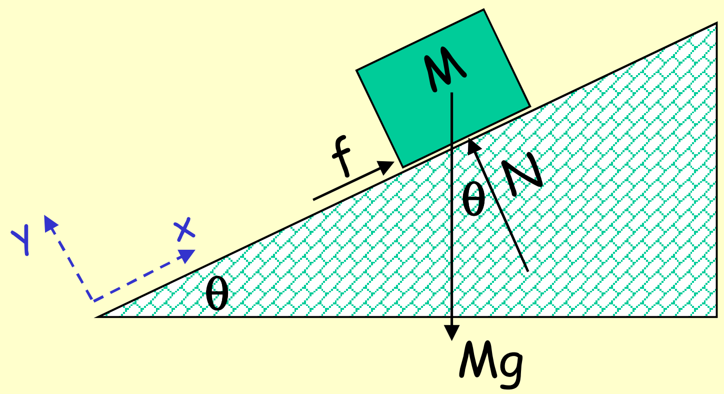
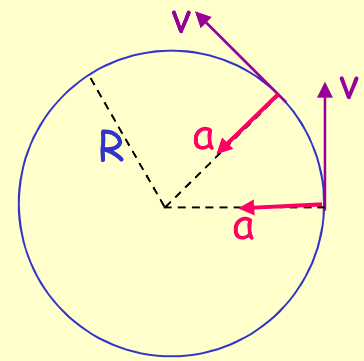
PHYS 100: Lecture 7

FRICTION and UNIFORM CIRCULAR MOTION



Static: $f \le \mu_S N$

Kinetic: $f = \mu_K N$



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

Music

BB

Who is the Artist?

A) Pete Fountain
B) Dr. Michael White
C) Al Hirt
D) George Lewis
E) Dr. John

Why??

FOUR DAYS TO MARDI GRAS

Master of traditional New Orleans jazz !!

Catch the Traditional Jazz Orchestra (Jeff Helgesen et al) at the Iron Post from 5pm -7pm on Fat Tuesday !

Midterm Exam

Next FRIDAY (Mar 11): Review Lecture
257 Loomis

Following Tuesday (10/19) Midterm Exam
7pm in 136 Loomis

any conflicts???

WHAT DID YOU FIND DIFFICULT?

Real forces in centripetal acceleration.

VERY IMPORTANT DISTINCTION HERE.

Newton's Second Law : $\vec{a} = \dfrac{\vec{F}_{net}}{m}$

↑ Kinematics (description)

↑ Dynamics (cause)

