Physics 1

Chapter 6 Force & Motion - II

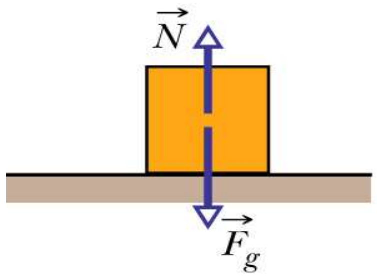
1. Friction
2. Properties of friction
3. The Drag Force & Terminal Speed
4. Uniform Circular Motion & Force

Review & Summary

Questions

Exercises & Problems

Friction Force



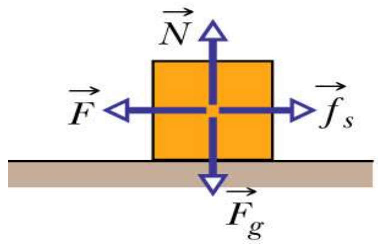
An object at rest on a surface:

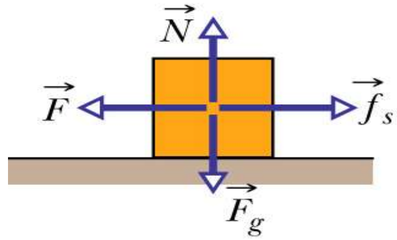
$$\vec{N} = -\vec{F}_g$$

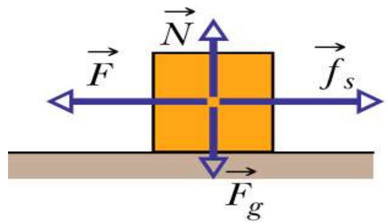
No friction force here!

The friction force is a "*passive force*" in that it only arises when ***F*** is applied.

An increasing pull, ***F***, is applied to the object.



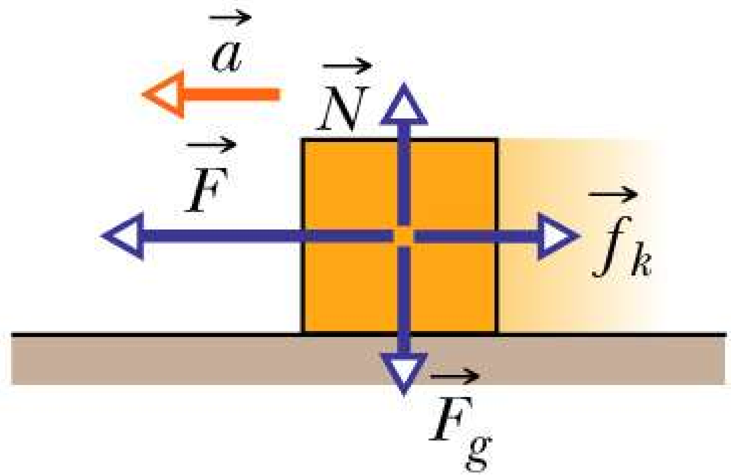




The object is not accelerated because an equal and opposite friction force arises between the object and the surface:

$$\vec{F} = -\vec{f}_S$$

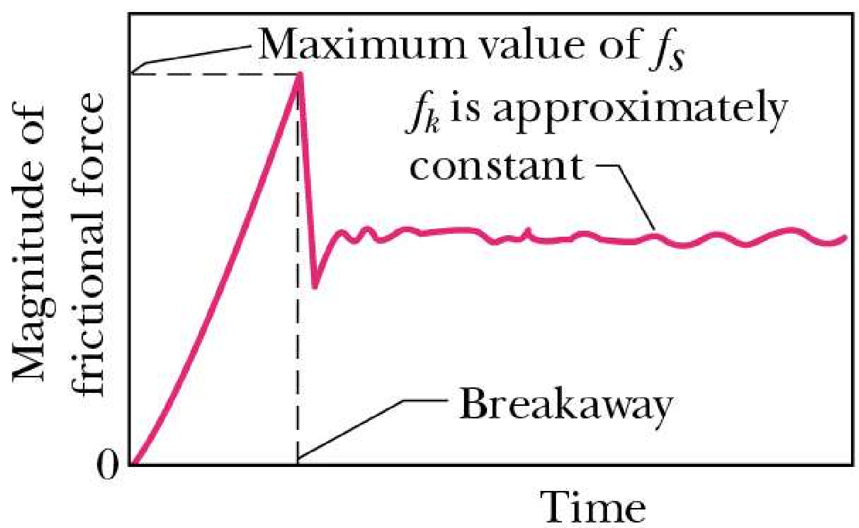
Friction Force



Eventually the object will be accelerated when the pull is greater than the friction force between the object and the surface:

$$\vec{F}_{net} = \vec{F} - \vec{f}_K = m\vec{a}$$

The Friction Force



f_S = static friction force

f_K = kinetic friction force

It's easier to keep an object sliding than it is to get the sliding started.

