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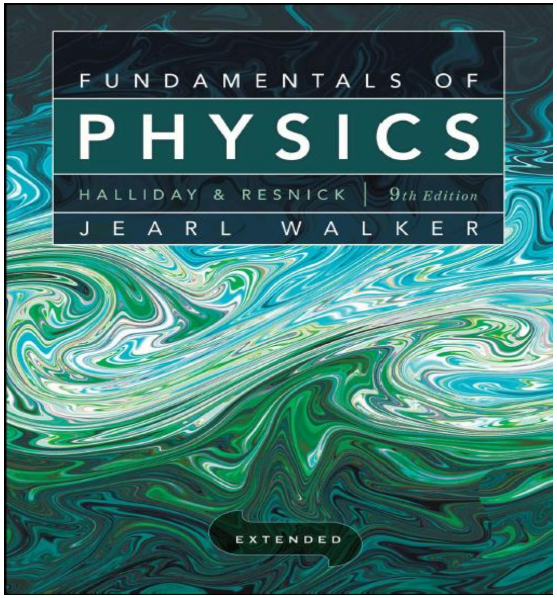
CHAPTER 6
FORCE AND MOTION II



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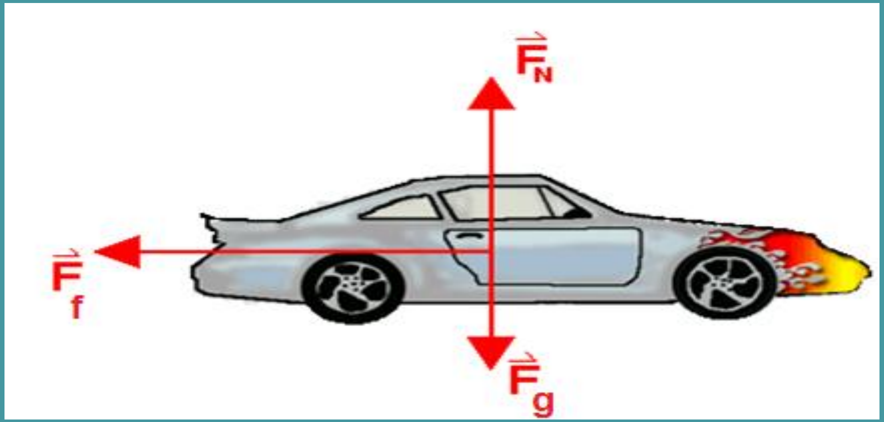
In this chapter we will cover the following topics:

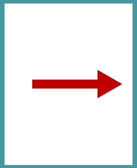
- ➔ Description of the **frictional force** between two objects.

- ➔ Properties of friction and **coefficients for static and kinetic friction**.

- ➔ Revisit **uniform circular motion** and using the concept of ***centripetal force.***

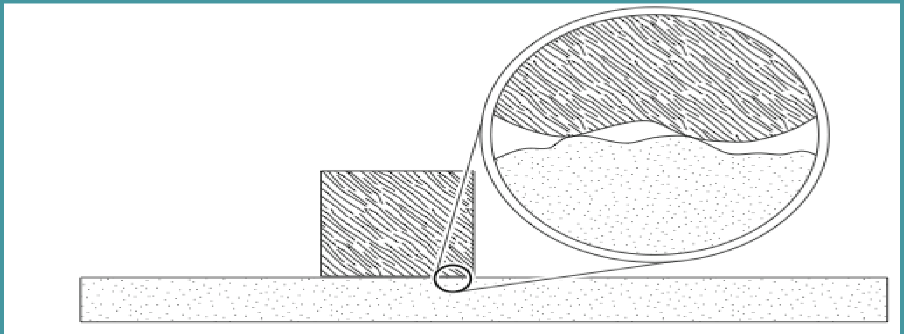
- ➔ ***Applications for Newton's second law*** to describe the motion.

