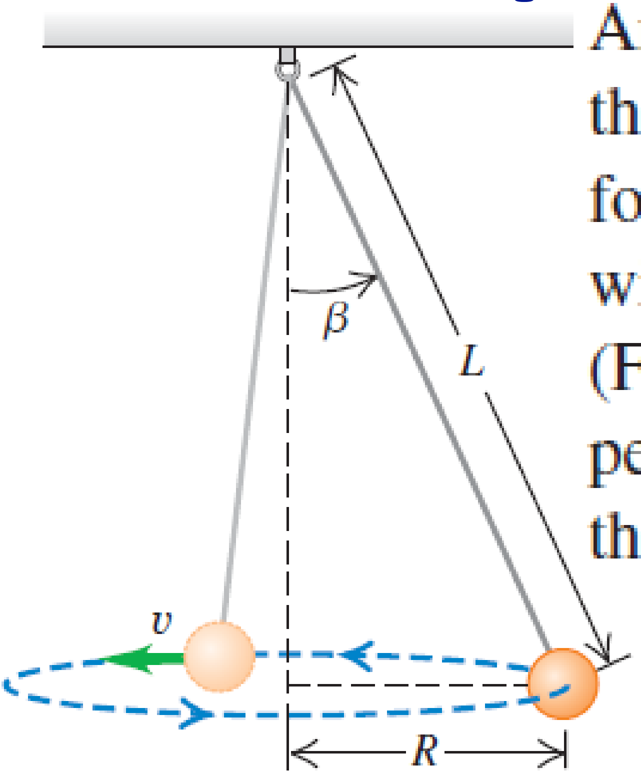
$$F = ma_{\text{rad}} = (25.0\text{ kg})(1.37\text{ m/s}^2)$$
$$= 34.3\text{ kg}\cdot\text{m/s}^2 = 34.3\text{ N}$$





We point the positive x-direction toward the center of the circle.

Example 5.20: A Conical Pendulum

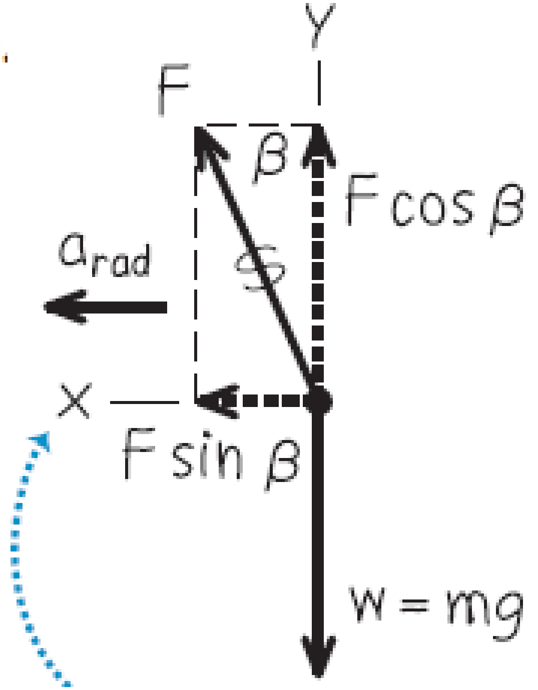


An inventor designs a pendulum clock using a bob with mass m at the end of a thin wire of length L. Instead of swinging back and forth, the bob is to move in a horizontal circle with constant speed v, with the wire making a fixed angle β with the vertical direction (Fig. 5.32a). This is called a *conical pendulum* because the suspending wire traces out a cone. Find the tension F in the wire and the period T (the time for one revolution of the bob).

$$\sum F_x = F\sin\beta = ma_{\text{rad}}$$

$$\sum F_y = F\cos\beta + (-mg) = 0$$

plug in F



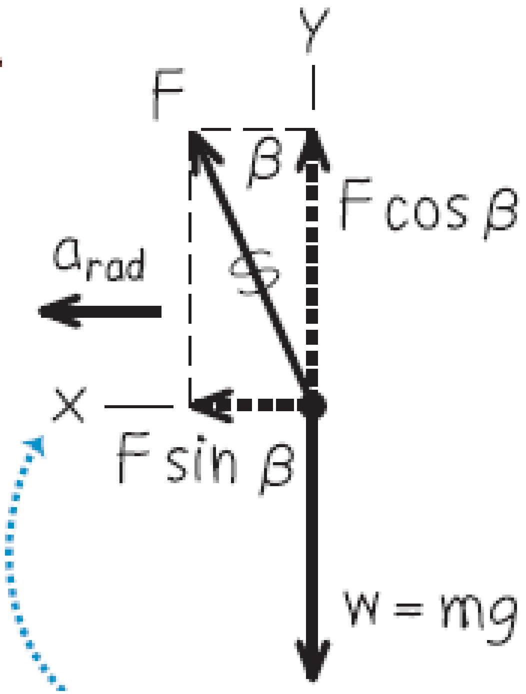
These are two equations for the two unknowns F and β.

$\sum F_y$ gives $F = mg/\cos\beta$;

$$\boxed{a_{\text{rad}} = g\tan\beta}$$

Example 5.20: A Conical Pendulum

An inventor designs a pendulum clock using a bob with mass m at the end of a thin wire of length L. Instead of swinging back and forth, the bob is to move in a horizontal circle with constant speed v, with the wire making a fixed angle β with the vertical direction (Fig. 5.32a). This is called a *conical pendulum* because the suspending wire traces out a cone. Find the tension F in the wire and the period T (the time for one revolution of the bob).

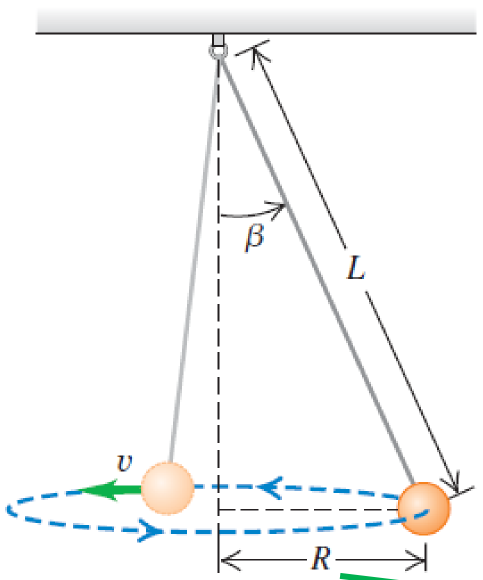


To relate β to the period T, we use Eq. (5.16) for a_{rad}, solve for T, and insert $a_{rad} = g \tan \beta$:

$$a_{rad} = \frac{4\pi^2 R}{T^2} \quad \text{so} \quad T^2 = \frac{4\pi^2 R}{a_{rad}}$$

