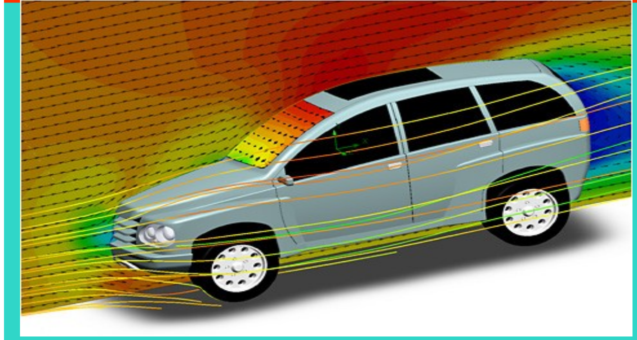
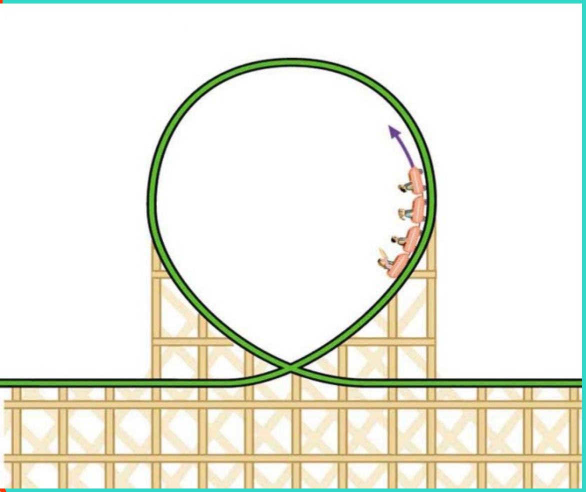


Chapter 6

Force and Motion II



i) $E_{mech} = KE + PE = \frac{1}{2}mv^2 + \frac{1}{2}kx^2$ (2)

At extreme points: $v = 0 \rightarrow KE = 0$
$x = x_m \rightarrow PE = \frac{1}{2}kx_m^2$ (1)

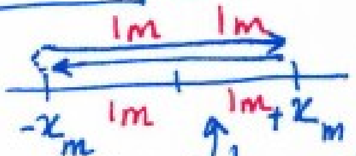
SHM: $v(t) = -\omega x_m \cos(\omega t + \phi)$

$v_m = 5\ m/s$ & $\omega = \sqrt{\frac{k}{m}} = \sqrt{\frac{100\ N/m}{4\ kg}} = 5\ rad/s$ (2)

$\Rightarrow 5\ m/s = 5\ rad/s\ x_m \Rightarrow x_m = 1\ m$ (1)

$\Rightarrow E_{mech} = PE = \frac{1}{2}kx_m^2 = \frac{1}{2}\,100\ N/m\,(1m)^2 = 50\ J$ (2) (2)

ii) $t = 10\ s$, $T = \frac{2\pi}{\omega} = \frac{2\pi}{5\ rad/s} = 1.26\ s$ (2)



1 period ⇓ 4 m: total distance travelled in one period (1)

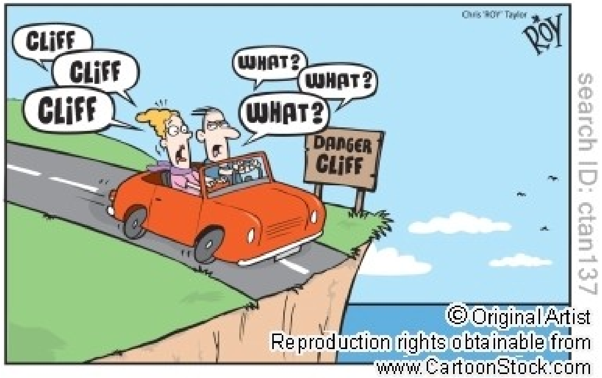
1.26 s	4 m
10 s	x

$x_{total} = \frac{(4m)(10s)}{(1.26s)} = 31.75\ m$ (2)

total distance travelled in 10 s

6-2 Friction Force

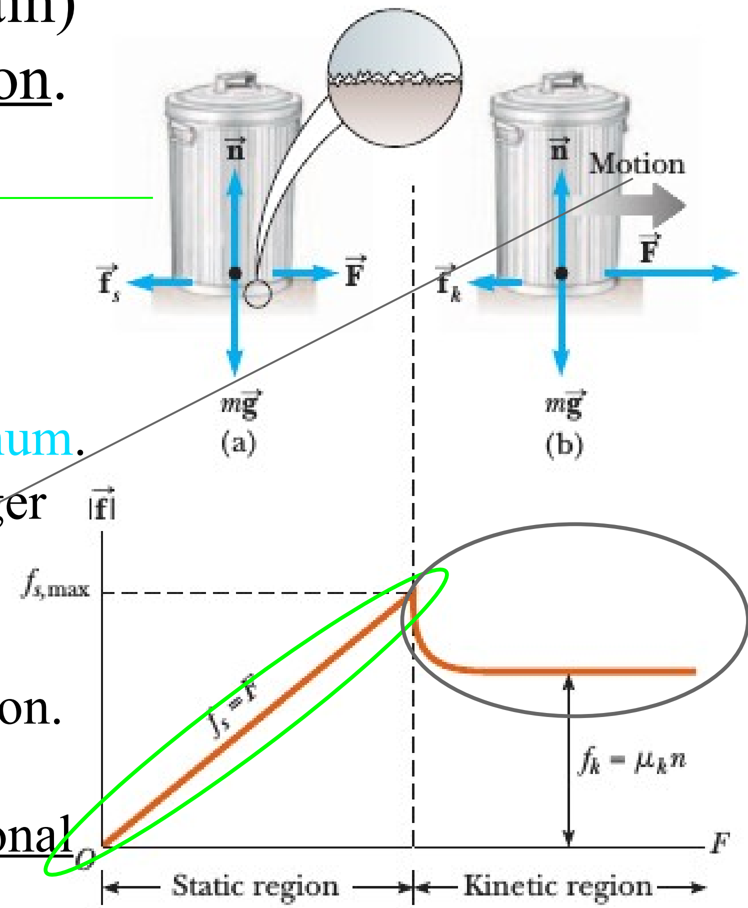
- <u>Question: If the friction were absent, what would happen?</u>
- Answer:
  - You could **not stop** without the friction of the brakes and the tires.
  - You could **not walk** without the friction between your shoes and the ground.
  - Your car even would **not start** moving if it wasn't for the friction of the tires against the street.
  - You could **not hold** a pencil in your hand without friction. It would slip out when you tried to hold it to write.



Frictional forces are very common in our everyday lives.

- But overcoming friction forces is **also** important:
  - Efficiency in engines. (20% of the gasoline used in an automobile goes to counteract friction in the drive train)
  - Anything that we want to remain in motion.
- Two types of friction.

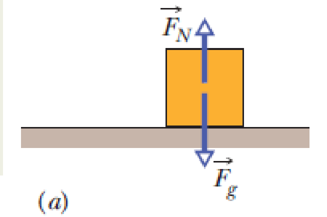
1. The **static frictional force**: no motion f_s
   - The *opposing force* that **prevents** an object from moving.
   - Can have *any magnitude* from 0 N up to a maximum.
   - Once the maximum is reached, forces are no longer in equilibrium and the *object slides*.
2. The **kinetic frictional force**: motion f_k
   - The *opposing force* that **acts** on an object in motion.
   - Has only *one value*.
   - Generally smaller than the maximum static frictional force.



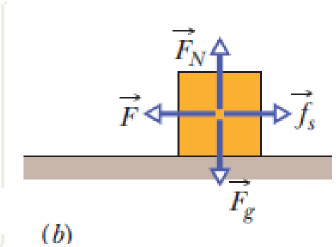
f_s is the **static frictional force**

f_k is the **kinetic frictional force**

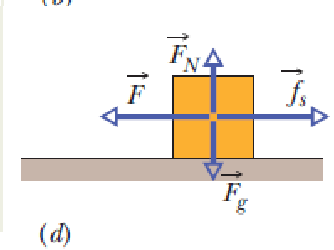
6-2 Friction Force



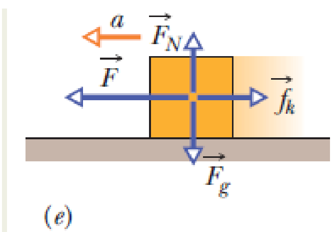
There is no attempt at sliding. no motion. NO FRICTION



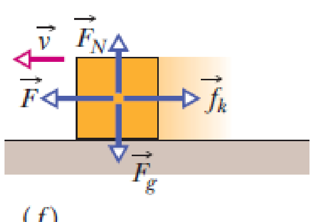
Force *F attempts* sliding but is balanced by the frictional force.
No motion.
STATIC FRICTION



Force *F is now* stronger but is still balanced by the frictional force.
No motion.
LARGER **STATIC FRICTION**



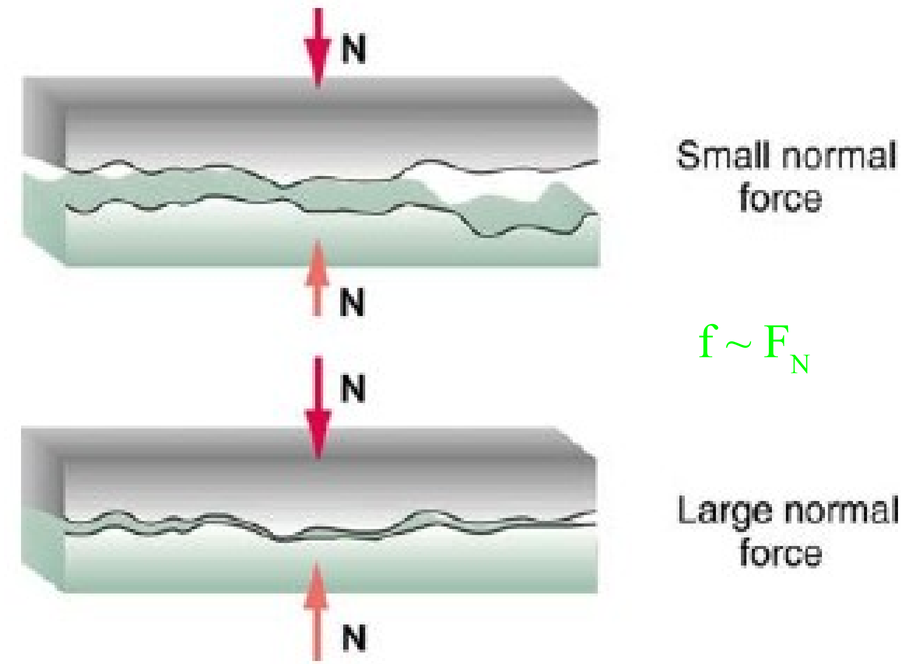
Finally, the applied force has overwhelmed the static frictional force. Block slides and accelerates.
WEAK **KINETIC FRICTION**