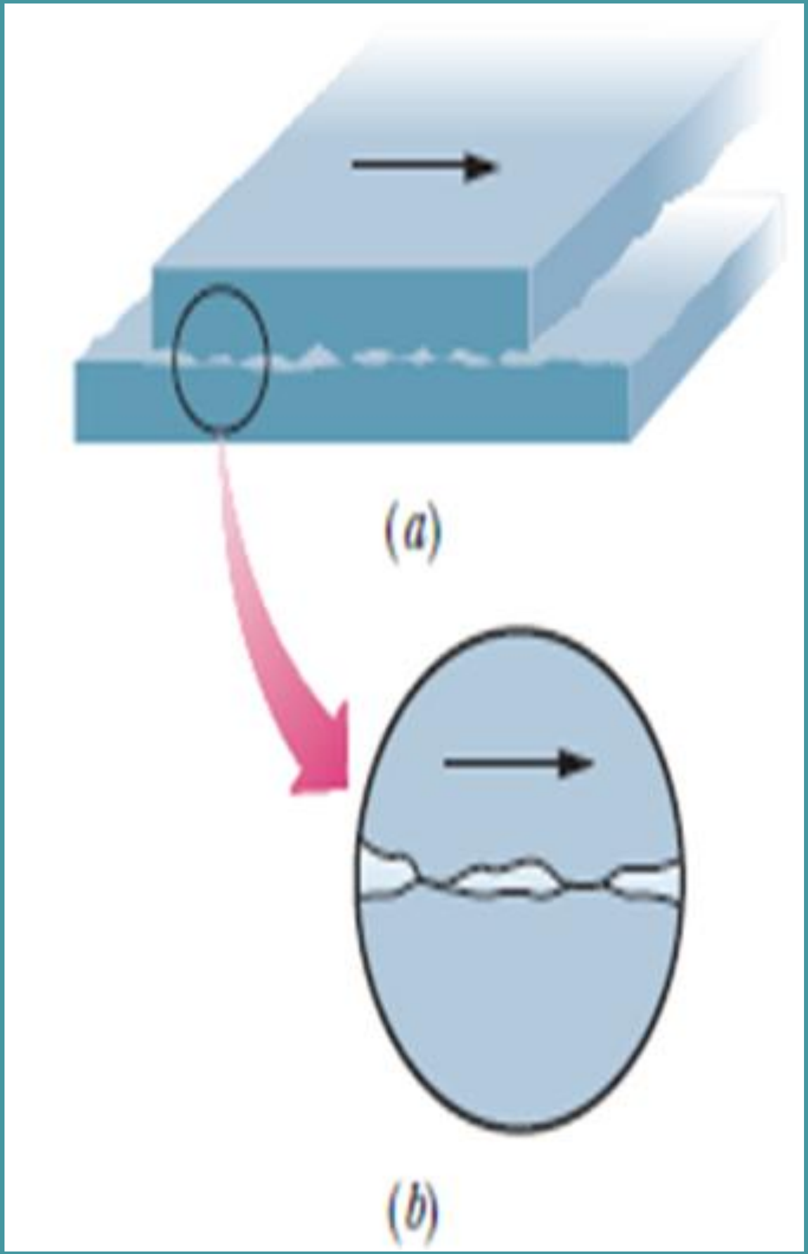




- ***Friction*** is the force that opposes the motion between two **surfaces** that **touch** eachother (*type of a contact force*).

- ***The amount of friction depends on:***
  - **Roughness** of the surfaces
  - **Normal force** pushing the surfaces **together**