$$\vec{F} = -\vec{f}_S$$

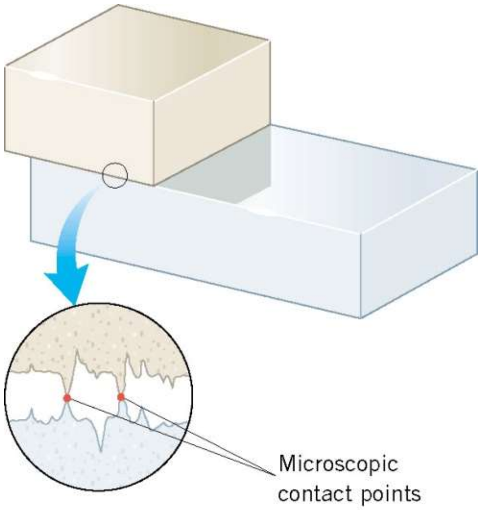
not moving

$$\vec{F} - \vec{f}_K = m\,\vec{a}$$

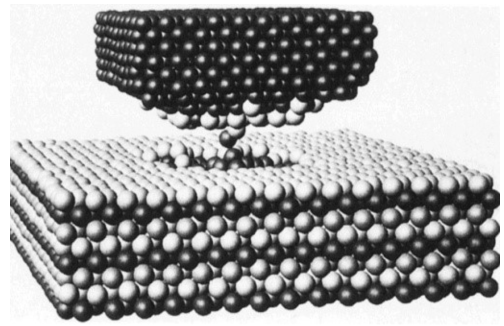
accelerating

The Friction Force

Two surfaces in contact:



Microscopic "cold welding" occurs.

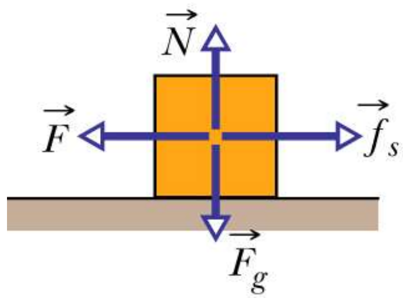


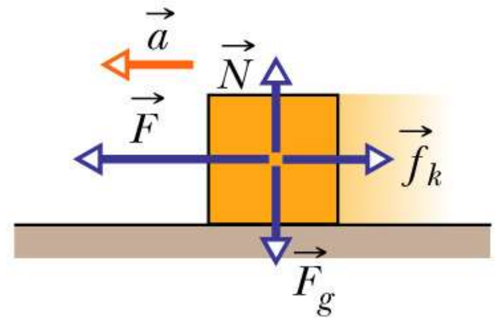
Molecular bonding occurs at points of contact.

The friction force is complicated and details are not completely understood!

Properties of Friction

Experimentally, it is found that the friction force depends on how strongly the surfaces are pressed together; i.e. the Normal Force, ***N***.





$$\left|\vec{f}_{S,\max}\right| = \mu_S \left|\vec{N}\right|$$

$$\left|\vec{f}_K\right| = \mu_K \left|\vec{N}\right|$$

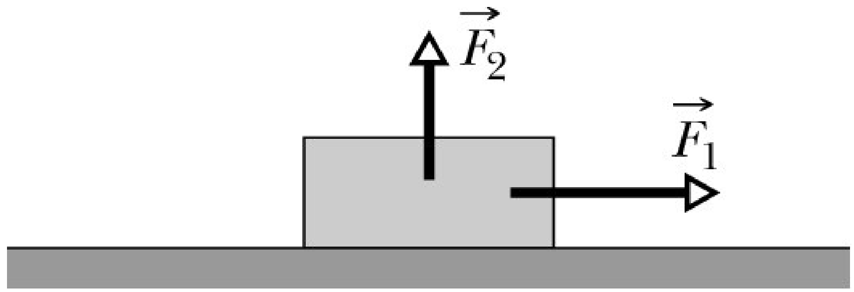
μ_S = coefficient of static friction

μ_k = coefficient of kinetic friction

Experimentally, the friction force is also found <u>not</u> to depend on the surface area!
μ_k only weakly depends on the speed.

Checkpoint

2 applied forces:



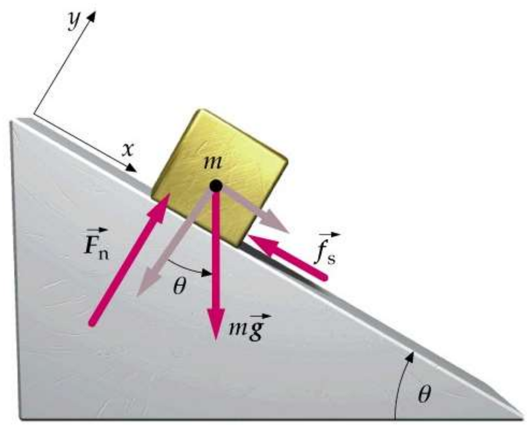
As F_2 increases, but before the box begins to slide, what happens to;

a) Magnitude of frictional force on the box
b) Magnitude of the normal force on the box from the floor
c) The maximum value of the static frictional force on the box

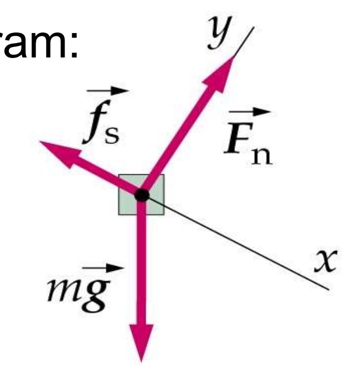
Example: Block on an Inclined Plane with Friction

θ is increased until the block is about to slide.

$$\mu_S = ?$$



Free-Body Diagram:



Apply Newton's 2nd Law: $\vec{F}_{net} = m\,\vec{a}$

$$\sum F_x = m\,g\sin\theta - f_S = m\,a_x = 0$$

$$\sum F_y = F_n - m\,g\cos\theta = m\,a_y = 0$$

Friction Force: $f_S = \mu_S\,F_n$

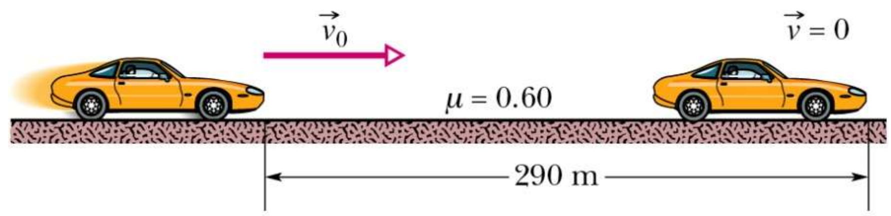
$$\mu_S = \frac{m\,g\sin\theta}{F_n} = \frac{m\,g\sin\theta}{m\,g\cos\theta}$$

$$\mu_S = \tan\theta$$

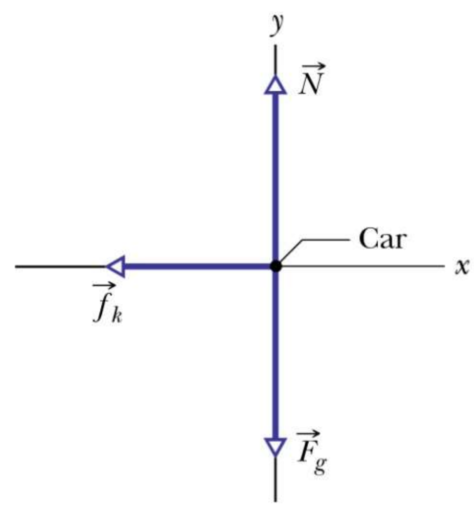
Sample Problem

Wheels locked

If it took 290m to stop
$\mu_k = 0.60$
How fast when wheels locked?



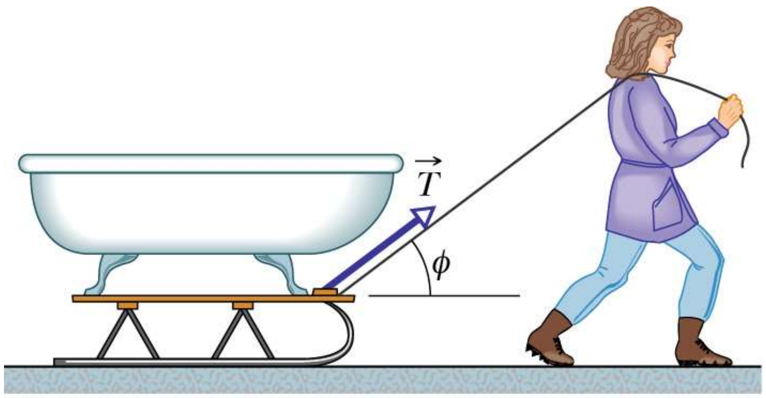
(a)



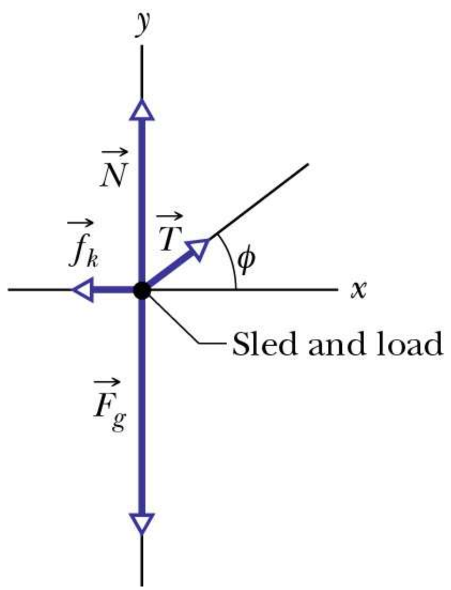
(b)

Sample Problem

M = 75 kg
Constant velocity, level surface
$\mu_k = 0.10$
$\phi = 42^0$
What is T ?

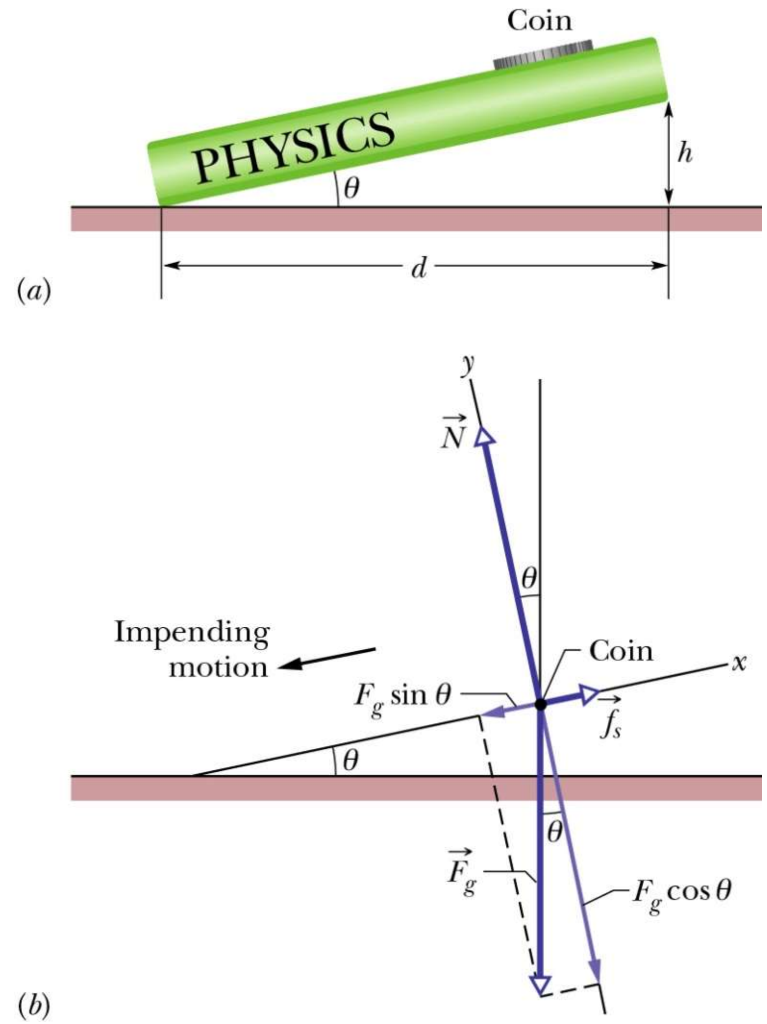


(a)