To maintain the speed, weaken force *F to match* the weak frictional force.
SAME WEAK **KINETIC FRICTION**

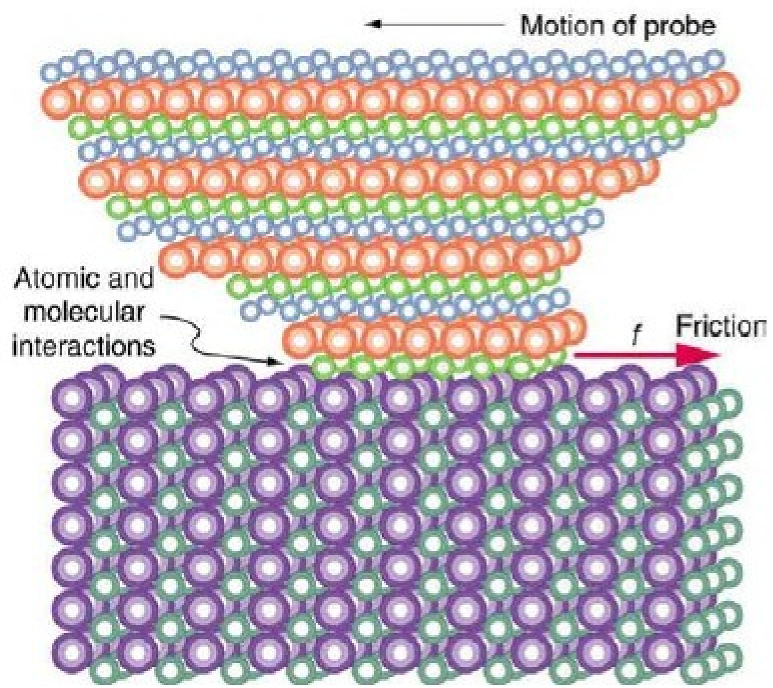
- When two surfaces are placed together, only the high points to touch each other.
  - Many contact points do *cold-weld* together.
  - Force required to break the welds and maintain the motion.
  - Microscopic and Macroscopic views at next slide.

- Figure (Macroscopic View): Two rough surfaces in contact have a much smaller area of actual contact than their total area. When there is a greater normal force as a result of a greater applied force, the area of actual contact increases as does friction.

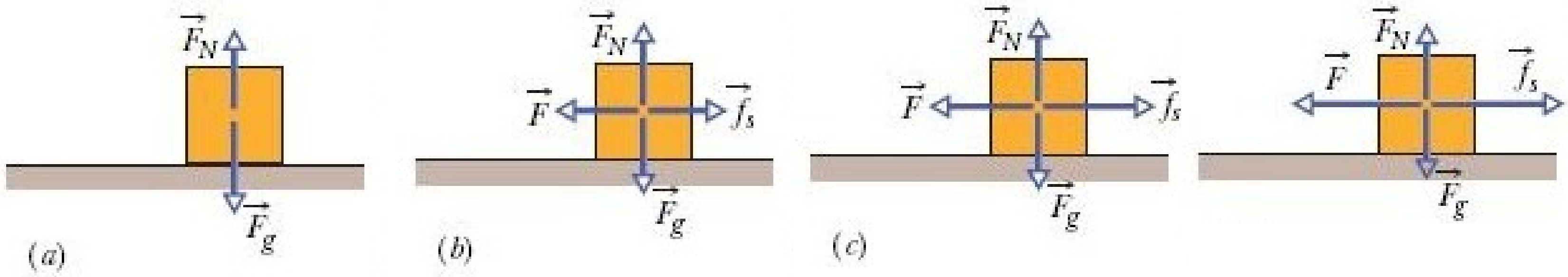


$f \sim F_N$

- Figure (Atomistic Scale): The tip of a probe is deformed sideways by frictional force as the probe is dragged across a surface.



Property 1. If the body does not move, then the static frictional force and the component of **F** that is parallel to the surface balance each other. They are equal in magnitude, and is f_s directed opposite that component of **F**.



Property 2. The magnitude of has a maximum value $f_{s,max}$ *that is given by*

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

where μ_s *is the **coefficient of static friction*** and F_N ***is the magnitude of the normal force*** on the body from the surface.

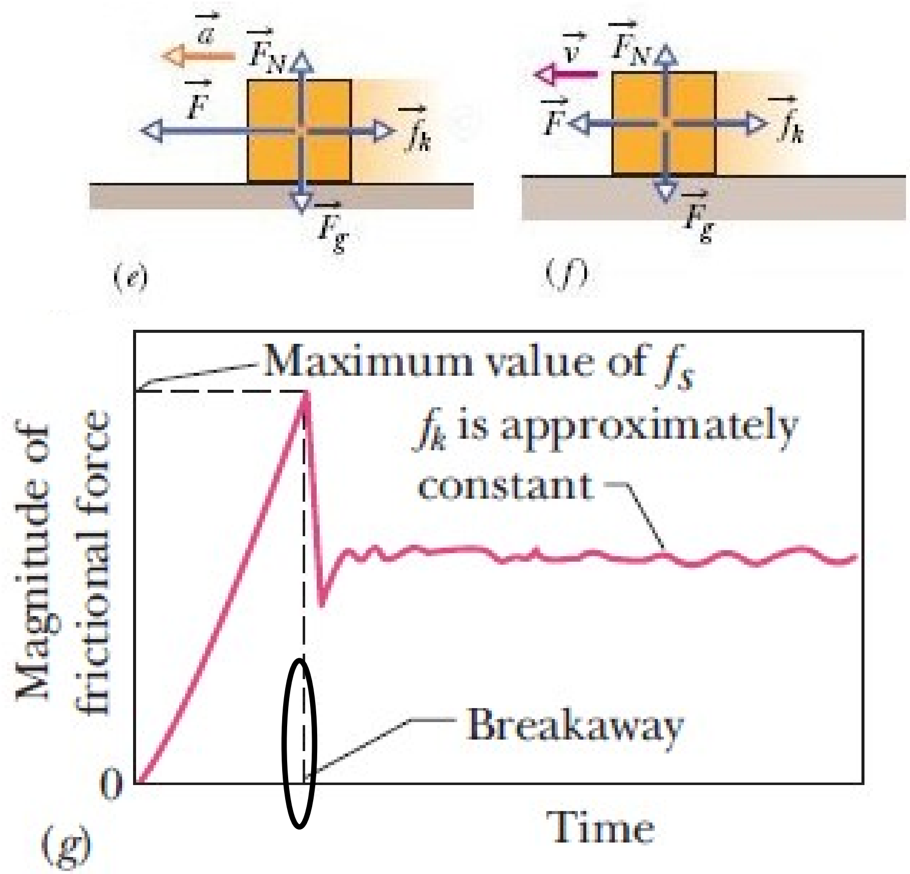
- *If the magnitude of the component of **F** that is parallel to the surface exceeds $f_{s,max}$, then the body begins to slide along the surface.*

$$F > f_{s,max} \approx \mu_s F_N$$

Property 3. If the body begins to slide along the surface, the magnitude of the frictional force rapidly decreases to a value f_k given by

$$f_k = \mu_k F_N,$$

where μ_k is the ***coefficient of kinetic friction.***
Thereafter, during the sliding, ***a kinetic frictional force*** f_k opposes the motion.

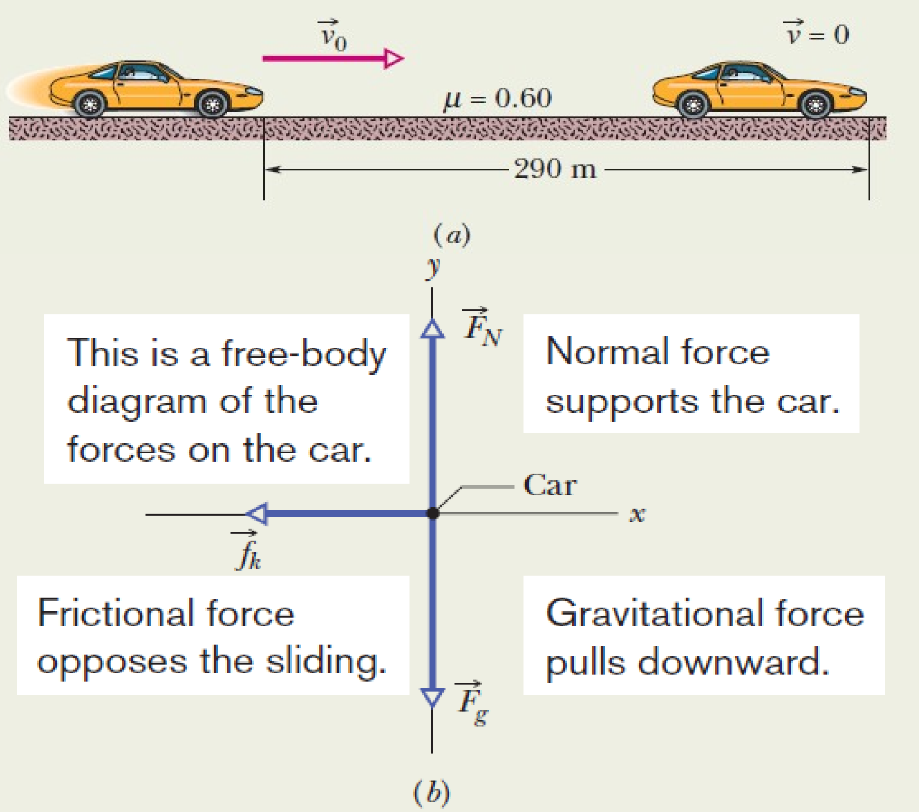


- The values of the friction coefficients are unitless and must be determined experimentally.
- Assume that μ_k does not depend on velocity.

6-3 Properties of Friction

Example:

If a car's wheels are "locked" (kept from rolling) during emergency braking, the car slides along the road. Ripped-off bits of tire and small melted sections of road form the "skid marks" that reveal that cold-welding occurred during the slide. The record for the longest skid marks on a public road was reportedly set in 1960 by a Jaguar on the M1 highway in England (Fig. 6-3*a*)—the marks were 290 m long! Assuming that $\mu_k = 0.60$ and the car's acceleration was constant during the braking, how fast was the car going when the wheels became locked?