$$T = 2\pi \sqrt{\frac{R}{g \tan \beta}}$$

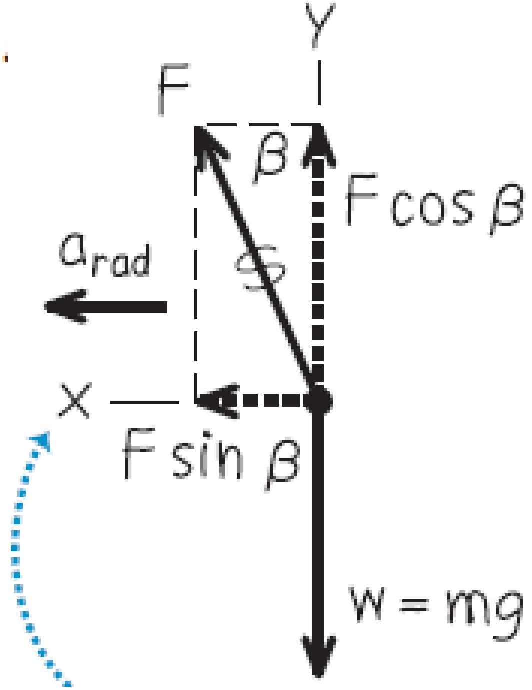
Example 5.20: A Conical Pendulum



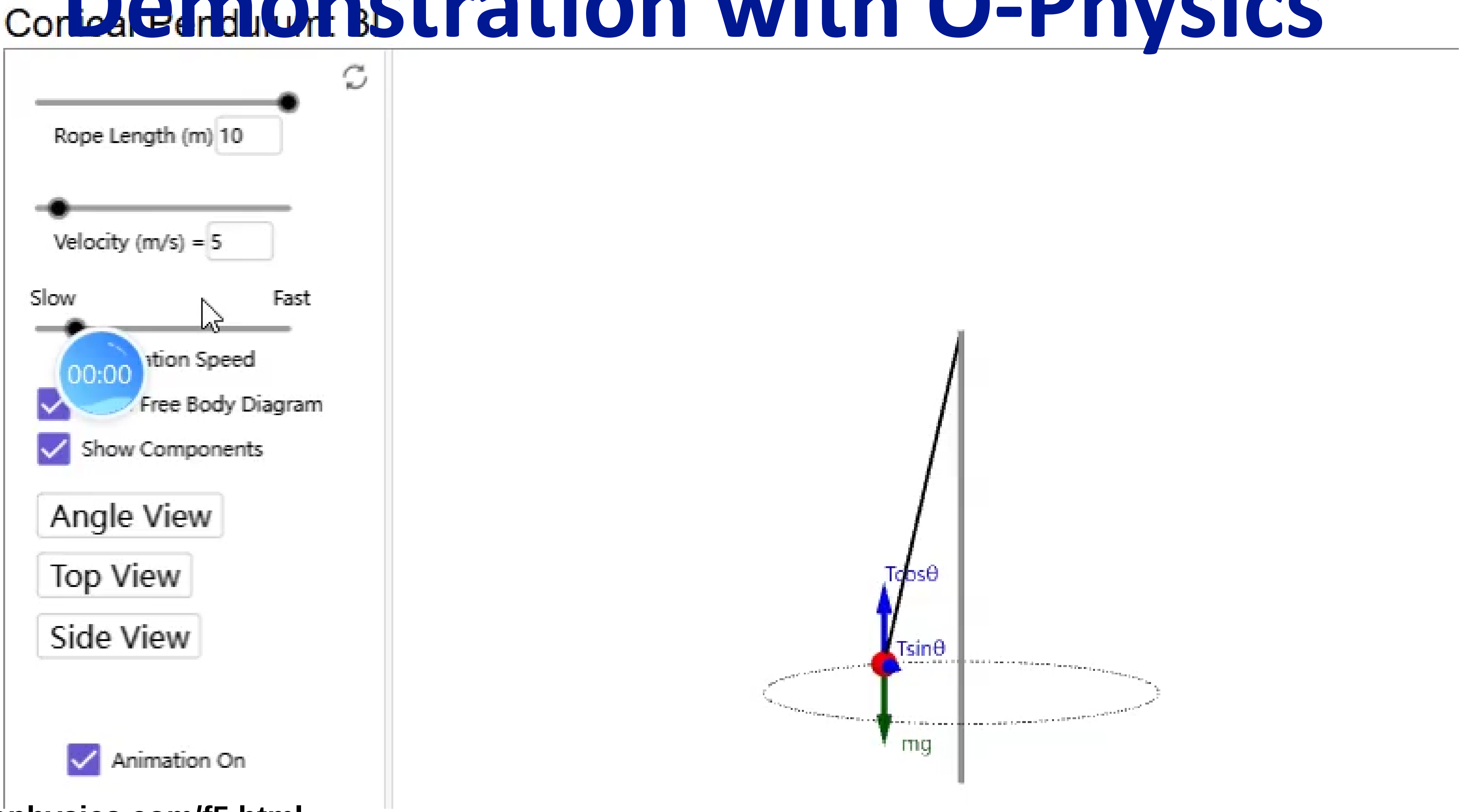
An inventor designs a pendulum clock using a bob with mass m at the end of a thin wire of length L. Instead of swinging back and forth, the bob is to move in a horizontal circle with constant speed v, with the wire making a fixed angle β with the vertical direction (Fig. 5.32a). This is called a *conical pendulum* because the suspending wire traces out a cone. Find the tension F in the wire and the period T (the time for one revolution of the bob).

Figure 5.32a shows that $R = L \sin \beta$. We substitute this and use $\sin \beta / \tan \beta = \cos \beta$:

$$T = 2\pi \sqrt{\frac{L \cos \beta}{g}}$$



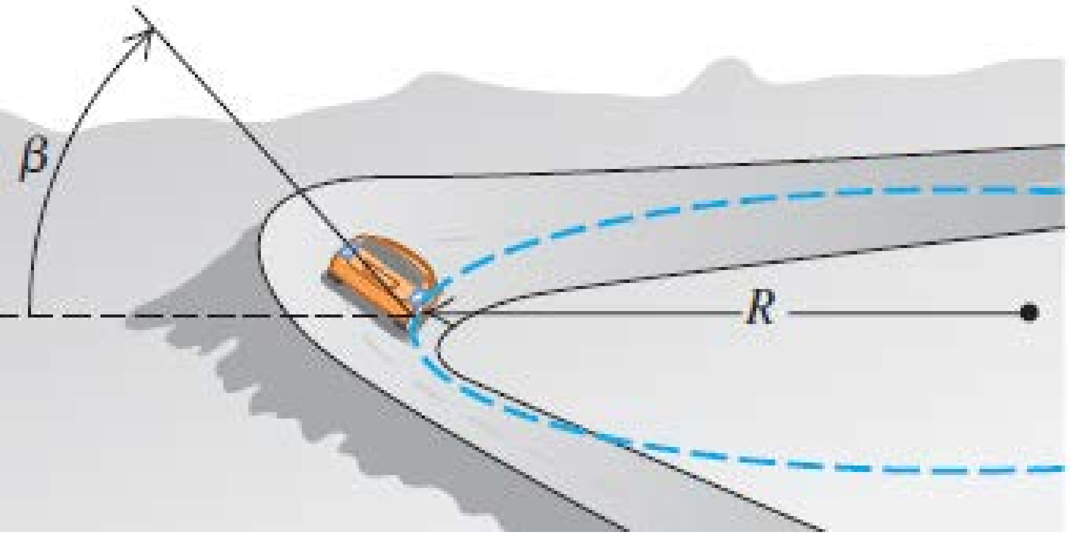
Demonstration with O-Physics



https://ophysics.com/f5.html

Example 5.22: Rounding a banked curve

For a car traveling at a certain speed, it is possible to bank a curve at just the right angle so that no friction at all is needed to maintain the car's turning radius. Then a car can safely round the curve even on wet ice. (Bobsled racing depends on this same idea.) Your engineering firm plans to rebuild the curve in Example 5.21 so that a car moving at a chosen speed v can safely make the turn even with no friction (Fig. 5.34a). At what angle β should the curve be banked?



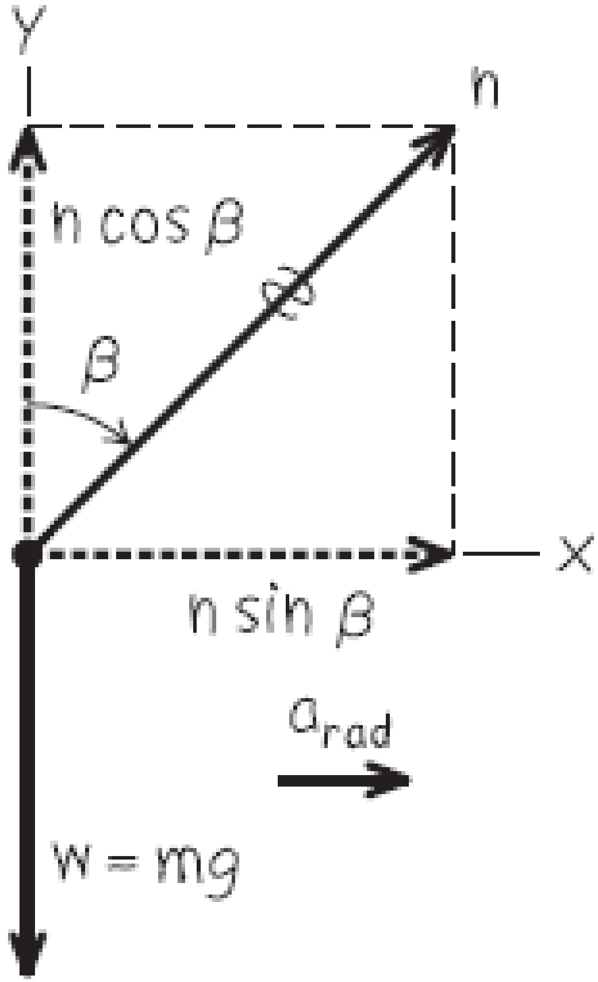
$$\sum F_x = n \sin \beta = m a_{\text{rad}}$$

$$a_{\text{rad}} = v^2/R$$

$$\sum F_y = n \cos \beta + (-mg) = 0$$

$$n = mg/\cos \beta$$

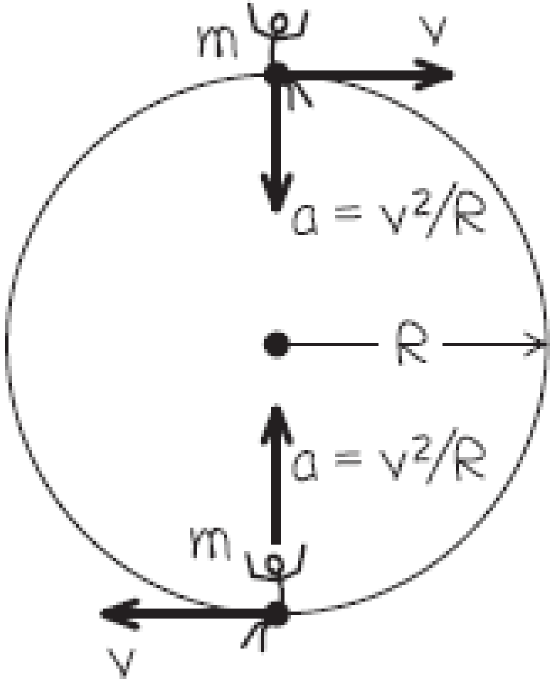
$$\tan \beta = \frac{a_{\text{rad}}}{g} = \frac{v^2}{gR}$$



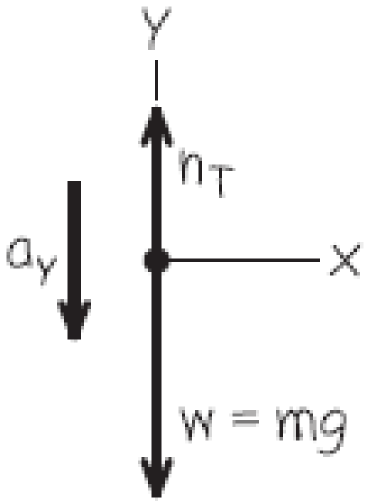
$$\beta = \arctan \frac{v^2}{gR}$$

Example 5.23: Uniform circular motion in a vertical circle

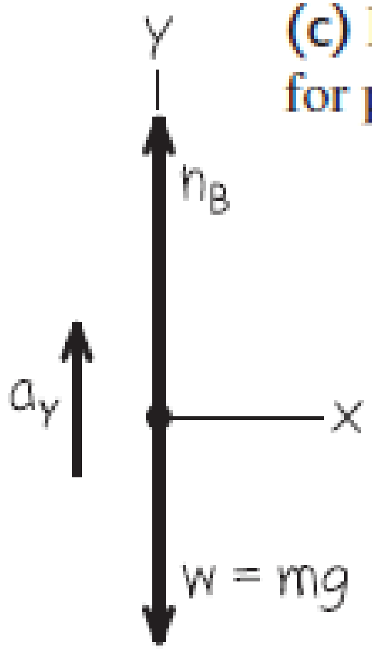
A passenger on a carnival Ferris wheel moves in a vertical circle of radius R with constant speed v. The seat remains upright during the motion. Find expressions for the force the seat exerts on the passenger at the top of the circle and at the bottom.