Newton's Second Law works in INERTIAL FRAMES

A Rotating Body is NOT an INERTIAL FRAME

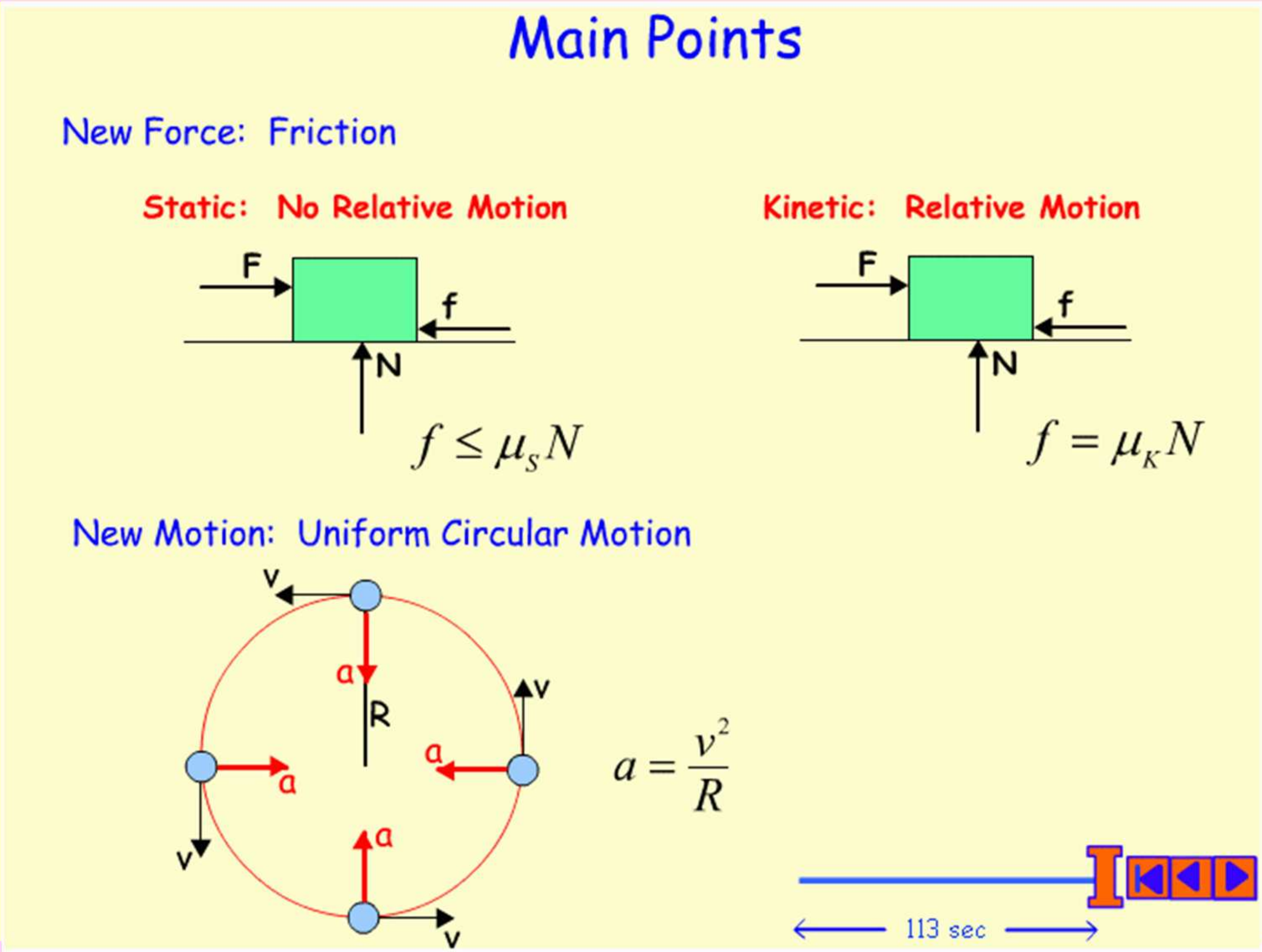
The only FORCES that should appear on a FREE BODY DIAGRAM are REAL FORCES

As of now, you know about: weight, normal, tension, friction and "applied"

EVERYTHINGGGGG!!!!!!

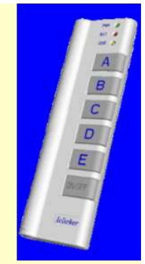
THE BIG IDEAS

NOTE: THE BIG IDEAS ARE ALWAYS GIVEN IN THE LAST SLIDE



1. Frictional forces oppose relative motion:
2. Static (use $\Sigma F_i = 0$) & Kinetic (use $f = \mu_K N$) are different
3. Uniform circular motion has centripetal acceleration = v^2/R

Direction of Frictional Forces



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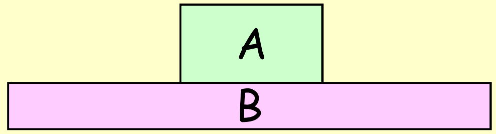
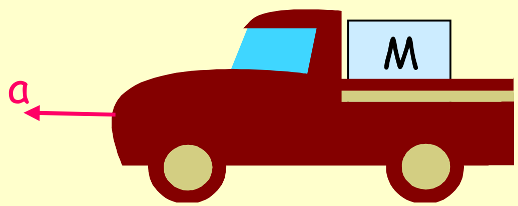
Two ways to determine f_{BonA}:



- Friction forces oppose relative motion (A relative to B)
- Draw freebody diagram and use Newton's Second Law

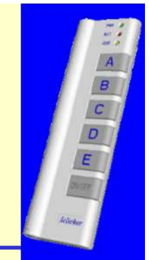
A block of mass M rests on the bed of a truck that is accelerating to the left



What is the direction of the frictional force that the bed of the truck exerts on the block?