Assume that the constant acceleration *a was due only to a kinetic frictional* force on the car from the road, directed opposite the direction of the car's motion. This results in:

$\mu_k F_N$ $\qquad -f_k = ma,$ $\qquad -\mu_k mg = ma$

where *m is the car's mass. The minus sign indicates the direction* of the kinetic frictional force.

Calculations: The frictional force has the magnitude $f_k = \mu_k F_N$,

where F_N is the magnitude of the normal force on the car from the road. Because the car is not accelerating vertically,

$$F_N = mg.$$

Thus, $\qquad f_k = \mu_k F_N = \mu_k mg$ $\qquad$ no mass dependence

$$a = -f_k/m = -\mu_k mg/m = -\mu_k g,$$

where the minus sign indicates that the acceleration is in the negative direction. Use

$$v^2 = v_o^2 + 2a(x - x_o)$$

where $(x-x_o) = 290$ m, and the final speed is 0.

Solving for v_o,

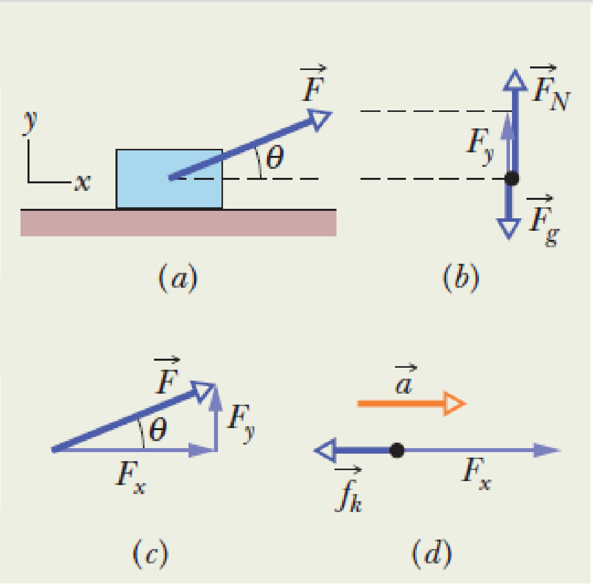
$$v_o = \sqrt{2\mu_k g(x - x_o)} = 58\ m/s$$

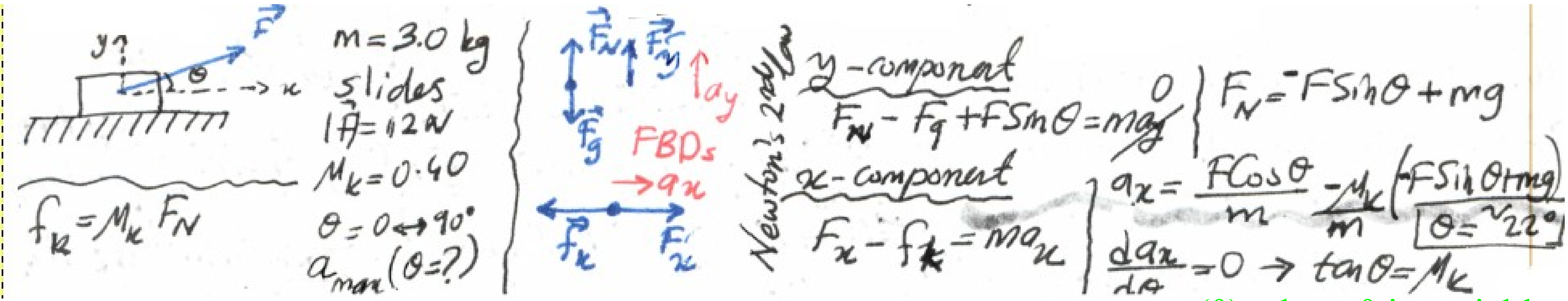
We assumed that *v = 0 at the far end of the skid marks.*

Actually, the marks ended only because the Jaguar left the road after 290 m. So *v_0 was at least 210 km/h.*

Example:

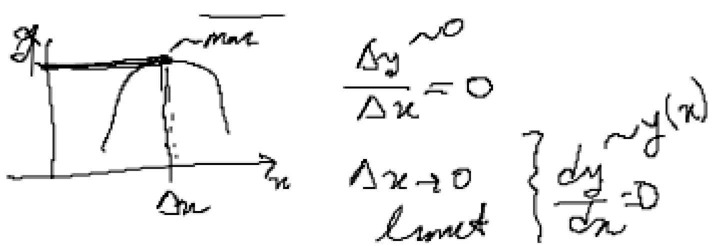
In Fig. 6-4*a*, a block of mass $m = 3.0$ kg slides along a floor while a force $\vec{F}$ of magnitude 12.0 N is applied to it at an upward angle θ. The coefficient of kinetic friction between the block and the floor is $\mu_k = 0.40$. We can vary θ from 0 to 90° (the block remains on the floor). What θ gives the maximum value of the block's acceleration magnitude a?





$a_x(\theta)$ where θ is variable

Finding a maximum: To find the value of θ that maximizes a, we take the derivative of a with respect to θ and set the result equal to zero:



- A body moving with speed v in uniform circular motion feels a **centripetal acceleration** directed towards the center of the circle of

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

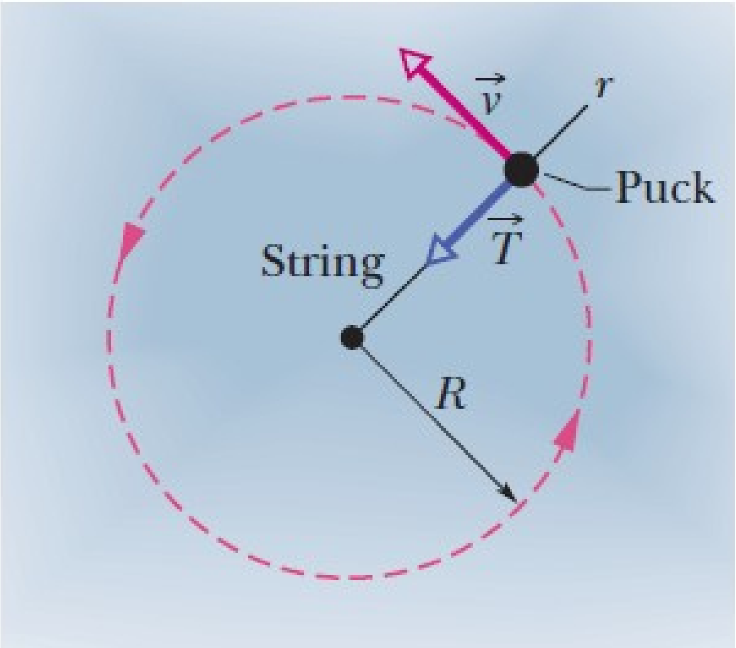


Fig. 6-8 An overhead view of a hockey puck moving with constant speed v in a circular path of radius R on a horizontal frictionless surface. The centripetal force on the puck is T, the pull from the string, directed inward along the radial axis r extending through the puck.

- Centripetal force is not a new *kind* of force, it is simply an application of force

$$F = m\frac{v^2}{R}$$

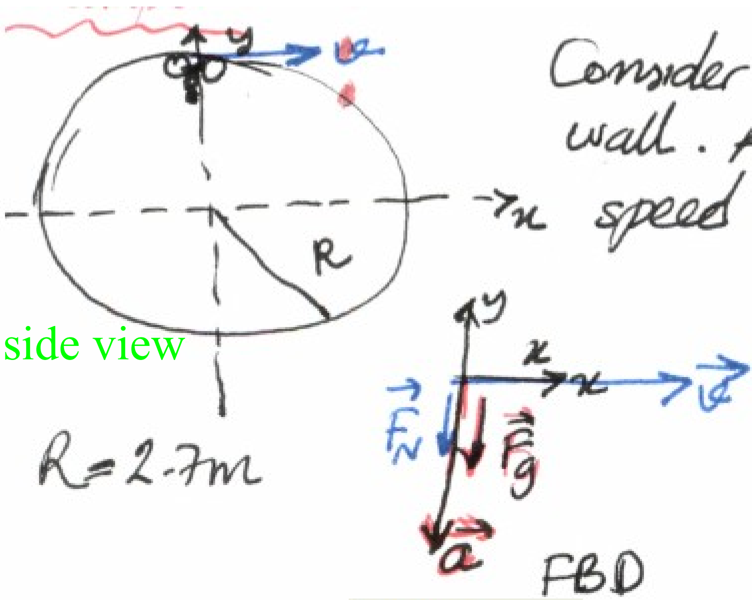
- For the puck on a string, *the string tension supplies the centripetal force* necessary to maintain circular motion

A centripetal force accelerates a body by changing the direction of the body's velocity without changing the body's speed.

Example: Bicycle going around a vertical loop

In a 1901 circus performance, Allo "Dare Devil" Diavolo introduced the stunt of riding a bicycle in a loop-the-loop (Fig. 6-9*a*). Assuming that the loop is a circle with radius $R = 2.7$ m, what is the least speed v that Diavolo and his bicycle could have at the top of the loop to remain in contact with it there?

(a)



Consider a man on bicycle turning around a circular wall. At the top of the wall, what should be his speed to remain in contact with the wall?