(b) Free-body diagram for passenger at top



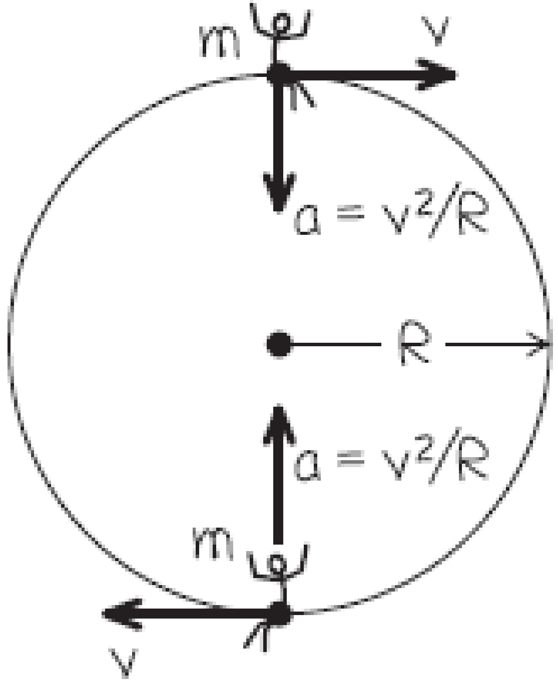
(c) Free-body diagram for passenger at bottom



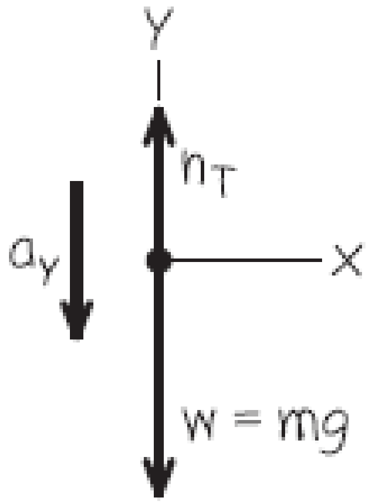
Note:
$\mathbf{n_T}$ & $\mathbf{n_B}$ are nonnegative
Directions of **n** are **opposite** to a_y

Example 5.23: Uniform circular motion in a vertical circle

A passenger on a carnival Ferris wheel moves in a vertical circle of radius R with constant speed v. The seat remains upright during the motion. Find expressions for the force the seat exerts on the passenger at the top of the circle and at the bottom.



(b) Free-body diagram for passenger at top



At top $a_y = -v^2/R$

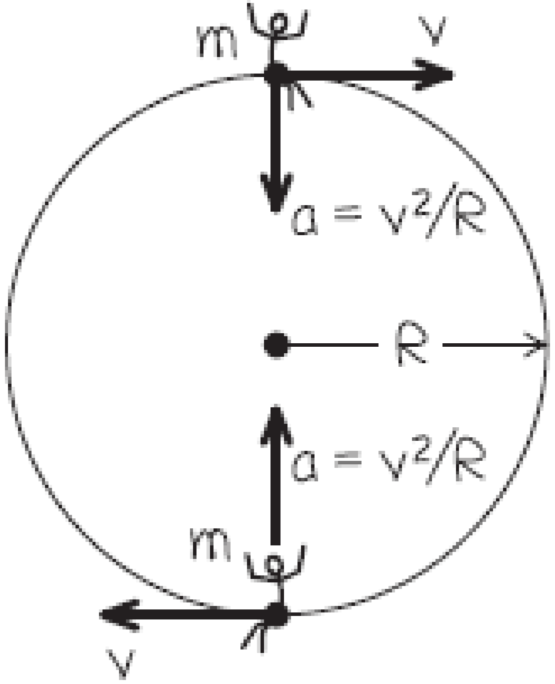
So:

$$\sum F_y = n_T + (-mg) = -m\frac{v^2}{R}$$

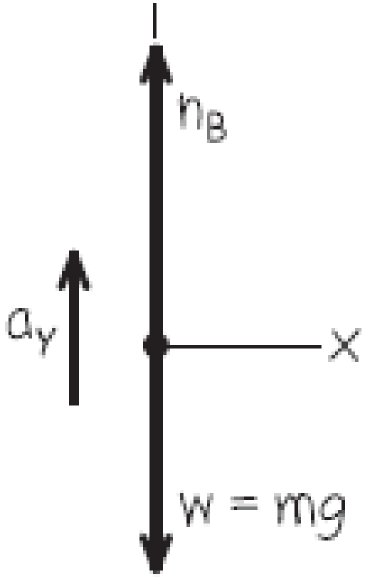
$$n_T = mg\left(1 - \frac{v^2}{gR}\right)$$

Example 5.23: Uniform circular motion in a vertical circle

A passenger on a carnival Ferris wheel moves in a vertical circle of radius R with constant speed v. The seat remains upright during the motion. Find expressions for the force the seat exerts on the passenger at the top of the circle and at the bottom.



(c) Free-body diagram for passenger at bottom

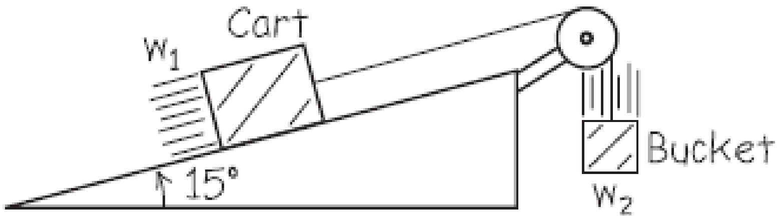


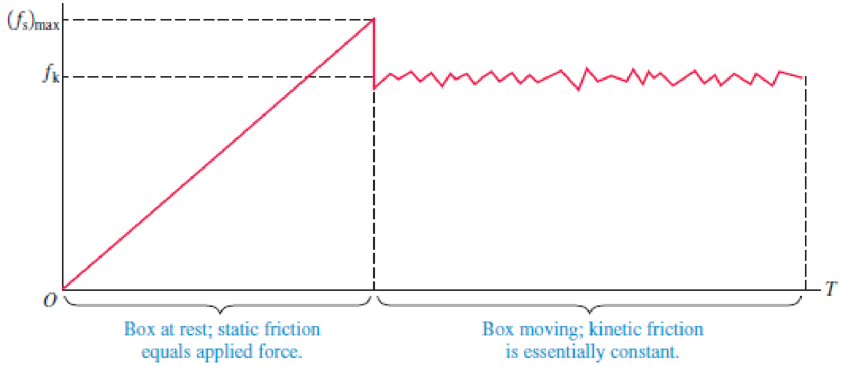
At bottom $a_y = +v^2/R$

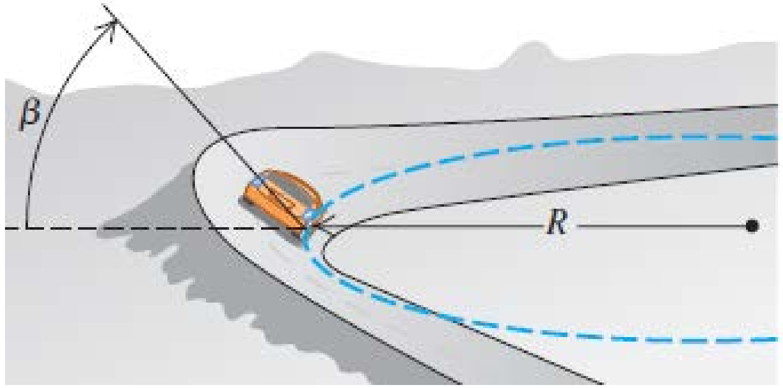
So: $$\sum F_y = n_{\mathrm{B}} + (-mg) = +m\frac{v^2}{R}$$