(A) To left ⟵ (B) To right ⟶ (C) $f = 0$

Direction of Frictional Forces



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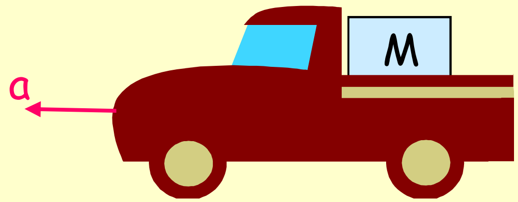
Suppose bed of truck were frictionless. What would be the motion of *M* relative to the truck?



(A) Slide forward ←

(B) Slide backward →

(C) Remain at rest

WHY??

Think of it from the reference frame of the ground (inertial)

Are there any horizontal forces on *M* ?

NO ! The block would remain at rest relative to the ground (a = 0)

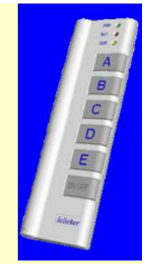
Since truck moves to the left, *M* would move to the right RELATIVE to theTRUCK

NOTE:

The Truck is NOT an INERTIAL FRAME ⇒ Newton's Second Law is NOT TRUE in TRUCK FRAME

$a \neq 0$ BUT $F_{net} = 0$

Direction of Frictional Forces



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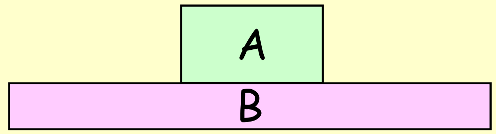
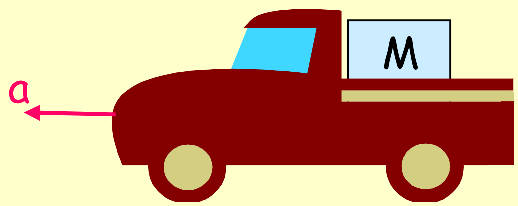
Two ways to determine f_{BonA}:



- Friction forces oppose relative motion (A relative to B)
- Draw freebody diagram and use Newton's Second Law

A block of mass M rests on the bed of a truck that is accelerating to the left

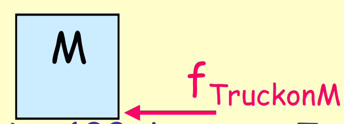


What is the direction of the frictional force that the bed of the truck exerts on the block?

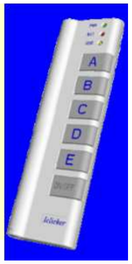
(A) To left ⟵ (B) To right ⟶ (C) $f = 0$

Since, in absence of friction, *M* would slide back (to right),
the friction force on *M* must OPPOSE this motion and point forward (to left)

We can get this result from Newton's Second Law ALSO.
knowing that the acceleration is to the LEFT !

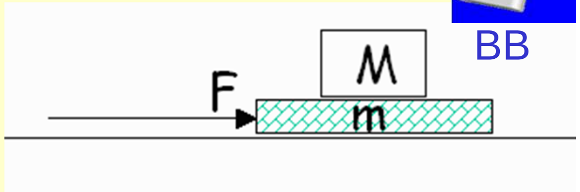


Preflight 1



A constant force F is applied to block m and both blocks are observed to move together with constant acceleration.

What is the frictional force f that m exerts on M?



BB

(A) $f < F$: f points to left

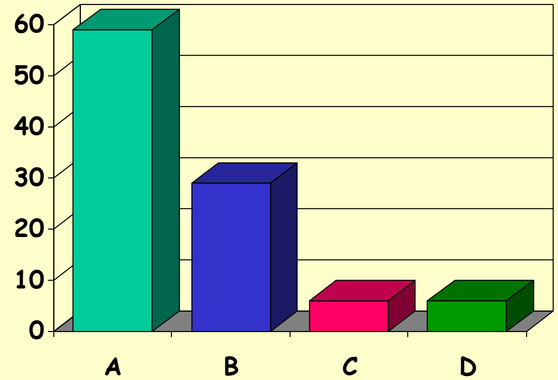
(B) $f < F$: f points to right

(C) $f > F$: f points to left

(D) $f > F$: f points to right

You said:

- Since they both move to the right, then F has to be greater than f so that it is able to overcome friction and move. f points to the left because it has to oppose the motion of m.
- For starters, f must point to the right. If the frictional force was not great enough to allow the blocks to move together than M would slide off m on the left side of the block. To counter that f points to the right to allow them to move together. Also, f does not have to be large than F because block M has mass, and the force of Mg will contribute to the staying on the block m. f only has to be what it is to do the job it does.