Newton's 2nd law $\quad F_{net,y} = ma_y$

$$-F_N - F_g = m(-a) = -m\frac{v^2}{R}$$

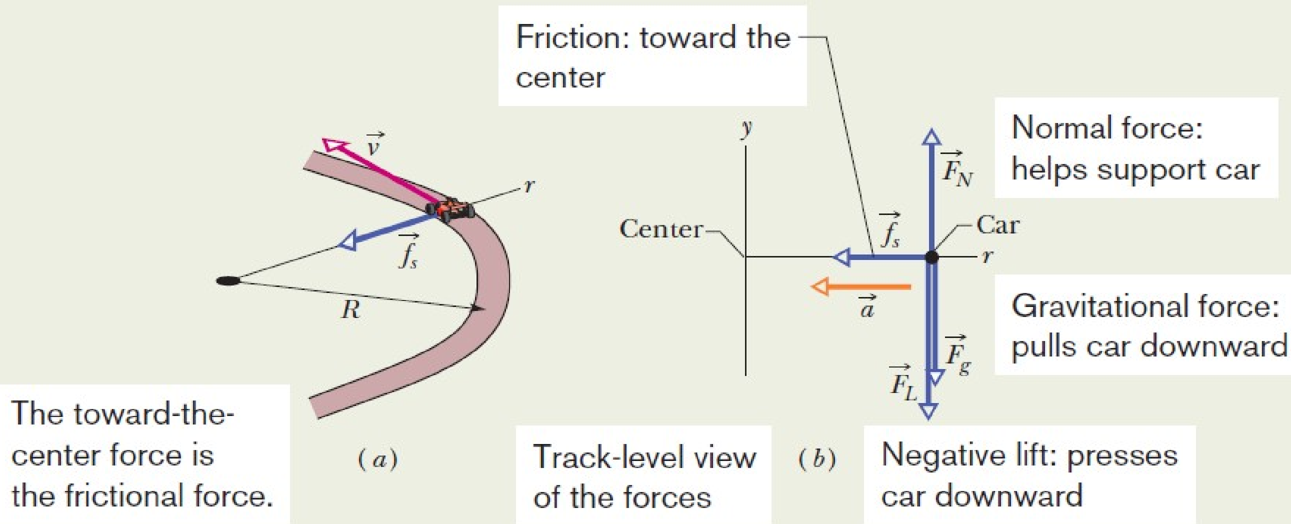
remain in contact → just about losing contact $F_N = 0$

$$0 - mg = -m\frac{v^2}{R} \Rightarrow v = \sqrt{gR} = 5.1\ m/s$$

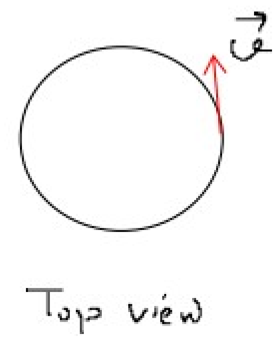
The net force provides the toward-the-center acceleration.

Example: **Car in a circular turn**

Figure 6-10*a* represents a Grand Prix race car of mass $m = 600$ kg as it travels on a flat track in a circular arc of radius $R = 100$ m. Because of the shape of the car and the wings on it, the passing air exerts a negative lift $\vec{F}_L$ downward on the car. The coefficient of static friction between the tires and the track is 0.75. (Assume that the forces on the four tires are identical.)



a) If the car is on the verge of sliding out of the turn when its speed is 28.6 m/s, what is the magnitude of the negative lift F_L acting downward on the car?



(b) The magnitude F_L *of the negative lift on a car depends* on the square of the car's speed v^2, *just as the drag force* does .Thus, the negative lift on the car here is greater when the car travels faster, as it does on a straight section of track. What is the magnitude of the negative lift for a speed of 90 m/s?

Example: (Cont.)

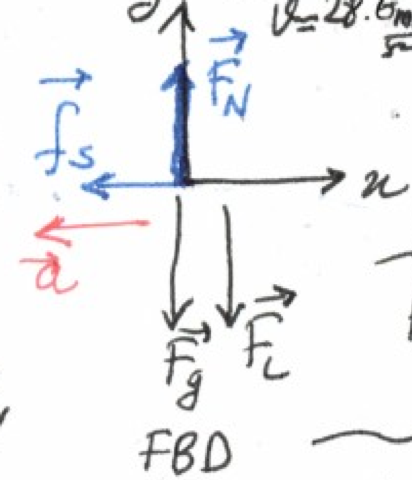
Car in flat circular turn

$m = 600\,kg \quad R = 100\,m$

$\mu_s = 0.75$

- A centripetal force must act which is frictional force
- Car is Not Sliding $\xrightarrow{\text{not motion in radial direction}}$ a static frictional force
- Just about sliding $\Rightarrow f_s \rightarrow f_{s,max} = \mu_s F_N$

i) $F_L = ?$ when $v = 28.6\,m/s$ — Newton's 2nd law



x: $-f_s = m(-a) = m\left(-\frac{v^2}{r}\right)$

y: $F_N - F_g - F_L = m a_y = 0$

$$\Rightarrow \mu_s F_N = m\frac{v^2}{r} \quad (1)$$
$$F_N = mg + F_L \quad (2)$$

$$F_L = \frac{m}{\mu_s}\frac{v^2}{r} - mg = (600\,kg)\left(\frac{(28.6\,m/s)^2}{(0.75)(100\,m)} - 9.8\,m/s^2\right) = 663.\ N$$

$F_L \propto v^2$ as in Drag Force

ii) $F_L = ?$ when $v = 90\,m/s$ — F_L is proportional to v^2

$$\frac{F_{L,90}}{F_L} = \frac{(90\,m/s)^2}{(28.6\,m/s)^2} \rightarrow F_{L,90} = 6572\,N$$

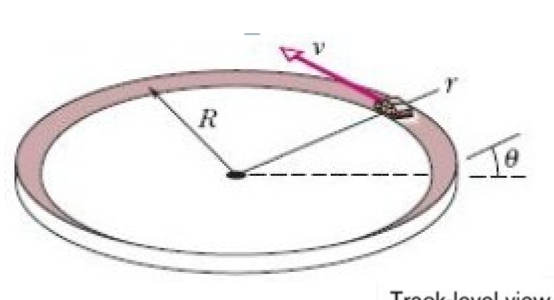
Notice that $F_g = (600\,kg)(9.8\,m/s^2) = 5880\,N$

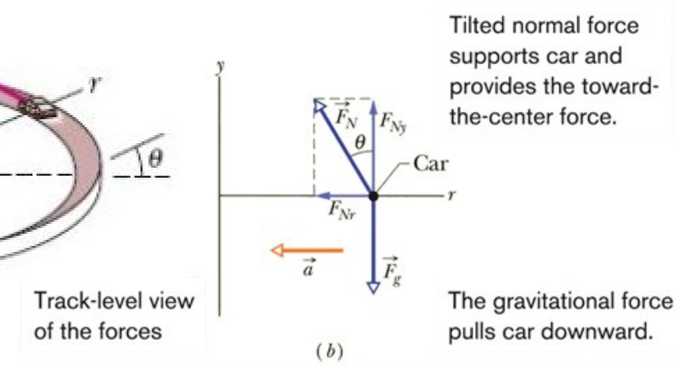
$F_{L,90} > F_g \Rightarrow$ upside down motion!!

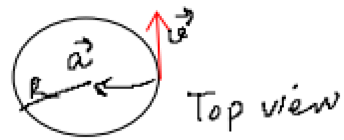
$v = 90\,m/s \approx 324\,km/h$

Example: Car in a banked circular turn

Curved portions of highways are always banked (tilted) to prevent cars from sliding off the highway. When a highway is dry, the frictional force between the tires and the road surface may be enough to prevent sliding. When the highway is wet, however, the frictional force may be negligible, and banking is then essential. Figure 6-13*a* represents a car of mass *m* as it moves at a constant speed *v* of 20 m/s around a banked circular track of radius $R = 190$ m. (It is a normal car, rather than a race car, which means any vertical force from the passing air is negligible.) If the frictional force from the track is negligible, what bank angle θ prevents sliding?





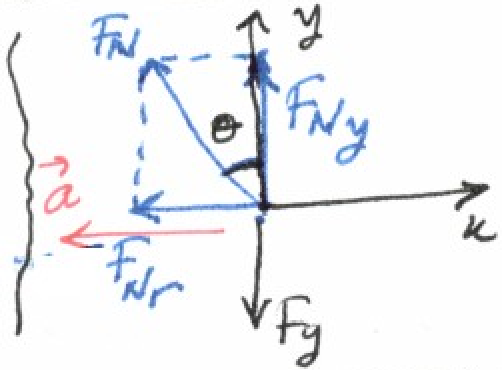


Car in banked circular turn

$v = 20$ m/s

$R = 190$ m

$\theta = ?$ without sliding



Newton's 2nd law

x

$$-F_N \sin\theta = m(-a) = m\left(-\frac{v^2}{r}\right)$$

$$F_N = \frac{1}{\sin\theta}\frac{mv^2}{r} \quad (1)$$

y

$$F_N\cos\theta - F_g = ma_y = 0$$

$$F_N = \frac{F_g}{\cos\theta} \quad (2)$$

Eliminate F_N from 1 & 2

(1) = (2)

$$\frac{1}{\sin\theta}\frac{mv^2}{r} = \frac{F_g}{\cos\theta} \;(F_g = mg) \Rightarrow \frac{v^2}{gr} = \tan\theta$$

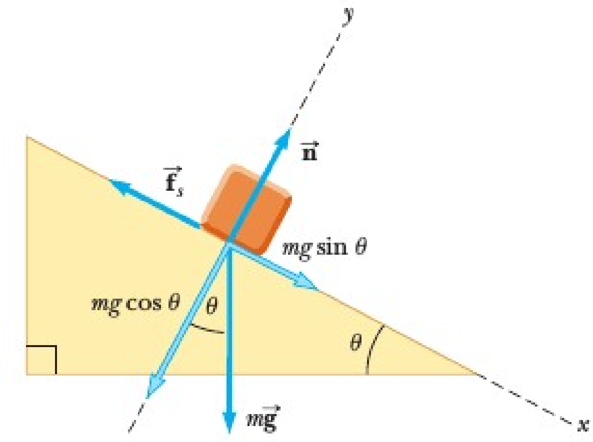
$$\Rightarrow \theta = \tan^{-1}\frac{(20\,m/s)^2}{(9.8\,m/s^2)(190\,m)} \Rightarrow \boxed{\theta = 12^\circ}$$

$$\boxed{v = \sqrt{gr\tan\theta}}$$

Example:

(Serway 5.11) Experimental Determination of μ_s and μ_k

The following is a simple method of measuring coefficients of friction. Suppose a block is placed on a rough surface inclined relative to the horizontal as shown in Figure. The incline angle is increased until the block starts to move. Show that you can obtain μ_s by measuring the critical angle Θ_c at which this slipping just occurs.



We have a motion or NOT?

$$(1)\ \sum F_x = mg\sin\theta - f_s = 0 = ma_x$$

$$(2)\ \sum F_y = n - mg\cos\theta = 0 = ma_y$$

2nd law

$$f_s = mg\sin\theta = \left(\frac{n}{\cos\theta}\right)\sin\theta = n\tan\theta$$

$$\mu_s n = n\tan\theta_c$$

$$\mu_s = \tan\theta_c$$

no motion: μ_s

For example, if the block just slips at $\theta_c = 20.0°$, we find that $\mu_s = \tan 20.0° = 0.364$.

Once the block starts to move at $\theta \geq \theta_c$, it accelerates down the incline and the force of friction is $f_k = \mu_k n$. If θ is reduced to a value less than θ_c, however, it may be possible to find an angle θ_c' such that the block moves down the incline with constant speed as a particle in equilibrium again ($a_x = 0$). In this case, use Equations (1) and (2) with f_s replaced by f_k to find μ_k: $\mu_k = \tan\theta_c'$ where $\theta_c' < \theta_c$.