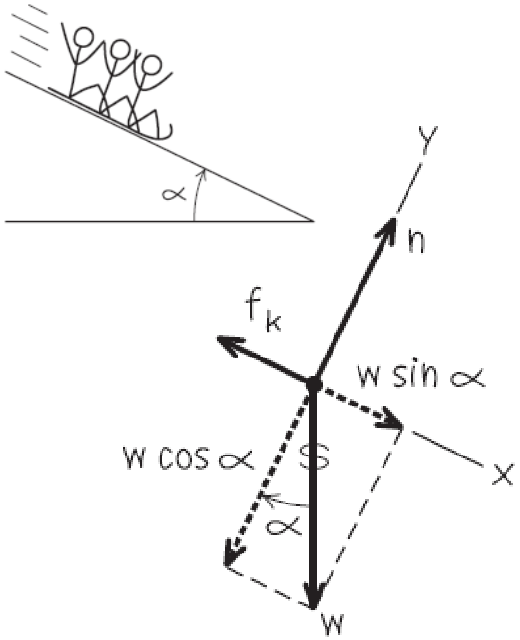
$$n_{\mathrm{B}} = mg\left(1 + \frac{v^2}{gR}\right)$$

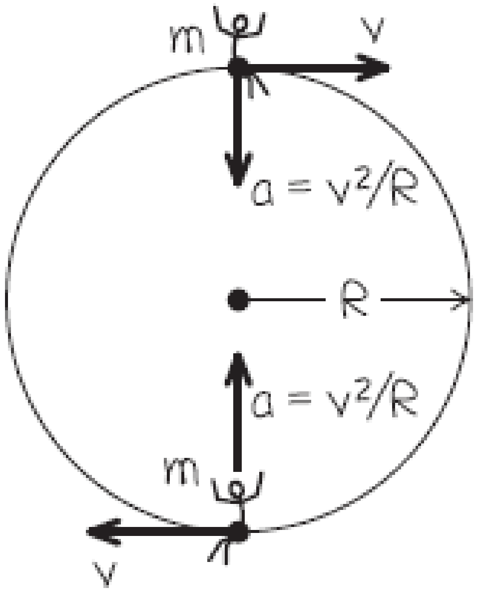
Summary (will be tested)

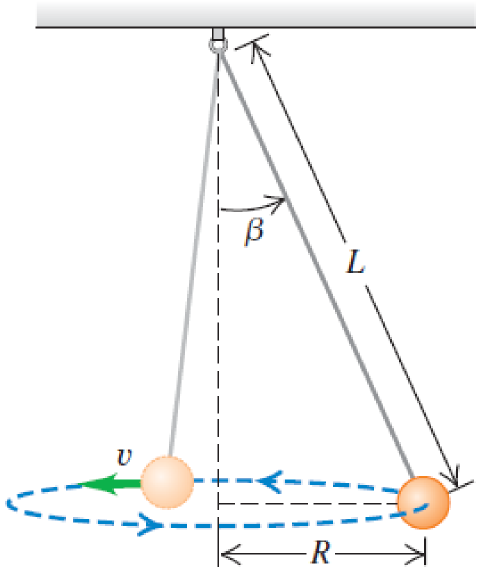


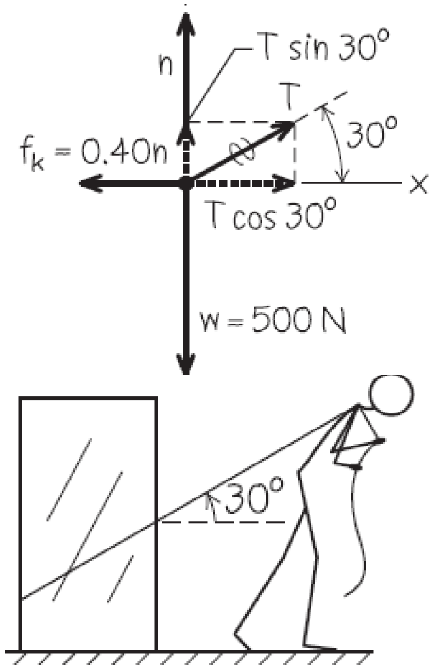












Kinematics & Mechanics So Far

Except integrals, all materials are the same as local high school classes,
But squeezed in only 3 weeks, instead of 3 months!

It is NOT easy if you haven't learned kinematics & mechanics before, so PLEASE spend more time studying!

Exam Questions Breakup

- **60% - High-school level for a local student**
- 70% - In class examples excluding calculus
- 80% - In class examples with calculus
- 90% - Examples and in-class exercise
- 97% - plus the homework questions
- 100% - plus some challenging problems

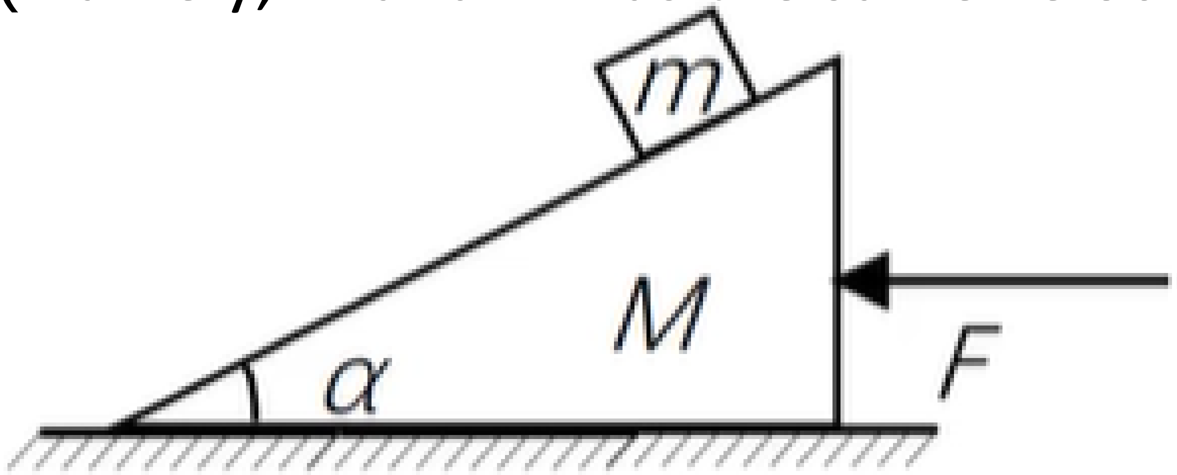
High School Problems Here:

一木块放在光滑的斜面体上，木块质量为m，斜面体质量为M，斜面的倾角为α，如图所示，欲使木块相对斜面静止、所用水平推力应是：（地面阻力不计）

A. $Mg\tan\alpha$ B. $(M+m)g\tan\alpha$

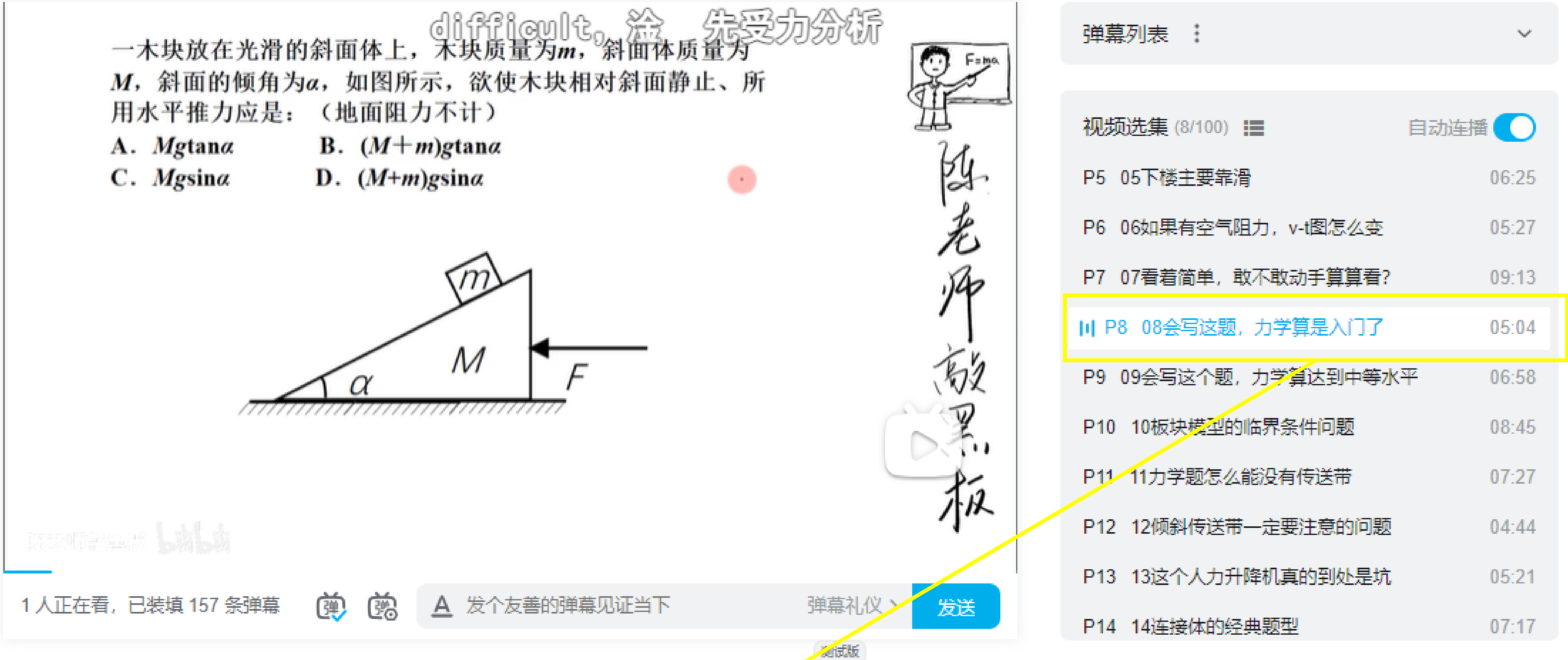
C. $Mg\sin\alpha$ D. $(M+m)g\sin\alpha$

Translation: If all surfaces are **frictionless**, what is ***F*** so that the block *m* does NOT move relative to *M*? （Namely, m and M has the same velocity）



https://www.bilibili.com/video/BV15J411N7zL?p=8&vd_source=261d63ed49848c62e97dfca18798cf44

High School Problems Here:



“If you can solve this problem, you start to understand mechanics”

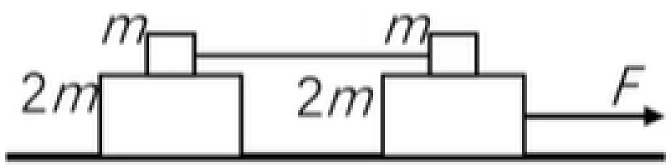
https://www.bilibili.com/video/BV15J411N7zL?p=8&vd_source=261d63ed49848c62e97dfca18798cf44

High School Problems Here:

如图所示，光滑水平面上放置质量分别为m和$2m$的四个木块，其中两个质量为m的木块间用一不可伸长的轻绳相连，木块间的最大静摩擦力是μmg。现用水平拉力F拉其中一个质量为$2m$的木块，使四个木块以同一加速度运动，则轻绳对m的最大拉力为（　　）

A. $\frac{3\mu mg}{5}$　　B. $\frac{3\mu mg}{4}$

C. $\frac{3\mu mg}{2}$　　D. $3\mu mg$



1 人正在看，已装填 347 条弹幕

已关闭弹幕　弹幕礼仪 >　发送

弹幕列表

视频选集 (9/100)　自动连

P6　06如果有空气阻力，v-t图怎么变

P7　07看着简单，敢不敢动手算算看？

P8　08会写这题，力学算是入门了

P9　09会写这个题，力学算达到中等水平

P10　10板块模型的临界条件问题

P11　11力学题怎么能没有传送带

P12　12倾斜传送带一定要注意的问题

P13　13这个人力升降机真的到处是坑

P14　14连接体的经典题型

P15　15牛顿运动定律加弹簧怎么办？

“If you can solve this problem, you are moderately good at mechanics”

How “difficult” will this class be?

I do think that he is sort of joking – the problems on the previous slide is unnecessarily hard in terms of **complexity**

But still, you need to be able to handle the examples I gave out in lectures and homework to pass the course.

I REALLY don’t want ANYONE to fail - now you can still catch up!

Remember to bring pencils and scratch paper to class!

Tablets with notebook apps can also work

Study Materials

- In-class examples and exercises
- Homework
- Problems that I have uploaded

大学物理 IA

授课老师:胡竞天

授课班级:【本】大学物理 IA[23级计算机（留学生）1班,23级计算机（留学生）2班,23级光电（留学生）1班,]