Sample Problem

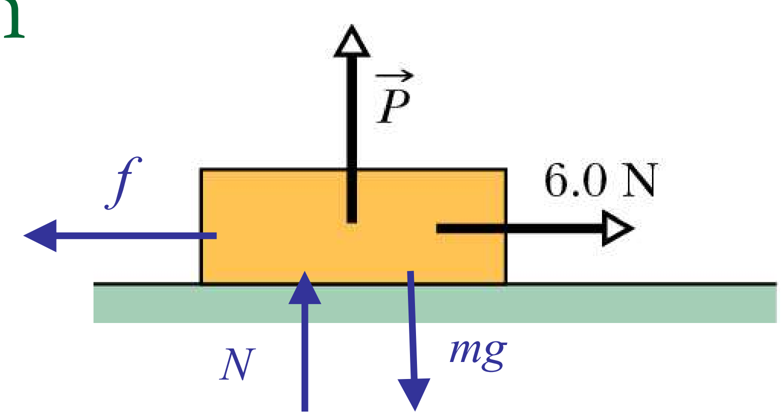
Coin of mass m at angle θ
"verge of sliding" at 13^0"
what is μ_s



Problem

Friction Force = ?
P = 8, 10, 12 Newtons

$m = 2.5\ kg$
$\mu_S = 0.40$
$\mu_K = 0.25$



$$6 - f = ma$$

$$P + N - mg = 0$$

a) $P = 8\,N$

$$N = (2.5)(9.8) - 8 = 16.5\,N$$

$$\left|\vec{f}_{S,\max}\right| = \mu_S \left|\vec{N}\right| = (0.4)(16.5) = 6.6\,N$$

$$\left|\vec{f}_{S,\max}\right| > 6.0\,N \qquad \therefore \text{ block does not move.}$$

$$\boxed{f = 6.0\,N}$$

b) $P = 10\,N$

$$N = (2.5)(9.8) - 10 = 14.5\,N$$

$$\left|\vec{f}_{S,\max}\right| = \mu_S \left|\vec{N}\right| = (0.4)(14.5) = 5.8\,N$$

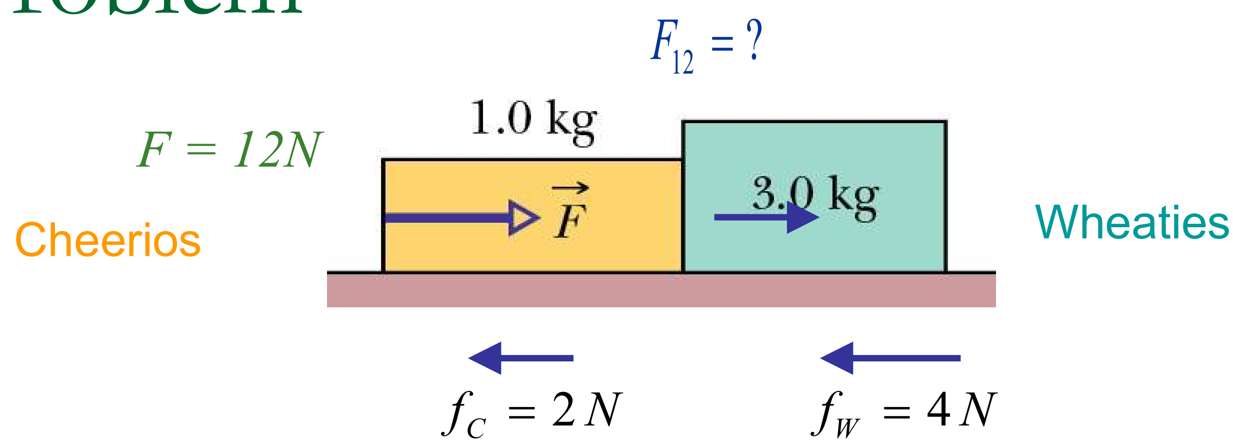
$$\left|\vec{f}_{S,\max}\right| < 6.0\,N \qquad \therefore \text{ block moves.}$$

$$\left|\vec{f}_K\right| = (0.25)(14.5) = 3.6\,N$$

$$\boxed{f = 3.6\,N}$$

c) $P = 12\,N$ $\qquad \boxed{f = 3.1\,N}$

Problem



Both Boxes:

$$F_{net} = ma$$

$$F - f_{total} = m_{total} a$$

$$12\ N - (2.0\ N + 4.0\ N) = (1.0\ kg + 3.0\ kg)a$$

$$a = 1.5\ {}^{m}/_{s^2}$$

Green Box:

$$F_{12} - f_W = m_W a$$

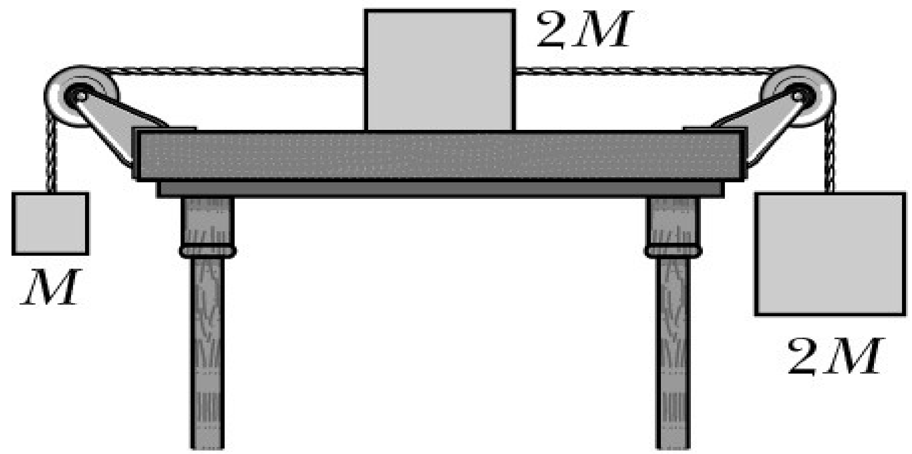
$$F_{12} - 4.0\ N = (3.0\ kg)(1.5\ {}^{m}/_{s^2})$$

$$F_{12} = 8.5\ N$$

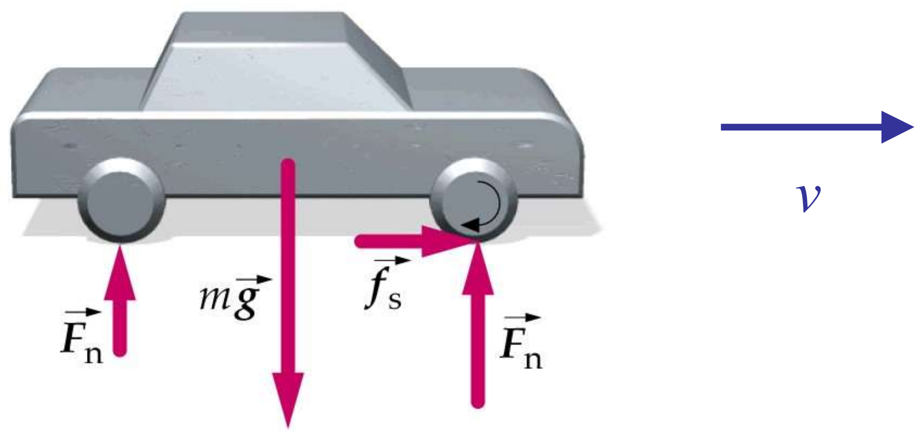
Problem

Three blocks released from rest
a = 1.5 m/s^2

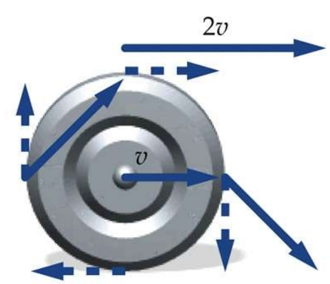
If M = 2.0 kg, what is magnitude of frictional force



Friction makes your car move!



The velocity of the point on the tire in contact with the road is <u>zero</u> relative to the ground.



static friction

The Drag Force & Terminal Velocity

Drag Force is generated when moving through a fluid.

For air: $D = \frac{1}{2} C \rho A v^2$

$\boldsymbol{C}$ = drag coefficient

ρ = air density

$\boldsymbol{A}$ = effective cross sectional area

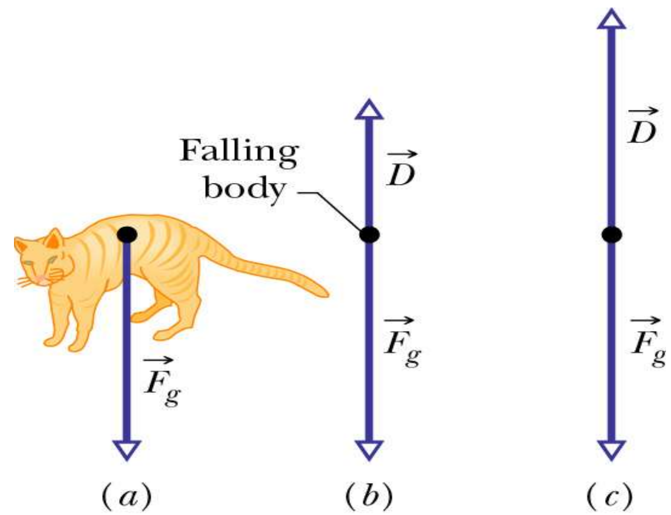
$\boldsymbol{v}$ = relative speed

For an object freely falling in air:

$$\vec{D} - \vec{F}_g = m\vec{a}$$

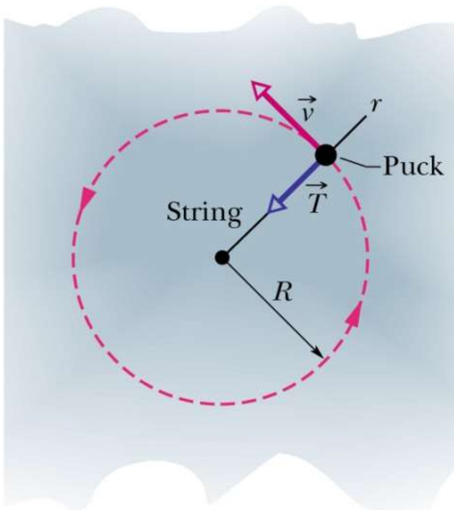
Terminal velocity occurs when ***v*** has grown to the point where ***D*** equals $\boldsymbol{F}_g$:

$$v_t = \sqrt{\frac{2F_g}{C\rho A}}$$



Uniform Circular Motion

Centripetal Force accelerates a body by changing the direction of a body's velocity without changing the body's speed.