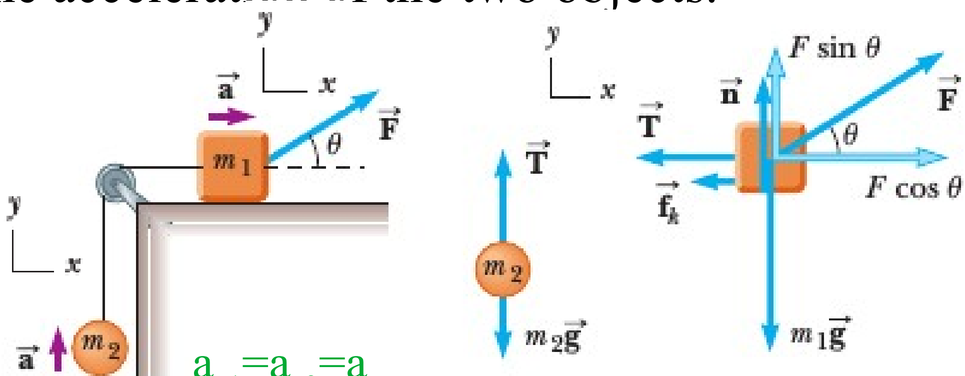
$\theta \uparrow : \theta_c \rightarrow \mu_s \rightarrow$ motion, acceleration

$\theta \downarrow : \theta_c' \rightarrow \mu_k \rightarrow$ motion, constant speed $\rightarrow$ acceleration is zero & $f_s \rightarrow f_k$ & $\mu_k = \tan\theta_c'$

Example:

(Serway 5.13) Acceleration of Two Connected Objects When Friction is Present

A block of mass m_1 on a rough, horizontal surface is connected to a ball of mass m_2 by a lightweight cord over a lightweight, frictionless pulley as shown in Figure. A force of magnitude F at an angle Θ with the horizontal is applied to the block as shown and the block slides to the right. The coefficient of kinetic friction between the block and surface is μ_k. Determine the magnitude of the acceleration of the two objects.



$a_{x1}=a_{y2}=a$

(1) $\sum F_x = F\cos\theta - f_k - T = m_1 a_x = m_1 a$

(2) $\sum F_y = n + F\sin\theta - m_1 g = 0$ $\quad m_1$

(3) $\sum F_y = T - m_2 g = m_2 a_y = m_2 a$ $\quad m_2$

(4) $f_k=\mu_k F_N$

(2) $n = m_1 g - F\sin\theta$

(4) $f_k = \mu_k(m_1 g - F\sin\theta)$

(3) for T

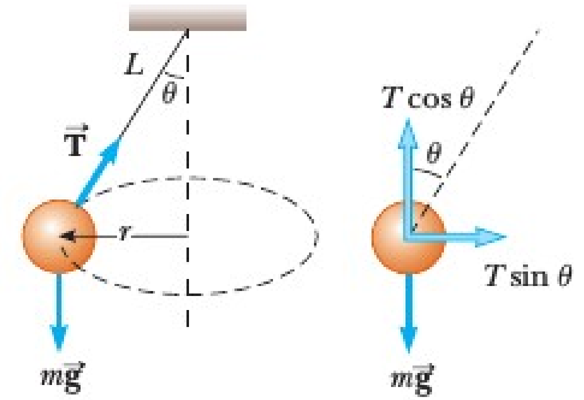
(1) $F\cos\theta - \mu_k(m_1 g - F\sin\theta) - m_2(a+g) = m_1 a$

(5) $$a = \frac{F(\cos\theta + \mu_k \sin\theta) - (m_2 + \mu_k m_1)g}{m_1 + m_2}$$

2 masses, 3 directions
→ 3 eqns
m_1: x, y
m_2: y

(Serway 6.1) The Conical Pendulum

A small ball of mass m is suspended from a string of length L. The ball revolves with constant speed *v* in a horizontal circle of radius r as shown in Figure. (Because the string sweeps out the surface of a cone, the system is known as a conical pendulum.) Find an expression for *v*.



$$\sum F_y = T\cos\theta - mg = 0$$

$$(1) \quad T\cos\theta = mg$$

$$(2) \quad \sum F_x = T\sin\theta = ma_c = \frac{mv^2}{r}$$

eliminate T

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

(mg/cosθ) sinθ=mv²/r

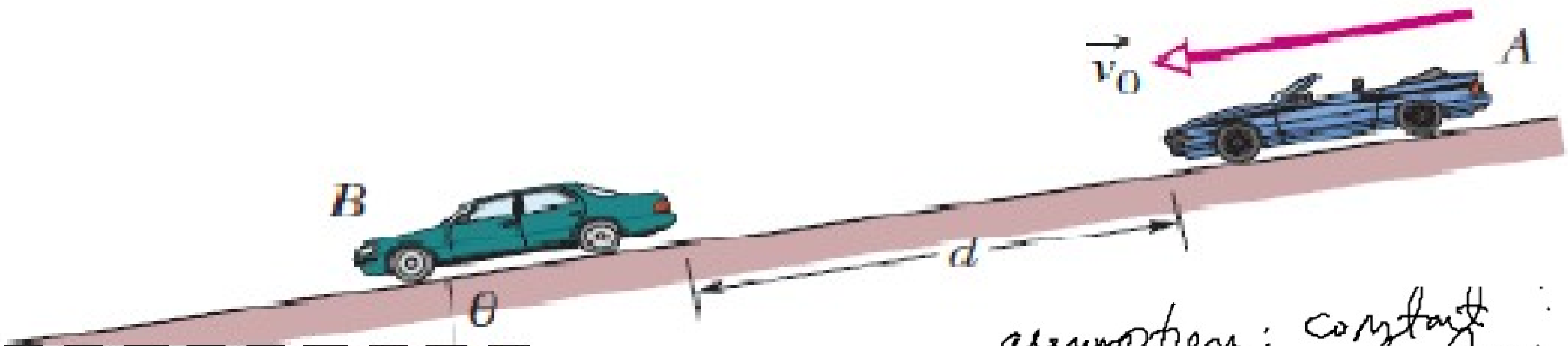
$$v = \sqrt{rg\tan\theta}$$

→ see previous example

$$v = \sqrt{Lg\sin\theta\tan\theta}$$

6 Solved Problems

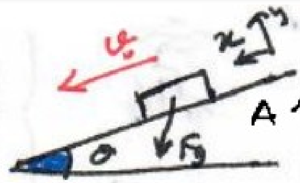
1. You testify as an *expert witness* in a case involving an accident in which car *A* slid into the rear of car *B* , which was stopped at a red light along a road headed down a hill (see Figure). You find that the slope of the hill is θ=12.0°, that the cars were separated by distance d=24.0 m when the driver of car *A* put the car into a slide (it lacked any automatic anti-brake-lock system), and that the speed of car *A* at the onset of braking was υ_0=18.0 m/s. With what speed did car *A* hit car *B* if the coefficient of kinetic friction was (a) 0.60 (dry road surface) and (b) 0.10 (road surface covered with wet leaves)?

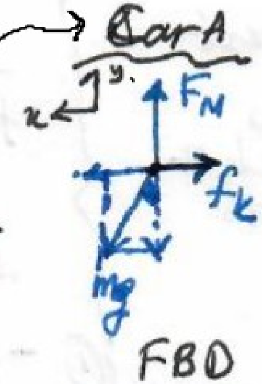


assumption: constant acceleration during the brake

(18) $v_0 = 18.0\ m/s$, $\theta = 12.0$, $d = 24.0\ m$

i) $\mu_K = 0.6$





Newton's 2nd law

① $mg\sin\theta - f_k = ma_x$

② $F_N - mg\cos\theta = ma_y = 0$

and we know $f_k = \mu_k F_N$

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② $F_N = mg\cos\theta$ & $f_k = \mu_k(mg\cos\theta)$

① $mg\sin\theta - \mu_k mg\cos\theta = ma$

$a = (9.8\ m/s^2)(\sin 12 - (0.6)\cos 12) = -3.71\ m/s^2$ ← μ_K

minus sign shows a deceleration. (slowing down)

$\Rightarrow v^2 = v_0^2 + 2a(x - x_0) = (18.0\ m/s)^2 + 2*(-3.71\ m/s^2)(24.0\ m)$

$\Rightarrow v = 12.1\ m/s$ Not zero, we have a hit

ii) Now, $\mu_K = 0.1$ less friction force that opposes motion

$a = (9.8\ m/s^2)(\sin 12 - (0.1)\cos 12) = +1.1\ m/s^2$ plus sign; still accelerating!!

($0.1 = \mu_K$)

$\rightarrow v^2 = (18.0\ m/s)^2 + 2(1.1\ m/s^2)(24.0\ m)$

$v = 19.4\ m/s$ larger hit velocity $> v_0$

2. In Figure, blocks A and B have weights of 44 N and 22 N, respectively. (a) Determine the minimum weight of block C to keep A from sliding if μ_s between A and the table is 0.20. (b) Block C suddenly is lifted off A. What is the acceleration of block A if μ_k between A and the table is 0.15?

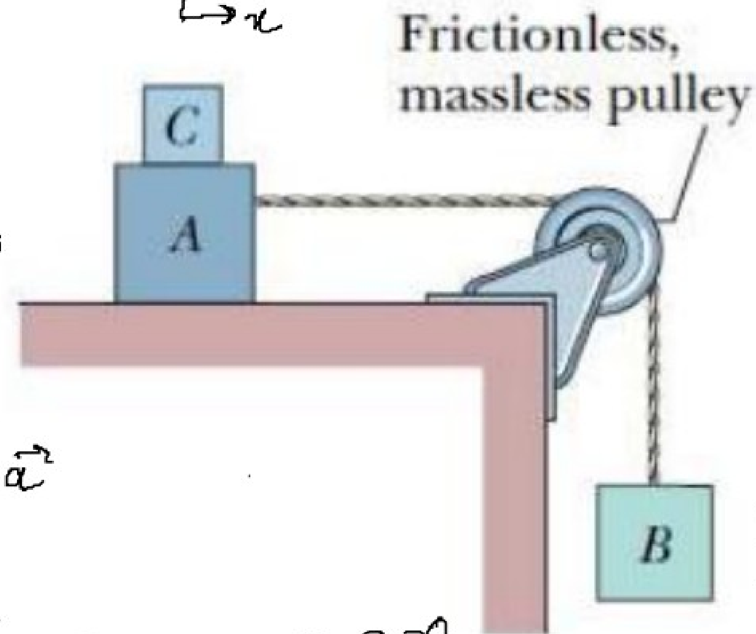
$w_A = 44N$

$w_B = 22N$

if we have a motion?