课程总览

课前

公告

课堂预习

课堂讨论

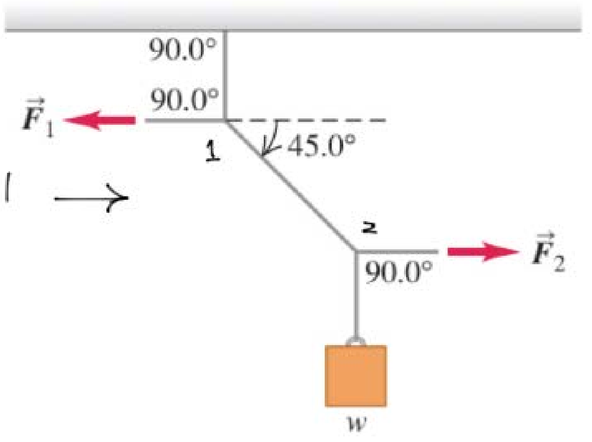
课堂课件

上传课件 引入课件 批量分享 批量删除

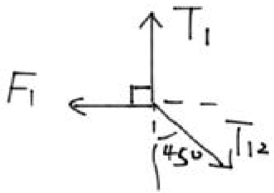
名称	大小	发布范围	上传时间
d-1-Rigid body rotation	11.03M	公开	2024-03-13 13:06
c-Impulse and momentum	16.06M	公开	2024-03-13 13:05
b-Work and Power	7.58M	公开	2024-03-13 13:04
b-potential energy and energy conser…	9.97M	公开	2024-03-13 13:03
a-Newton's Law 2	7.68M	公开	2024-03-13 13:03
a-Newton's Law 1	6.92M	公开	2024-03-13 13:02
a-Kinematics 2_ Vector, projectile, Ci…	12.14M	公开	2024-03-13 13:02
a-Kinematics 1_ Constant Accelerati…	7.62M	公开	2024-03-13 13:02

5.10 •• In Fig. E5.10 the weight w is 60.0 N. (a) What is the tension in the diagonal string? (b) Find the magnitudes of the horizontal forces $\vec{F}_1$ and $\vec{F}_2$ that must be applied to hold the system in the position shown.

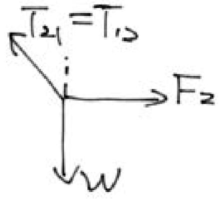
Figure **E5.10**



Point 1



Point 2



x: $F_2 = T_{12} \cdot \sin 45°$

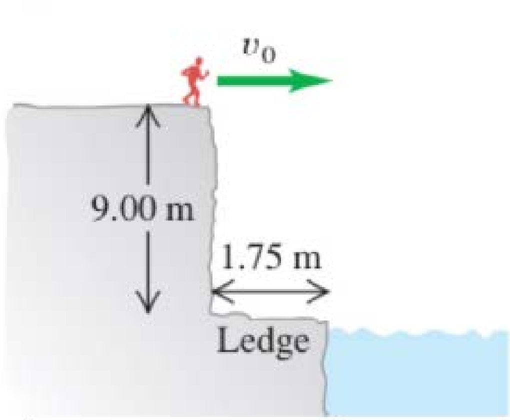
y: $W = T_{12} \cdot \cos 45°$

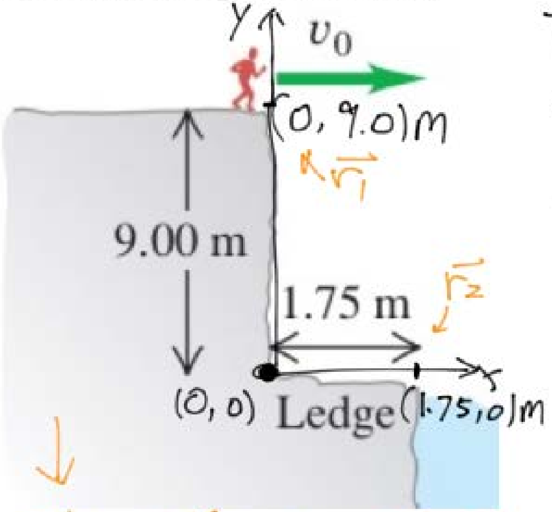
x: $F_1 = T_{12} \cdot \sin 45°$

y: $T_1 = T_{12} \cdot \cos 45°$

3.10 •• A daring 510-N swimmer dives off a cliff with a running horizontal leap, as shown in Fig. E3.10. What must her minimum speed be just as she leaves the top of the cliff so that she will miss the ledge at the bottom, which is 1.75 m wide and 9.00 m below the top of the cliff?

Figure **E3.10**





$\vec{a} = -g \cdot \hat{j} = (0, -9.8\,m/s^2)$

Text $\longrightarrow$ equations

Set the origin

Set up the coordinates

$\vec{r_1} = \overset{\to 0}{x_1} \cdot \hat{i} + y_1 \cdot \hat{j} = y_1 \cdot \hat{j} \qquad y_1 = 9.0\,m$

When she reaches ground

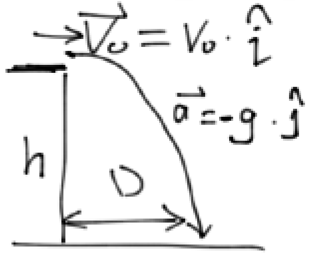
$\vec{r_2} = x_2 \cdot \hat{i} + y_2 \cdot \hat{j} \qquad y_2 = 0$

$\underbrace{y_2}_{0} = \underbrace{y_1}_{9.0m} + \underbrace{v_{0y}}_{0} \cdot t_2 - \frac{1}{2} g t_2^2 \Rightarrow t_2^2 = \frac{2y_1}{g} = \frac{18.0\,m}{9.8\,m/s^2} \approx 1.84\,s^2$

In x: $x_2 = v_0 t_2 \qquad t_2 = 1.355\,s$

$v_0 = x_2 / t_2 = 1.75\,m / 1.355\,s \approx 1.29\,m/s$

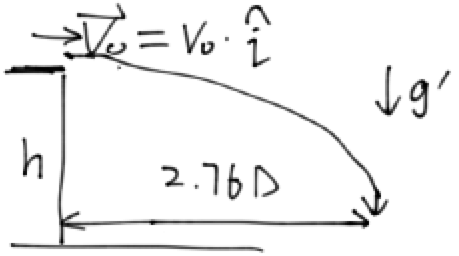
3.15 •• Inside a starship at rest on the earth, a ball rolls off the top of a horizontal table and lands a distance D from the foot of the table. This starship now lands on the unexplored Planet X. The commander, Captain Curious, rolls the same ball off the same table with the same initial speed as on earth and finds that it lands a distance $2.76D$ from the foot of the table. What is the acceleration due to gravity on Planet X?