Preflight 1: Direction

A constant force *F* is applied to block *m* and both blocks are observed to move together with constant acceleration.

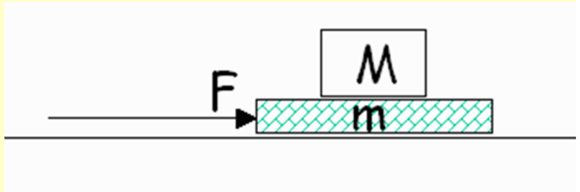
What is the frictional force *f* that *m* exerts on *M*?

(A) f < F : f points to left

(B) f < F : f points to right

(C) f > F : f points to left

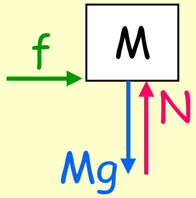
(D) f > F : f points to right



Two ways

In absence of friction, there would be NO horizontal force on *M*
Therefore *M* would NOT accelerate, but *m* would ACCELERATE to RIGHT
Therefore, RELATIVE to *m*, M would be moving to the LEFT.
The force *m* exerts on *M* then would OPPOSE this motion and point to the RIGHT

Free Body Diagram:



The acceleration of *M* is to the right (as measured in INERTIAL FRAME)

Newton's Second Law demands f to point to right since it is the ONLY horizontal force and must be the CAUSE of the acceleration of *M*.

Preflight 1: Magnitude

A constant force *F* is applied to block *m* and both blocks are observed to move together with constant acceleration.

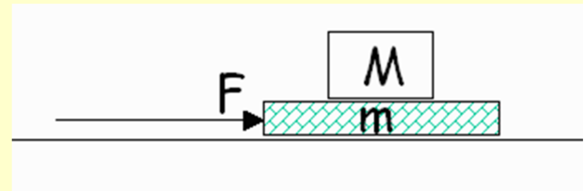
What is the frictional force *f* that *m* exerts on *M*?

(A) f < F : f points to left

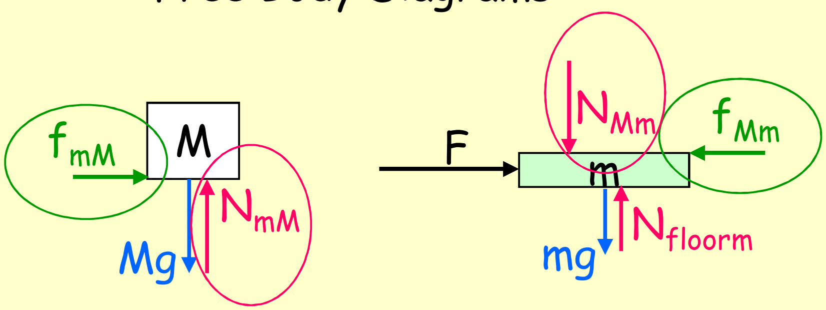
(B) f < F : f points to right

(C) f > F : f points to left

(D) f > F : f points to right



Free Body Diagrams:



NOTE the Action-Reaction Pairs

$$\vec{F}_{monM} = -\vec{F}_{Monm}$$

We used this info to draw f_{Mm} in the opposite direction to f_{mM}

Free Body for m

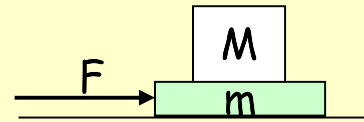
$$F - f_{Mm} = ma$$

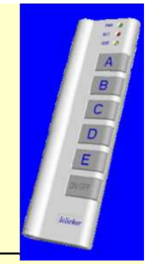
a > 0 (to right)

$$f_{Mm} < F$$

Follow Up

Case I





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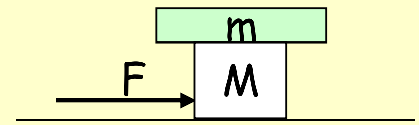
A constant force F is applied to block m in Case I and to block M in Case II and in both cases, both blocks are observed to move together with constant acceleration. ($M > m$)