$\Rightarrow$ No motion. $\rightsquigarrow \mu_s$

2 mass & 3 directions



m_A: f_s, F_N, $\vec{a}$, T, $m_A g + m_C g$

m_B: T, $\vec{a}$, $m_B g$

FBDs

F_{N_C}

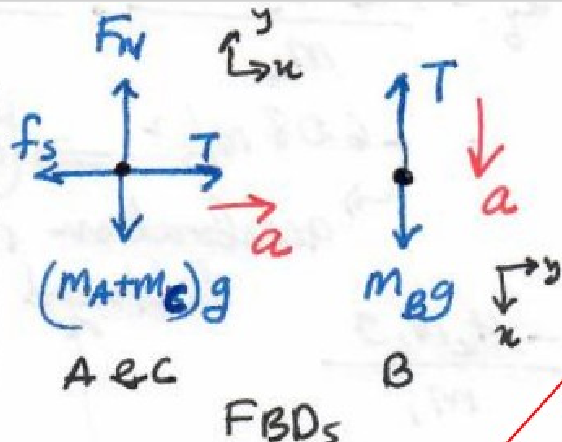
x: $T - f_s = m_A a_x = 0$

y: $F_N - (m_A + m_C) g = m_{AC} a_y = 0$

$-T + m_B g = m_B a_x = 0$

$f_s = \mu_s F_N$

(29) $m_A g = 44\,N = W_A$
$m_B g = 22\,N = W_B$
$\mu_s = 0.20$
$\mu_k = 0.15$



Newton's 2nd law

A & C

① $T - f_s = m_{AC} a_x = 0$

② $F_N - (m_{AC})g = m_{AC} a_y = 0$

B

③ $-T + m_B g = m a_x = 0$

i) $m_C = ?$ if no motion

from ②: $f_s = \mu_s F_N = \mu_s (m_A + m_C) g$

eliminate f_s

① $T - \mu_s (m_A + m_C) g = 0$
③ $T = m_B g$

$T_{AC} = \mu_s W_{AC}$, $T_B = W_B$; if sliding not to occur: $W_B < \mu_s W_{AC}$

$W_{AC} = \frac{22\,N}{0.20} = 110\,N$

$\rightarrow W_{AC} = W_A + W_C > 110\,N \Rightarrow 44\,N + W_C = 110\,N \Rightarrow$ $\boxed{W_C = 66\,N}$

ii) no m_C any more $\Rightarrow$ motion now $\rightarrow \mu_k$

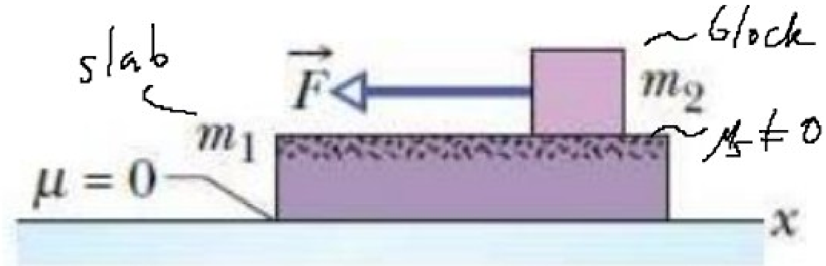
① $T - f_k = m_A a$
② $F_N - m_A g = 0$
③ $-T + m_B g = m_B a$

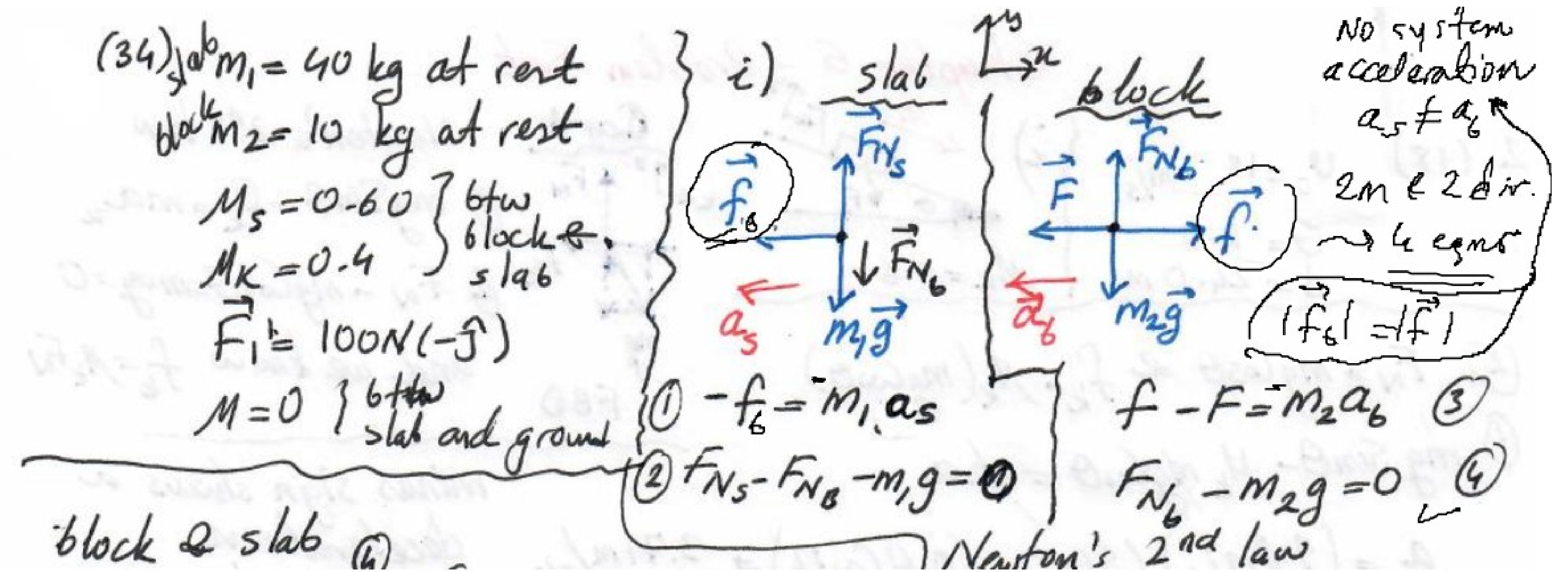
$T - \mu_k (m_A g) = m_A a$ ①
$T = m_B a + m_B g$ ③

$\frac{m_B g - \mu_k m_A g}{m_A + m_B} = a = \frac{22\,N - 0.15 \cdot 44\,N}{(44\,N + 22\,N)/9.8\,m/s^2}$

$\boxed{a = 2.29\,m/s^2}$

3.In Figure, a slab of mass m_1=40 kg rests on a frictionless floor, and a block of mass m_2=10 kg rests on top of the slab. Between block and slab, the coefficient of static friction is 0.60, and the coefficient of kinetic friction is 0.40. A horizontal force of magnitude 100 N begins to pull directly on the block, as shown. In unit-vector notation, what are the resulting accelerations of (a) the block and (b) the slab?





block & slab

④ $f_{s,max} = \mu_s F_{N_b} = (0.60)(10\,kg)(9.8\,m/s^2)$ (m_b)
$= 58.8\,N$

Newton's 2nd law

Assumption: If block does not slide on the slab
$|\vec{f}_b| = |\vec{f}|$
$\Rightarrow a_s = a_b$ ① & ③
$+m_1 a - F = m_2 a \Rightarrow F = +(m_1 + m_2) a$
$\Rightarrow a = \frac{+F}{(m_1 + m_2)}$
$\Rightarrow$ ③ $f_b = \frac{m_1 F}{(m_1 + m_2)}$ in magnitude

$\Rightarrow$ ③ $f_b = \frac{(40\,kg)(100\,N)}{(10\,kg + 40\,kg)} = 80\,N$

$|f_b| \overset{?}{=} |f|$

$\Rightarrow 80\,N > 58.8\,N$

block is sliding accross the slab!

if $F_? < 58.8 \rightarrow$ would have a system motion

$\Rightarrow a_s \neq a_b$

i) $f = \mu_k F_{N_b}$

④ $f = \mu_k m_2 g$

③ $a_b = \frac{\mu_k m_2 g - F}{-m_2} = \frac{(0.40)(10\,kg)(9.8\,m/s^2) - 100\,N}{-10\,kg}$
$= +6.08\,m/s^2 \Rightarrow \vec{a}_b = 6.08(-\hat{\imath})\,m/s^2$

acceleration is leftward

$|a_b| > |a_s|$

ii) ① $a_s = \frac{+f}{m_1} = \frac{+\mu_k m_2 g}{m_1}$
$= \frac{+(0.40)(10\,kg)(9.8\,m/s^2)}{40\,kg} = +0.98\,m/s^2$

$\vec{a}_s = 0.98(-\hat{\imath})\,m/s^2$

4. Two blocks with masses m_A = 20 kg and m_B = 80 kg are connected with a flexible cable that passes over a frictionless pulley as shown in Figure. The coefficient of friction between the blocks is 0.25. If motion of the blocks is impending, determine the coefficient of friction between block B and the inclined surface and the tension in the cable between the two blocks.