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

$$a = \frac{v^2}{R}$$

$$F_{net} = T = m\frac{v^2}{R}$$

A force, ***T***, must be exerted on the puck in order for it to execute uniform circular motion.

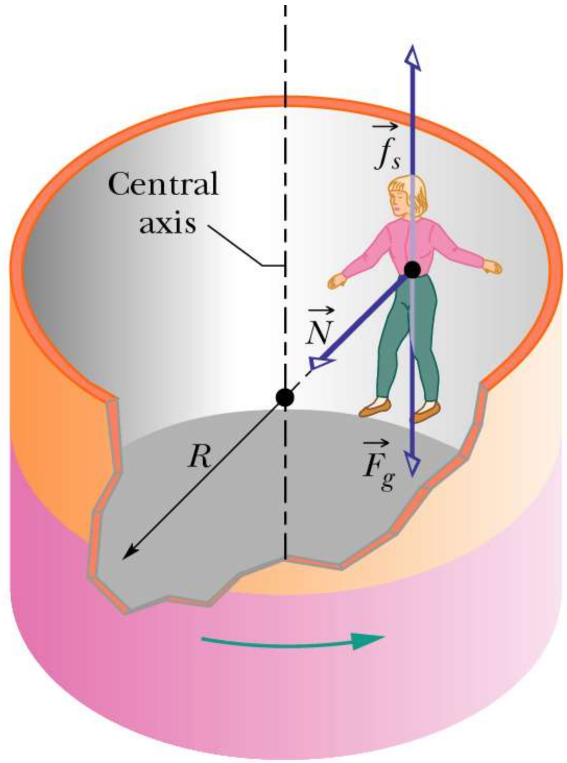
If one cuts the string, what direction does the puck fly off in?

What provides the centripetal force on the moon in order for it to execute uniform circular motion?

Sample Problem

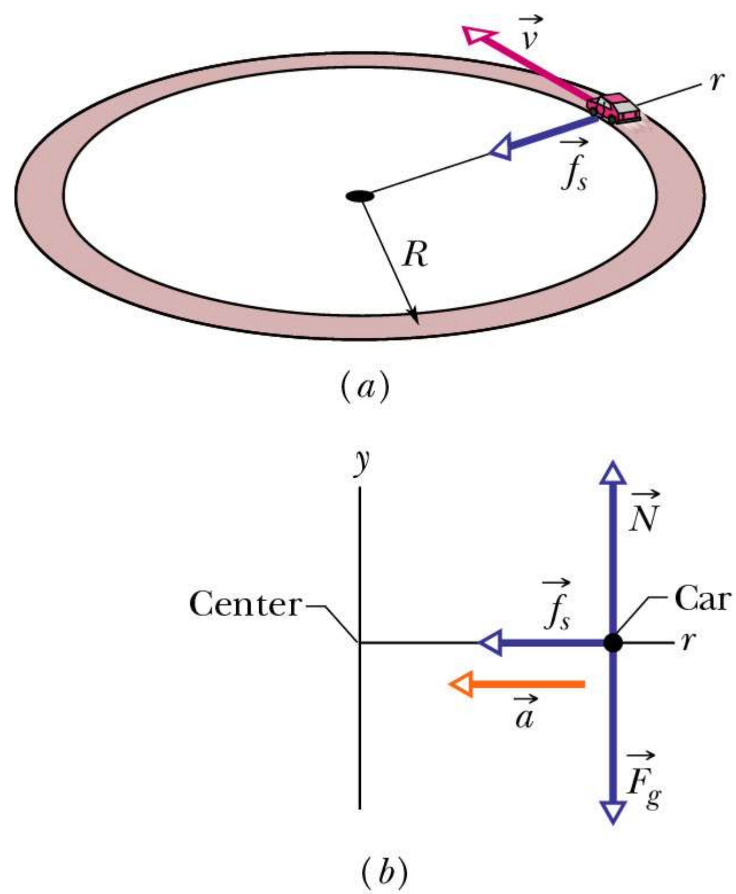
If $\mu_s = 0.40$
R = 2.1 m

What is the minimum speed v that the rider and cylinder for the rider not to fall?



Sample Problem

Stock car mass m = 1600 kg
v = 20 m/s
R = 190 m
Value of μ to be "verge of sliding"

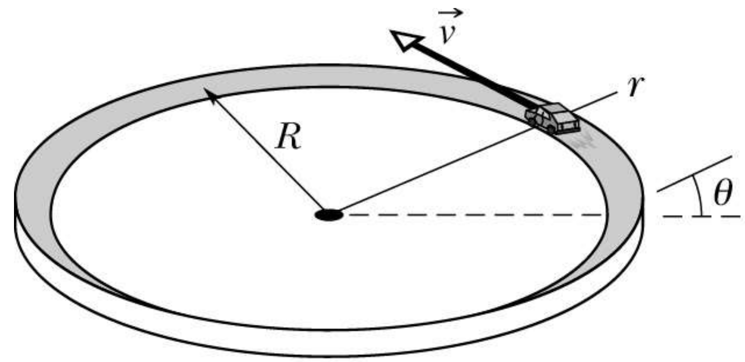


Sample Problem 6-11

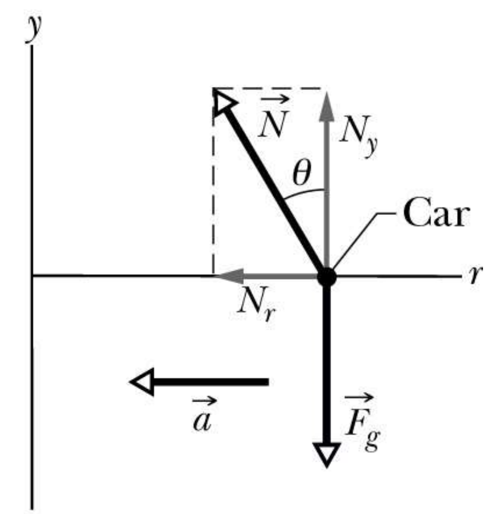
Can't always count on friction, so you BANK