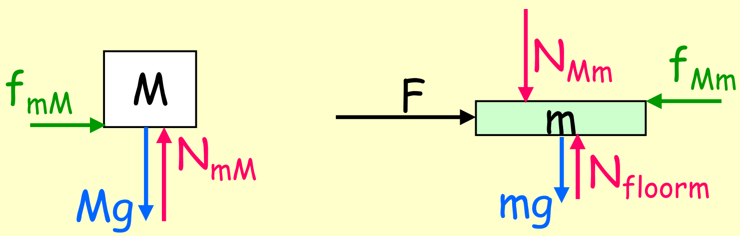
Compare the magnitude of the force f that m exerts on M.

(A) f(I) < f(II) (B) f(I) = f(II) **(C) f(I) > f(II)**

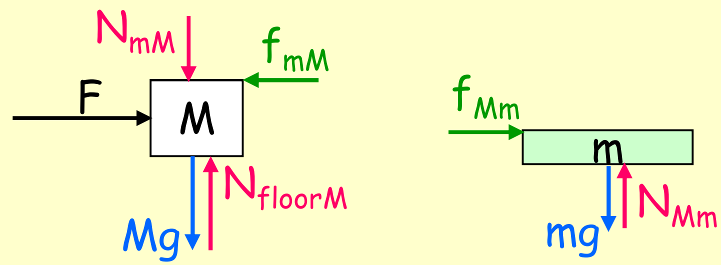
Case II



Free Body Diagrams
Case I



Free Body Diagrams
Case II



Newton's Second Law

$$f^{I}_{mM} = Ma$$

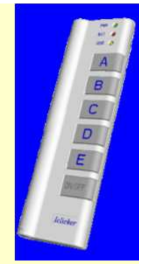
$M > m$ ⇒ $f^{I}_{mM} > f^{II}_{Mm}$

NOTE: These are real friction forces (NOT "ma" forces). They simply have the value = ma.

Newton's Second Law

$$f^{II}_{Mm} = ma$$

Static Friction



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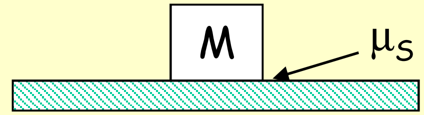
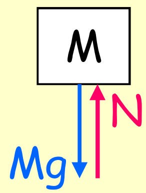
A block of mass M rests on a horizontal floor. The coefficient of static friction between the block and the floor is equal to μ_S.

What is f, the frictional force that the floor exerts on M?

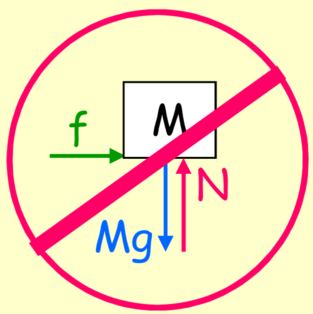
(A) $f = \mu_S Mg$ (B) $0 < f < \mu_S Mg$ (C) $f=0$



Free Body Diagram

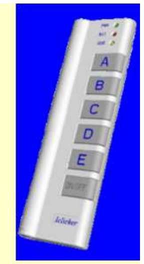


There is no force for the friction force to oppose !!



M would accelerate !!

Static Friction



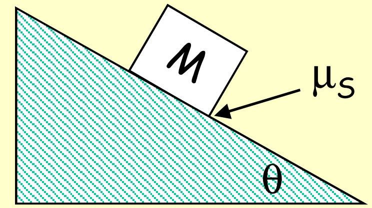
BB

A block of mass M rests on an incline of angle θ, as shown. The coefficient of static friction between the block and the floor is equal to μ_S.

What is f, the frictional force that the plane exerts on M?