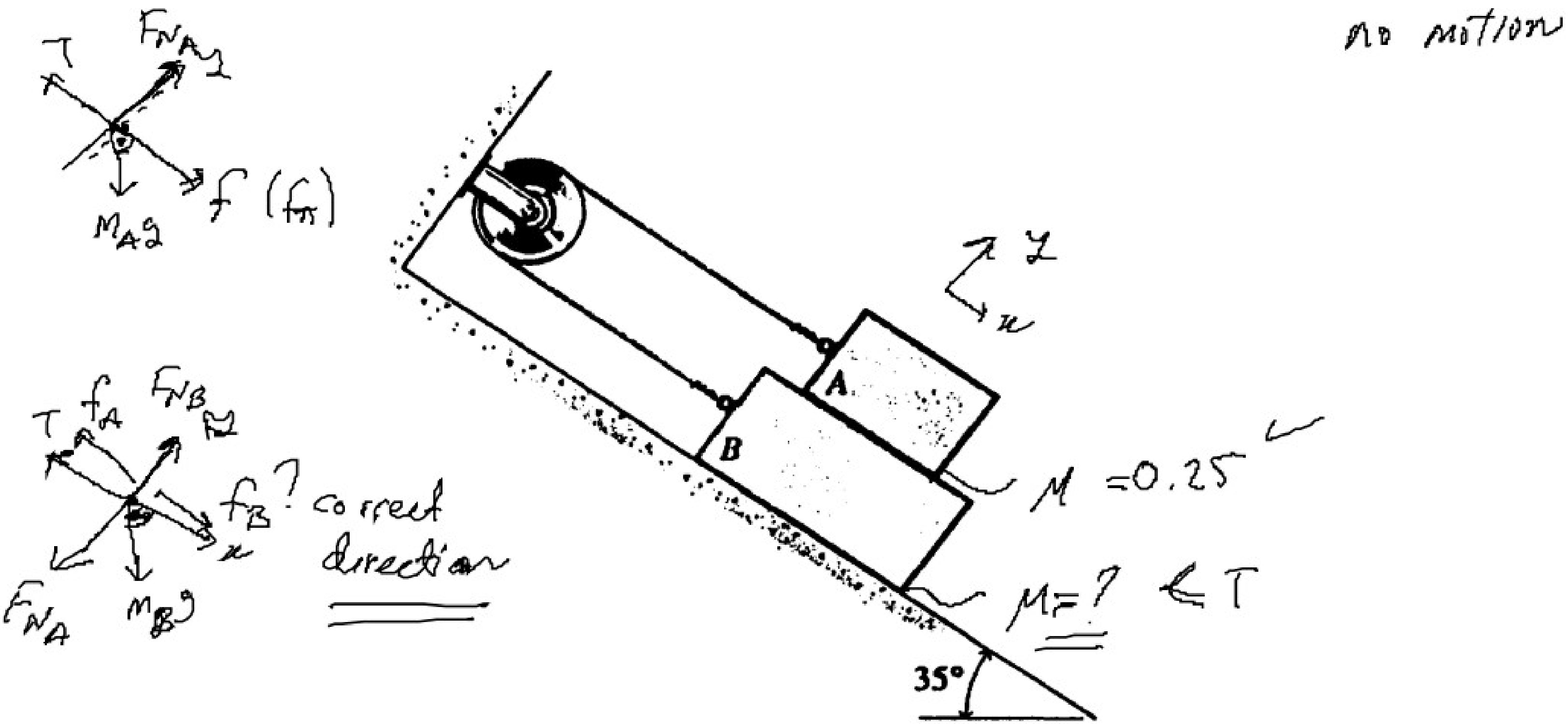
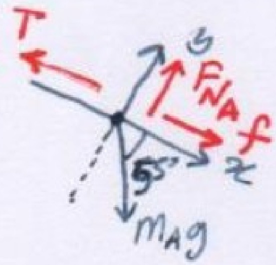
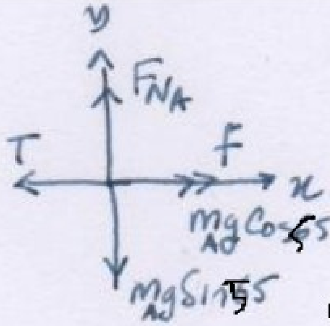


Fig. P9-4

(A)





① $\Sigma F_x = f + m_A g \cos 55 - T = m_A a_x = 0$

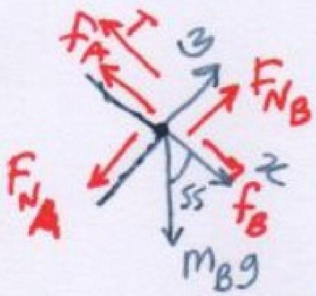
② $\Sigma F_y = F_{N_A} - m_A g \sin 55 = m_A a_y = 0$ ~ impending

② $F_{N_A} = m_A g \sin 55 = (20\,kg)(9.8\,m/s^2)\sin 55 = 160.55\,N$

$f = \mu F_{N_A} \Rightarrow 0.25(160.55\,N) + (20\,kg)(9.8\,m/s^2)\cos 55 = T$ ①

$T = 152.56\,N$

(B)



$\Sigma F_x = f_B - f_A - T + m_B g \cos 55 = m_B a_x = 0$ ③

$\Sigma F_y = F_{N_B} - F_{N_A} - m_B g \sin 55 = m_B a_y = 0$ ④

Direction of f_B?!

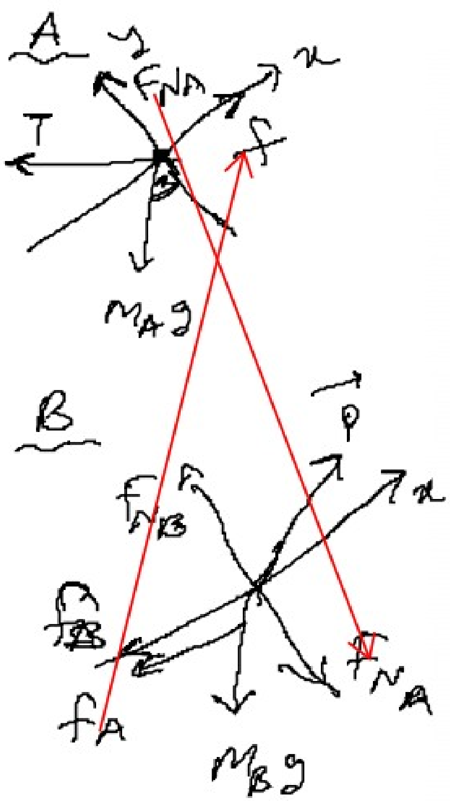
④ $F_{N_B} = F_{N_A} + (80\,kg)(9.8\,m/s^2)\sin 55 = 802.77\,N$

③ $\mu(802.77\,N) - (0.25)(160.55\,N) - 152.56\,N + (80\,kg)(9.8\,m/s^2)\cos 55 = 0$

$\Rightarrow \mu = -0.32 \rightarrow \mu = 0.32$ ✓ magnitude

since μ is found as negative! f_B is in $(-x)$

5. The masses of blocks A and B of Fig. P9-36 are $m_A = 40$ kg and $m_B = 85$ kg. If the coefficient of friction is 0.25 for both surfaces, determine the force **P** required to cause impending motion of block B.



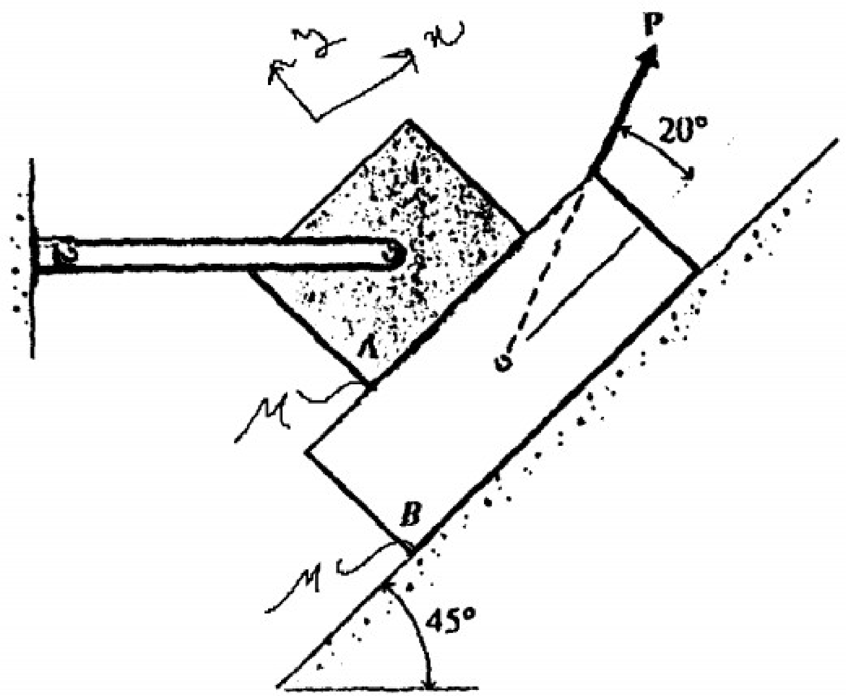
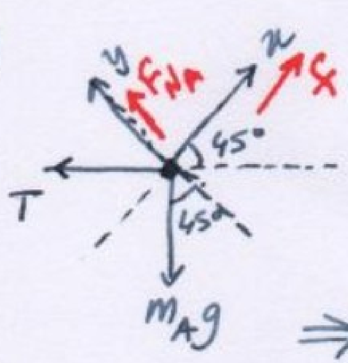


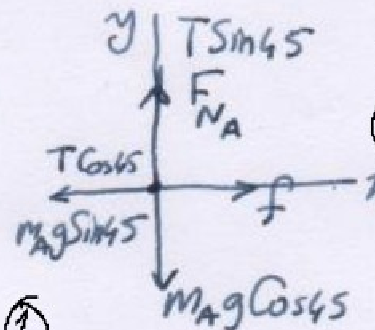
Fig. P9-36

FBDs

2 m & 2 directions → 4 eqns

(A)





(1) $\Sigma F_x = f - T\cos45 - m_A g \sin45 = m_A a_x = 0$ — impending

(2) $\Sigma F_y = T\sin45 + F_{N_A} - m_A g \cos45 = m_A a_y = 0$

(2) $T = -\dfrac{F_{N_A}}{\sin45} + m_A g \dfrac{\cos45}{\sin45}$

$\cos45 = \sin45$

$f = \mu_s F_{N_A}$, $\mu_s = 0.25$

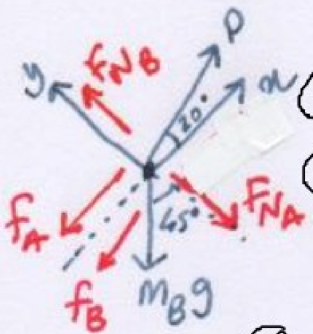
$\Rightarrow$ (1) $\mu_s F_{N_A} + F_{N_A}\dfrac{\cos45}{\sin45} - m_A g \cos45 - m_A g \sin45 = 0 \Rightarrow F_{N_A} = \dfrac{2 m_A g (0.707)}{1.25}$

$F_{N_A} = 443.5\,N$ ✓

$f = 0.25(443.5N)$

$f_A = 110.9N$

(B)



(3) $\Sigma F_x = -f - m_B g \sin45 + P\cos20 = m_B a_x = 0$

(4) $\Sigma F_y = F_{N_B} + P\sin20 - m_B g \cos45 - F_{N_A} = m_B a_y = 0$

where f is $f_A + f_B$ with $f_B = \mu_{s\,max} F_{N_B}$

(3) $-(110.9N + 0.25 F_{N_B}) - (8\,kg)(9.8\,m/s^2)\sin45 + P\cos20 = 0$ — 2 eqns & 2 unknowns F_{N_B} & P — eliminate