mass m
v = 20 m/s
R = 190 m

What bank angle θ makes reliance on friction unnecessary

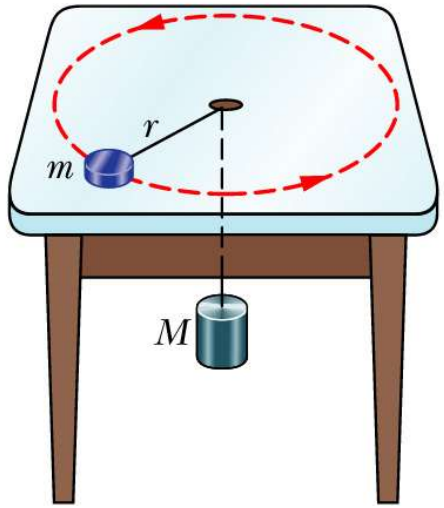


(a)



(b)

What speed keeps M at rest?



$$T = Mg = m\left(\frac{v^2}{r}\right)$$

$$v = \sqrt{\frac{Mgr}{m}}$$

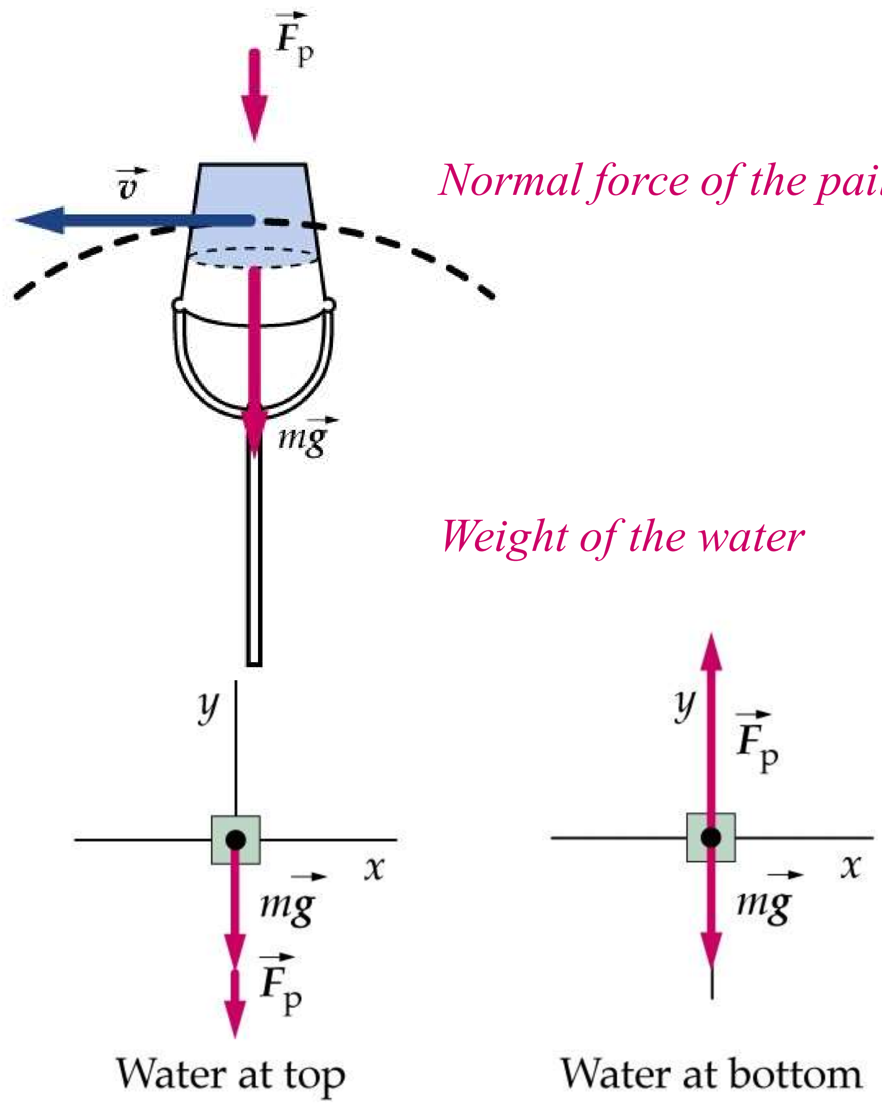
Swinging a pail of water in a vertical circle:

Normal force of the pail on the water

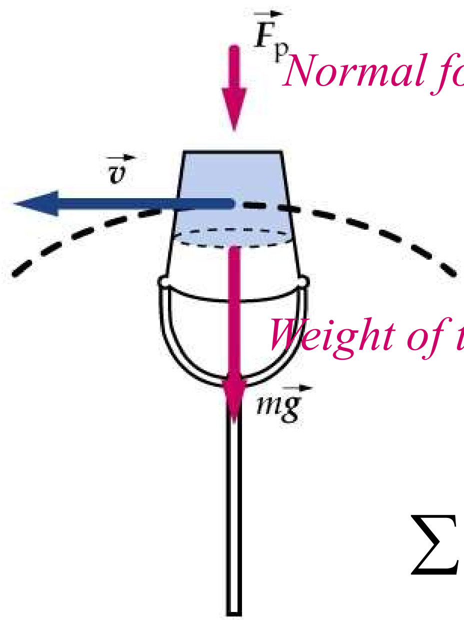
Velocity of the water

Weight of the water

Free-Body Diagrams:



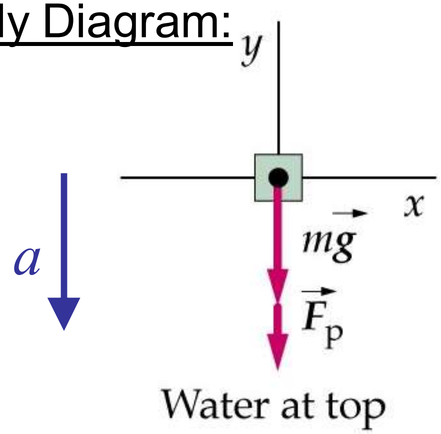
How slowly can one swing the pail of water without spilling



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

$$\sum F_y = -F_p - mg = m\left(-\frac{v^2}{r}\right)$$

Free-Body Diagram:



At the top, $\boldsymbol{F}_p$ cannot be upwards: $F_{p,\min} = 0$

Water is about to lose contact with the pail (i.e. spill).

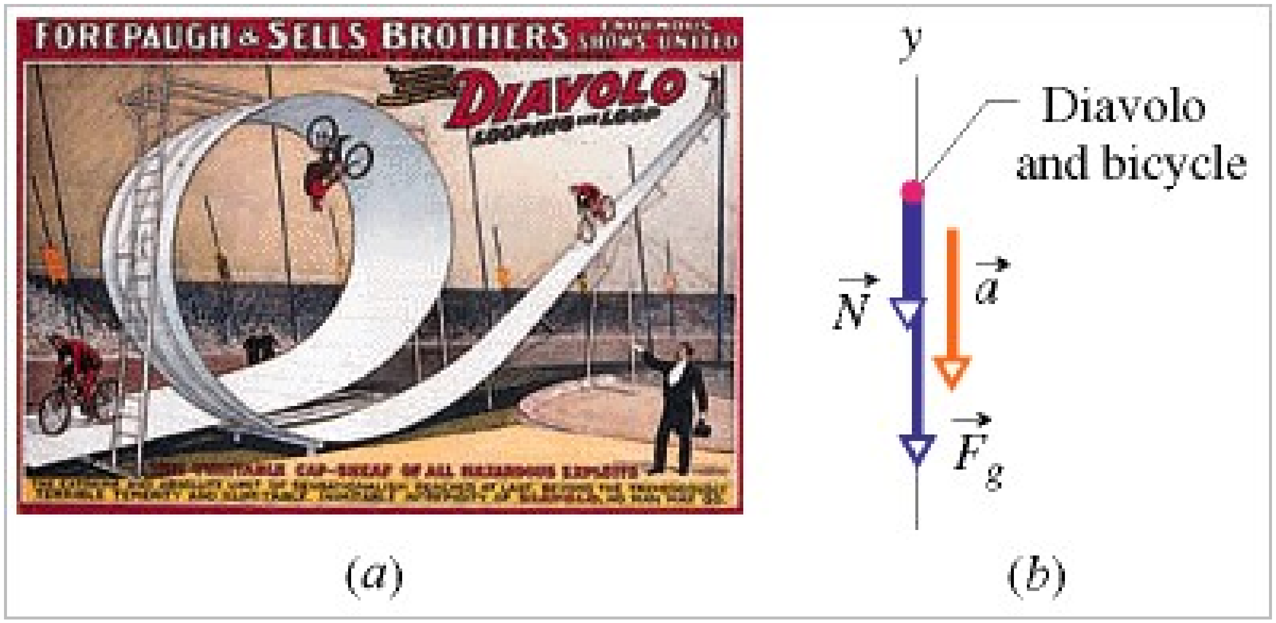
$$-mg = m\left(-\frac{v_{\min}^2}{r}\right)$$

$$v_{\min} = \sqrt{rg}$$

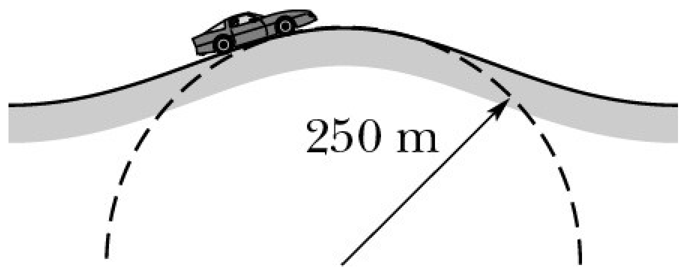
Sample Problem 6-7

R = 2.7 m

What is the least speed that Diavolo can have at the top of the loop and still make contact with the loop



Problem 6-64 Leave the road @ what speed?



$$mg - N = m\left(\frac{v^2}{r}\right)$$

About to leave the road when $N = 0$.

$$v_{max} = \sqrt{g\,r}$$

$$v_{max} = \sqrt{(9.8)(250)} = 49.5\,{}^{m}\!/_{s} = 178\,{}^{km}\!/_{h} = 110\,{}^{mi}\!/_{h}$$