(A) $f = \mu_S Mg\cos\theta$ (B) $f = \mu_S Mg\sin\theta$ (C) $f=0$

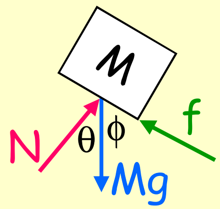
(D) $f = Mg\cos\theta$ **(E) $f = Mg\sin\theta$**



Free Body Diagram

Perpendicular to the plane:

$$N - Mg\cos\theta = 0$$



Parallel to the plane:

$$f - Mg\cos\phi = 0$$

$$f = Mg\cos\phi$$

$$\phi = 90^\circ - \theta$$

$$f = Mg\sin\theta$$

$$f < f_{max} = \mu_s N = \mu_s Mg\cos\theta$$

$$Mg\sin\theta < \mu_s Mg\cos\theta$$

$$\sin\theta < \mu_s\cos\theta$$

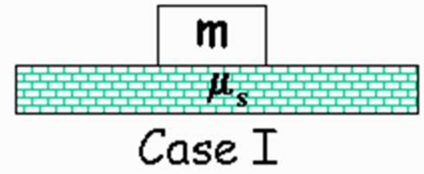
$$\tan\theta < \mu_s$$

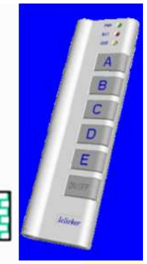
Preflight 3

In both cases a block of mass m is at rest on the surface which has a coefficient of static friction μ_S.

Compare f_I to f_{II}, the frictional forces on the blocks in I & II

(A) $f_I < f_{II}$ (B) $f_I = f_{II}$ (C) $f_I > f_{II}$





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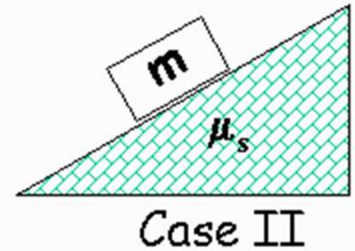
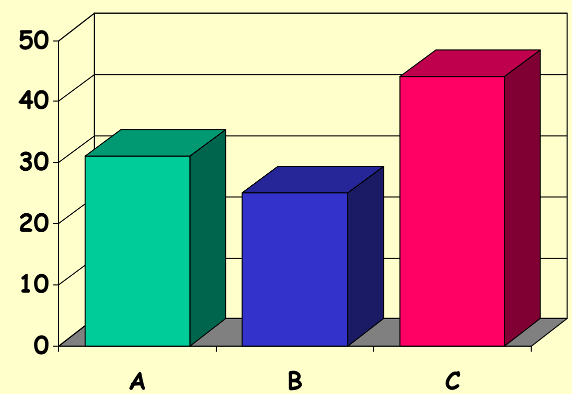


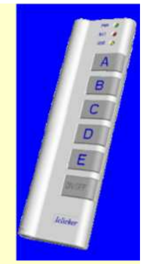
You said:

- Case one has no static friction added so case II would have a greater frictional force
- The force of friction would be the same because the block has the same mass.
- The frictional force depends on the Normal Force. The Normal force = mg in Case I, but it only equals Mgcos(theta) in case II. Therefore, the frictional force of Case I is greater than Case II.

f_I is ZERO !!



Uniform Circular Motion

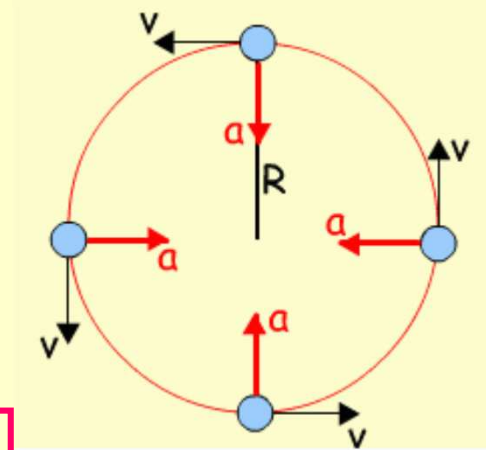


BB

KINEMATICS ONLY !!
MOTION HAS BEEN SPECIFIED

$$\vec{a} \equiv \frac{d\vec{v}}{dt} \quad \Rightarrow \quad \boxed{a = \frac{v^2}{R}}$$

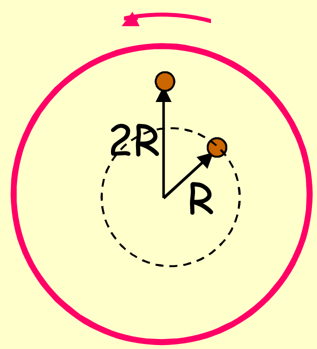
This is TRUE whenever you have uniform circular motion, no matter what kind of force causes it !!