(4) $F_{N_B} = -P\sin20 + (8\,kg)(9.8\,m/s^2)\cos45 + 443.5N$

$-110.9N - 0.25(-P\sin20 + (8\,kg)(9.8\,m/s^2)\cos45 + 443.5N) - (8\,kg)(9.8\,m/s^2)\sin45° + P\cos20 = 0$

$-110.9N + 0.086P - 147.26N - 110.9N - 589.02N + P\,0.94 = 0 \Longrightarrow$ $\boxed{P = 933.8N}$ ✓

Friction

- Opposes the direction of motion or attempted motion
- Static if the object does not slide
- Static friction can increase to a maximum

$$f_{s,\max} = \mu_s F_N, \quad \text{Eq. (6-1)}$$

- Kinetic if it does slide

$$f_k = \mu_k F_N, \quad \text{Eq. (6-2)}$$

Uniform Circular Motion

- Centripetal acceleration required to maintain the motion

$$a = \frac{v^2}{R} \quad \text{Eq. (6-17)}$$

- Corresponds to a centripetal force

$$F = m\frac{v^2}{R} \quad \text{Eq. (6-18)}$$

- Force points toward the center of curvature

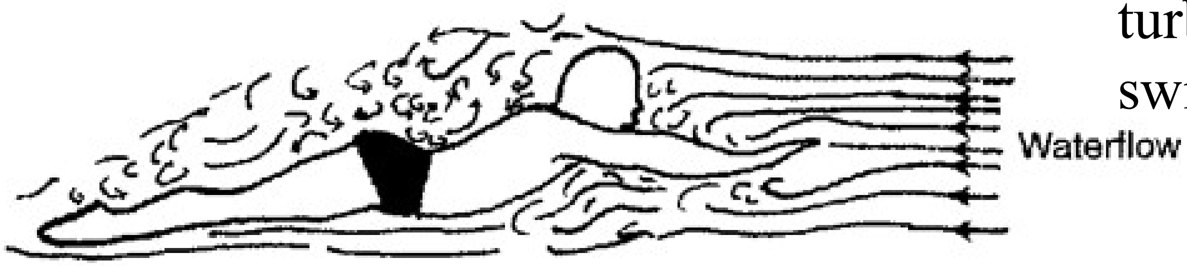
Additional Materials

Table 5.1 Coefficients of Static and Kinetic Friction

System	Static friction μ_s	Kinetic friction μ_k
Rubber on dry concrete	1.0	0.7
Rubber on wet concrete	0.7	0.5
Wood on wood	0.5	0.3
Waxed wood on wet snow	0.14	0.1
Metal on wood	0.5	0.3
Steel on steel (dry)	0.6	0.3
Steel on steel (oiled)	0.05	0.03
Teflon on steel	0.04	0.04
Bone lubricated by synovial fluid	0.016	0.015
Shoes on wood	0.9	0.7
Shoes on ice	0.1	0.05
Ice on ice	0.1	0.03
Steel on ice	0.4	0.02

- A **fluid** is anything that can flow (gas or liquid).
- When there is a relative velocity between a fluid and a body (either because the body moves through the fluid or because the fluid moves past the body), the body experiences a **drag force, D, that opposes the relative motion and points in the direction in** which the fluid flows relative to the body.

Small drag in streamlined position



Large drag in unstreamlined position

- Here we examine the drag force for
  - Air
  - With a body that is not streamlined
  - For motion fast enough that the air becomes turbulent (breaks into swirls)

- For cases in which air is the fluid, and the body is blunt (like a baseball) rather than slender (like a javelin), and the relative motion is fast enough so that the air becomes turbulent (breaks up into swirls) behind the body,

$$D = \tfrac{1}{2} C \rho A v^2,$$

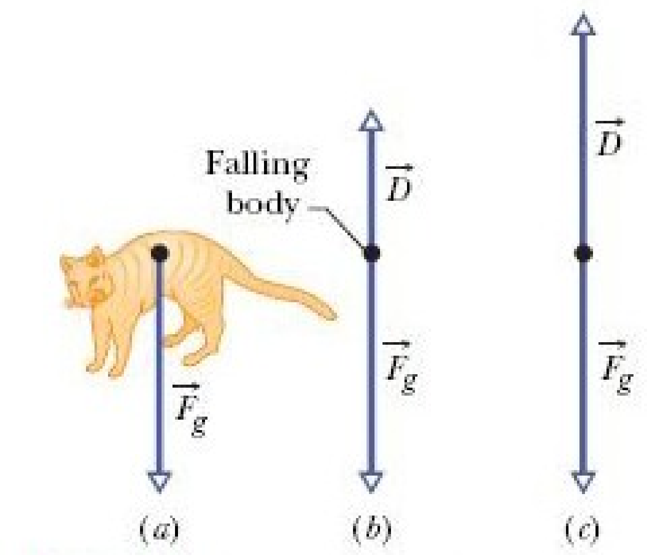
- Where:
  - *v* is the relative velocity
  - ρ is the air density (mass/volume)
  - *C* is the experimentally determined drag coefficient
  - *A* is the effective cross-sectional area of the body (the area taken perpendicular to the relative velocity)
- In reality, *C* is not constant for all values of *v*

- When a blunt body falls from rest through air, the drag force is directed upward; its magnitude gradually increases from zero as the speed of the body increases. From Newton's second law along *y axis*

$$D - F_g = ma,$$

where m is the mass of the body.

- Eventually, a = 0, and the body then falls at a constant speed, called the **terminal speed v_t** .



$$\frac{1}{2}C\rho A v_t^2 - F_g = 0,$$

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

The skier in an "egg position" to minimize air drag.

The sky divers in a horizontal "spread eagle" maximize air drag.

- Terminal speed can be increased by reducing A
- Terminal speed can be decreased by increasing A

Example:

A raindrop with radius $R = 1.5$ mm falls from a cloud that is at height $h = 1200$ m above the ground. The drag coefficient C for the drop is 0.60. Assume that the drop is spherical throughout its fall. The density of water ρ_w is 1000 kg/m^3, and the density of air ρ_a is 1.2 kg/m^3.

(a) As Table 6-1 indicates, the raindrop reaches terminal speed after falling just a few meters. What is the terminal speed?

(b) What would be the drop's speed just before impact if there were no drag force?

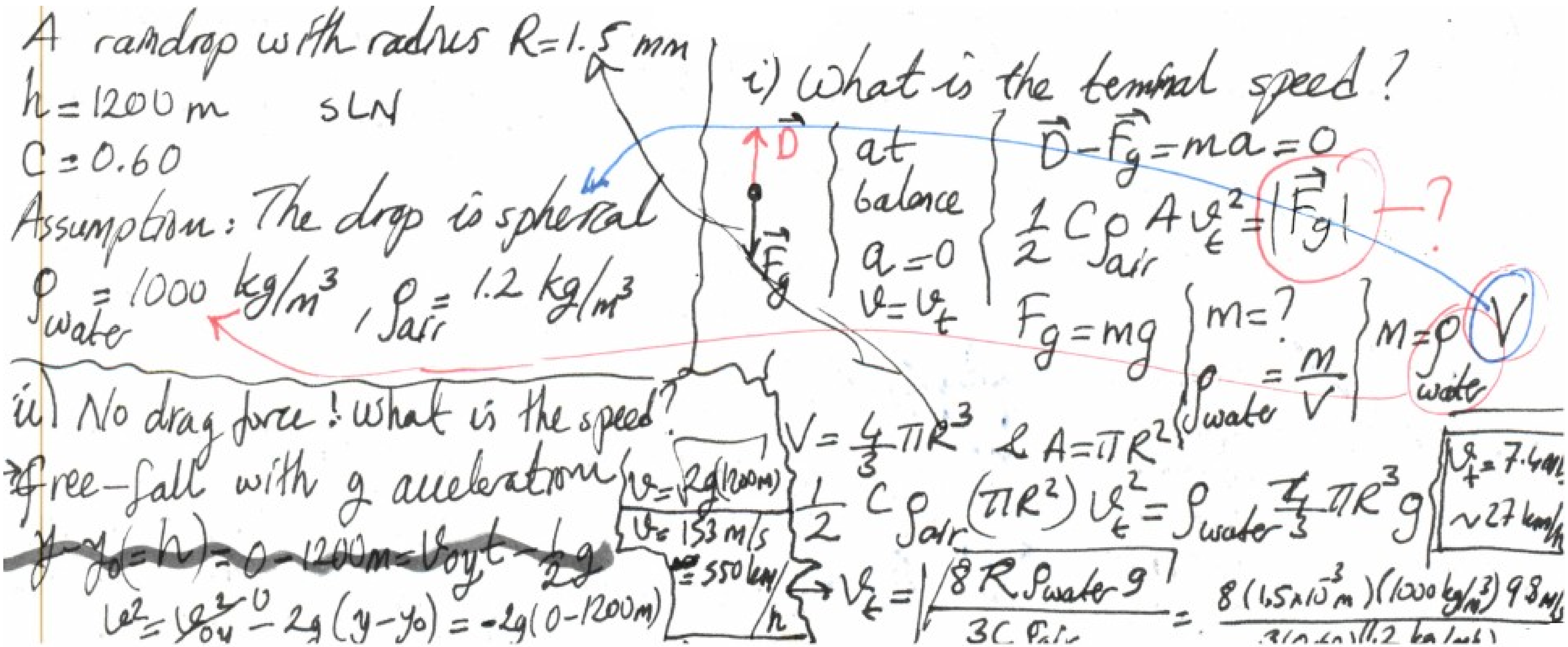


Table 5.2 Drag Coefficient Values **Typical values of drag coefficient C.**

Object	C
Airfoil	0.05
Toyota Camry	0.28
Ford Focus	0.32
Honda Civic	0.36
Ferrari Testarossa	0.37
Dodge Ram pickup	0.43
Sphere	0.45
Hummer H2 SUV	0.64
Skydiver (feet first)	0.70
Bicycle	0.90
Skydiver (horizontal)	1.0
Circular flat plate	1.12

Drag Force

- Resistance between a fluid and an object
- Opposes relative motion
- Drag coefficient *C* experimentally determined

$$D = \tfrac{1}{2}C\rho A v^2, \qquad \textbf{Eq. (6-14)}$$

- Use the effective cross-sectional area (area perpendicular to the velocity)

Terminal Speed

- The maximum velocity of a falling object due to drag

$$v_t = \sqrt{\frac{2F_g}{C\rho A}}. \qquad \textbf{Eq. (6-16)}$$