On earth

$h = \frac{1}{2} g t_1^2 \Rightarrow t_1 = \sqrt{\frac{2h}{g}}$

$D = V_0 t_1 = V_0 \cdot \sqrt{\frac{2h}{g}} \quad (1)$



$h = \frac{1}{2} g' t_2^2 \Rightarrow t_2 = \sqrt{\frac{2h}{g'}}$

$2.76D = V_0 \cdot \sqrt{\frac{2h}{g'}} \quad (2)$

(2) divided by (1):

$2.76 = \sqrt{\frac{g}{g'}} \Rightarrow g' = \frac{g}{7.62} = 1.29\,m/s^2$

3.36 • Crossing the River II. (a) In which direction should the motorboat in Exercise 3.35 head in order to reach a point on the opposite bank directly east from the starting point? (The boat's speed relative to the water remains 4.2 m/s.) (b) What is the velocity of the boat relative to the earth? (c) How much time is required to cross the river?

$$\vec{v}_{P/A} = \vec{v}_{P/B} + \vec{v}_{B/A}$$

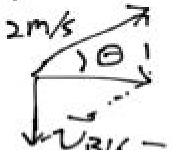
P is the moving guy

A is ground

B is river

(a) We want $\vec{v}_{P/A}$'s y component to be 0

$|\vec{v}_{P/B}| = 4.2\,m/s$



$\vec{v}_{P/A} = |v_{P/A}| \cdot \hat{i}$

$\vec{v}_{B/A} = -2.0\ m/s\ \hat{j}$

$$\vec{v}_{P/A} = \vec{v}_{P/B} + \vec{v}_{B/A} \quad \text{relative to ground}$$

$$= \underbrace{|v_{P/B}| \cos\theta\, \hat{i}}_{v_{P/A,x}} + \underbrace{|v_{P/B}| \cdot \sin\theta\, \hat{j}}_{v_{P/A,y}} + |v_{B/A}| \cdot \hat{j}$$

"Directly east" $\quad v_{P/A,y} = 0$

So $|v_{P/B}| \cdot \sin\theta + |v_{B/A}| = 0$

$4.2\,m/s \cdot \sin\theta - 2.0\ m/s = 0$

$\theta = \arcsin\left(\frac{2.0}{4.2}\right) = 28.44°$

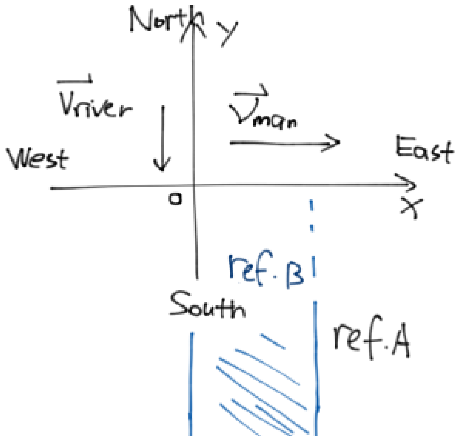
So $\vec{v}_{P/A} = |v_{P/B}| \cdot \cos\theta \cdot \hat{i}$

$= 4.2\,m/s \cdot \cos 28.44° \ \hat{i}$

$= 3.69\ m/s\ \hat{i}$

(c)

$$\Delta t = \frac{\Delta x}{v_{P/A,x}} = \frac{800\,m}{3.69\,m/s} = 216.8\,s$$



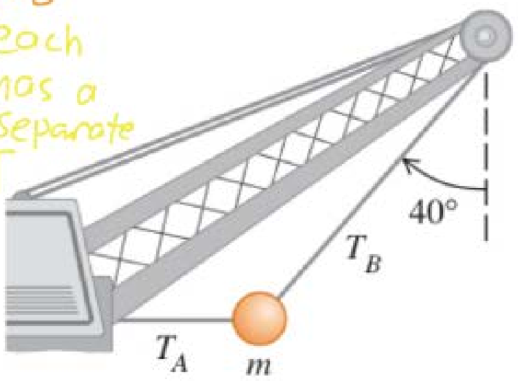
If you are swimming to the other side, what is your best strategy?

5.6 •• A large wrecking ball is held in place by two light steel cables (Fig. E5.6). If the mass m of the wrecking ball is 4090 kg, what are (a) the tension T_B in the cable that makes an angle of 40° with the vertical and (b) the tension T_A in the horizontal cable?

$m = 0$

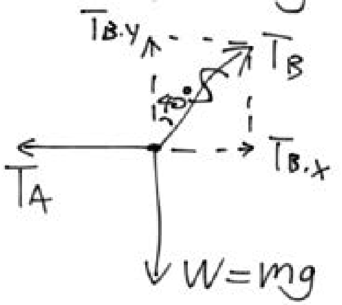
each has a separate T

Figure **E5.6**



5.7 •• Find the tension in

For both (a) and (b), we need the free body diagram



In equilibrium

$\sum \vec{F} = 0$

in x: $T_{B}x = T_A$

in y: $T_{B.y} = W$

In y: $\left.\begin{array}{l} T_{B.y} = T_B \cdot \cos 40^\circ \\ W = m \cdot g \end{array}\right\} \Rightarrow T_B = \dfrac{m \cdot g}{\cos 40^\circ}$

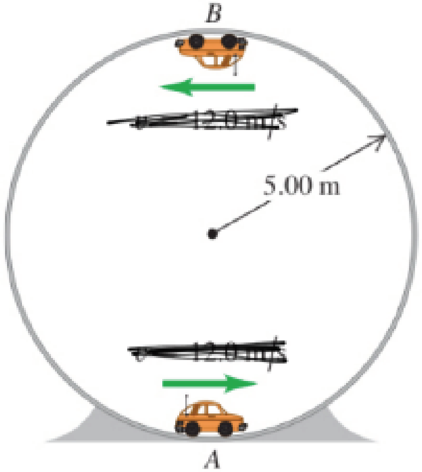
$$= \frac{4090\ \text{kg} \cdot 9.8\ \text{m/s}^2}{0.766}$$

$$= 5.23 \times 10^4\ \text{N}$$

Section 5.4 Dynamics of Circular Motion

5.42 •• A small car with mass 0.800 kg travels at constant speed on the inside of a track that is a vertical circle with radius 5.00 m (Fig. E5.42). If the normal force exerted by the track on the car when it is at the top of the track (point B) is 6.00 N, what is the normal force on the car when it is at the bottom of the track (point A)?

Figure **E5.42**



5.43 •• A machine part consists of a thin 40.0-cm-long bar with small 1.15-kg masses fastened by screws to its ends. The

Uniform circular motion

$F_{total} = m\dfrac{v^2}{R}$

$= m a_{rad}$

magnitude of a_{rad} is the same

Point A:

$\vec{n}_A$ ↑, $m\vec{g}$ ↓

$|\sum \vec{F}_A| = |\vec{n}_A| - |m\vec{g}|$

$\uparrow \vec{a}_A = \dfrac{v^2}{R}\ \hat{i}$

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

$n_A - mg = m\dfrac{v^2}{R}$

Part B:

$m\vec{g}$ ↓, $\vec{n}_B$ ↓

$|\sum \vec{F}_B| = |\vec{n}_B| + |m\vec{g}|$

$\downarrow \vec{a}_B = \dfrac{v^2}{R} \cdot (-\hat{i})$

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

$n_B + mg = m\dfrac{v^2}{R}$

6.0N 0.8kg

$n_A - mg = n_B + mg$

$n_A = 2mg + n_B = 2 \times 0.8\ \text{kg} \times 9.8\ \text{m/s}^2 + 6.0\ \text{N} = 21.68\ \text{N}$

Too much materials? Let's get organized

Haven't used Newton's laws for >10 years, but I still retains most of the knowledge. **How?**

The knowledge of physics is highly ***structured***.

So I made this quick sheet (also uploaded as ("Kinematics and Newton's law")