A block of mass *M* rests on a turntable. The turntable makes one complete revolution in *P* seconds. Two pennies are at rest relative to the turntable and are located at distances *R* and 2*R* from the center,

We want to determine the accelerations of the pennies.
First step: What is the speed of the penny at *R*?

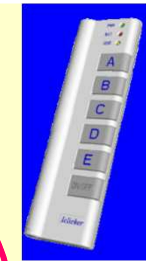
(A) $v = RP$ (B) $v = 2\pi RP$ (C) $v = \frac{R}{P}$ (D) $v = \frac{2\pi R}{P}$



Distance = 2πR
Time = P

P is called the PERIOD

Uniform Circular Motion

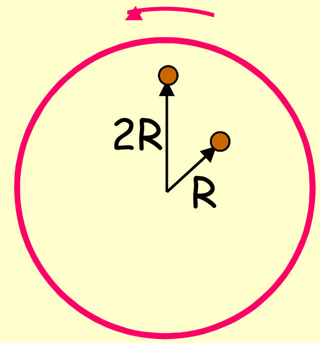

BB

A block of mass M rests on a turntable. The turntable makes one complete revolution in P seconds. Two pennies are at rest relative to the turntable and are located at distances R and $2R$ from the center.

Compare the accelerations of the pennies at R and 2R.

(A) $a(R) = \frac{1}{4}a(2R)$ (B) $a(R) = \frac{1}{2}a(2R)$ (C) $a(R) = a(2R)$

(D) $a(R) = 2a(2R)$ (E) $a(R) = 4a(2R)$



$$v = \frac{2\pi R}{P} \quad \text{at } R$$

Acceleration at R: $a_R = \frac{v^2}{R} \Rightarrow a_R = \frac{1}{R}\left(\frac{4\pi R^2}{P^2}\right) = \frac{4\pi}{P^2}R$

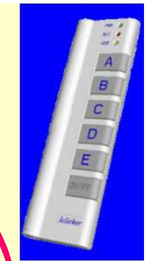
Acceleration at 2R: $v_{2R} = \frac{2\pi(2R)}{P} \Rightarrow a_{2R} = \frac{1}{2R}\left(\frac{16\pi R^2}{P^2}\right) = \frac{8\pi}{P^2}R$

$$a_R = \tfrac{1}{2}a_{2R}$$

General: $$a = \omega^2 R$$

ω is Angular Velocity (radians/sec): $\omega \equiv \frac{v}{R}$

Uniform Circular Motion



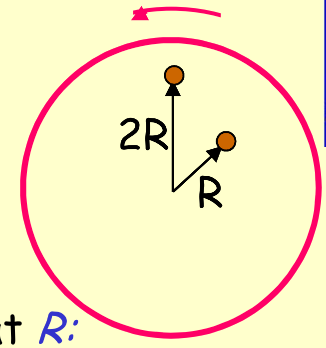
BB

A block of mass *M* rests on a turntable. The turntable makes one complete revolution in *P* seconds. Two pennies are at rest relative to the turntable and are located at distances *R* and 2*R* from the center.

Compare the net forces on the pennies at R and 2R.

(A) $F(R) = \frac{1}{4}F(2R)$ (B) $F(R) = \frac{1}{2}F(2R)$ (C) $F(R) = F(2R)$

(D) $F(R) = 2F(2R)$ (E) $F(R) = 4F(2R)$



at *R*:

$$v = \frac{2\pi R}{P} \qquad a = \omega^2 R$$

$$\omega \equiv \frac{v}{R} = \frac{2\pi}{P}$$

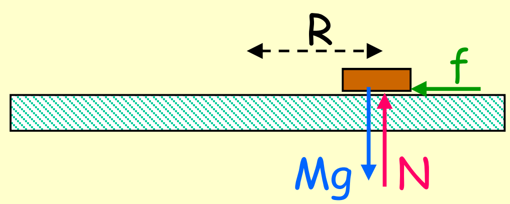
$$F_{net} = ma$$

$$a = \omega^2 R$$

$$F_{net} = m\omega^2 R$$

WHAT IS THIS FORCE ??

FRICTION !!



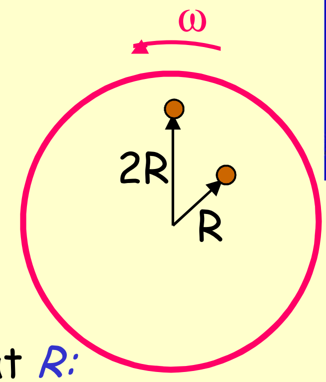
side view

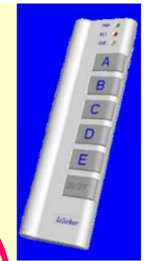
Here: $f = m\omega^2 R$

It must also be true that:

$$f \le \mu_s Mg$$

DEMO





BB

Friction force responsible for penny's acceleration
Friction force is proportional to the distance from the center

$$f = m\omega^2 R$$

As I increase the angular velocity, what will happen?

(A) Both pennies fly off at same time

(B) Penny at R flies off first

(C) Penny at 2R flies off first

at *R:*

$$v = \frac{2\pi R}{P} \qquad a = \omega^2 R$$

$$\omega \equiv \frac{v}{R} = \frac{2\pi}{P}$$

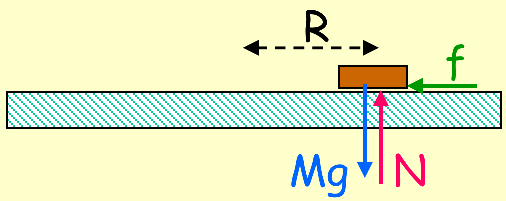
WHY !!

As ω increases, the frictional force must increase (to provide increased acceleration)

$$f = m\omega^2 R$$

There is, however, a maximum possible frictional force:

$$f_{\max} = \mu_S M g$$



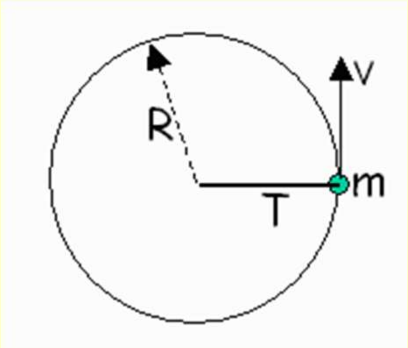
The force at 2R is always bigger than the force at R
The force at 2R will reach maximum before the force at R

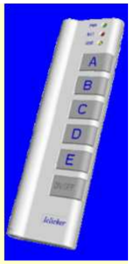
Preflight 5

Mass *m* is connected to a string and moves with speed *v* in uniform circular motion of radius *R* in horizontal plane. The tension in the string is *T*.
If we double the radius (*R′* = 2*R*), but keep the period of the motion the same, how is *T′* related to *T*?

(A) $T' = \frac{1}{4}\ T$ (B) $T' = 1/2\ T$ (C) $T' = T$

(D) $T' = 2\ T$ (E) $T' = 4\ T$





BB

KEY

$v = \frac{2\pi R}{P}$	➡	v doubles when R doubles
$a = \frac{v^2}{R}$	➡	a doubles when R doubles
$T = ma$	➡	T doubles when R doubles

You said:

- T=(MV^2)/R, so if you double the radius, the equation will be multiplied by 1/2.
- If you double the Radius you have to double the speed to keep the period the same. Since the Tension force in this case is mv^2/R, doubling the radius and velocity would result in a net change of 2 to the original Tension.
- to double the radius and keep the period the same, the ball will now travel twice as far in the same time interval. this will press the need for a greater velocity (v to 2v). in equations in relation to kinematics, the velocity is a squared term. thus, if he transition from v to 2v, our force to hold this will go from T to 4T (2 squared is four).