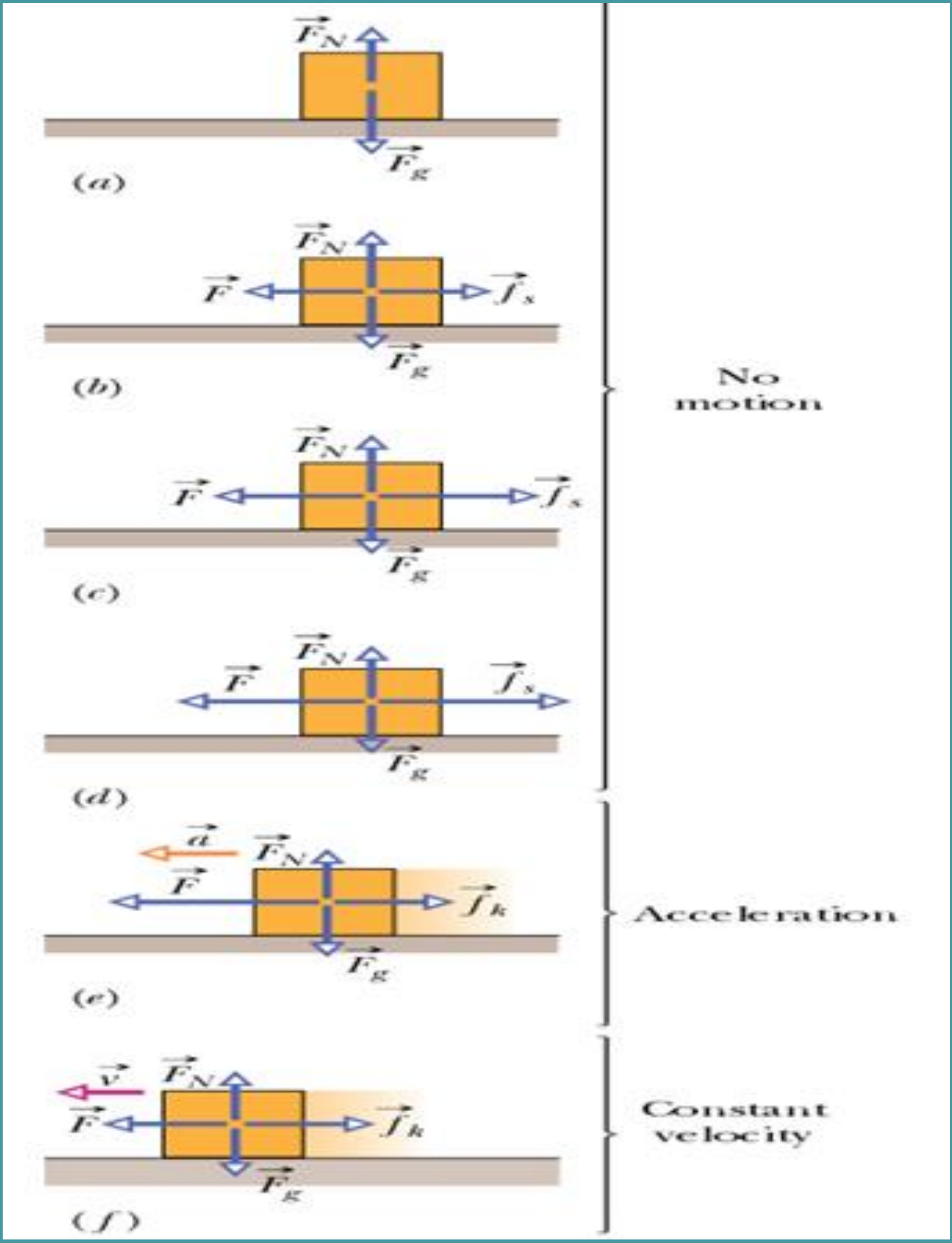


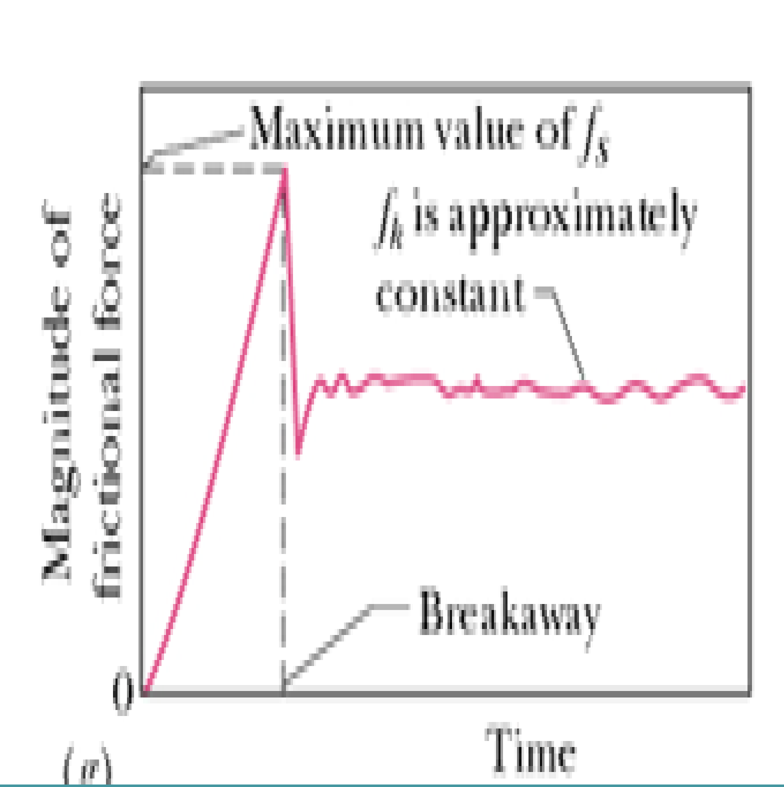


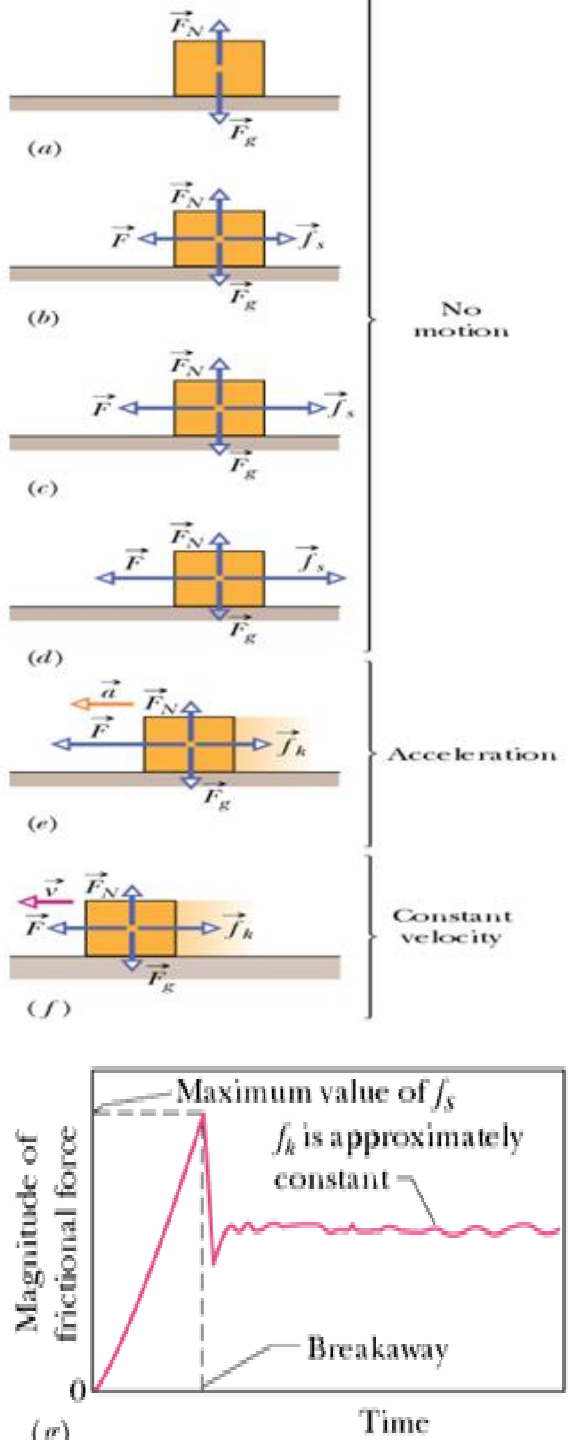
Frictional Force

The mechanism of sliding friction. (*a*) The upper surface is sliding to the right over the lower surface in this enlarged view. (*b*) A detail, showing two spots where cold-welding has occurred. Force is required to break the welds and maintain the motion.

Frictional Force







Friction: We can explore the basic properties of friction by analyzing the following experiment based on our every day experience. We have a heavy crate resting on the floor. We push the crate to the left (frame b) but the crate does not move. We push harder (frame c) and harder (frame d) and the crate still does not move. Finally we push with all our strength and the crate moves (frame e). The free body diagrams for frames a-e show the existence of a new force $\vec{f}_s$ which balances the force $\vec{F}$ with which we push the crate. This force is called the static frictional force. As we increase F , f_s also increases and the crate remains at rest. When F reaches a certain limit the crate "breaks away" and accelerates to the left. Once the crate starts moving the force opposing its motion is called the kinetic frictional force $\vec{f}_k$. $\boxed{f_k < f_s}$. Thus if we wish the crate to move with constant speed we must decrease F so that it balances f_k (frame f). In frame (g) we plot f versus time t

Kinetic Friction occurs when **force** is applied to an object and the object **moves**.

Eg: ***Sliding Friction:*** Pushing an object across a surface

Rolling Friction: Between wheels and a surface

Fluid Friction: Opposes the motion of objects traveling through a fluid (air or water)

Static Friction occurs when force **applied** to an object does **not** cause the object to **move**.

Static Frictional Force

Property 1. If the two surfaces do not move with respect to each other, then the static frictional force $\vec{f}_s$ balances the applied force $\vec{F}$.

Property 2. The magnitude f_s of the static friction is not constant but varies from 0 to a maximum value $\boxed{f_{s,\max} = \mu_s F_N}$ The constant μ_s is known as the coefficient of static friction. If F exceeds $f_{s,\max}$ the crate starts to slide

$$\boxed{0 < f_s \le \mu_s F_N}$$

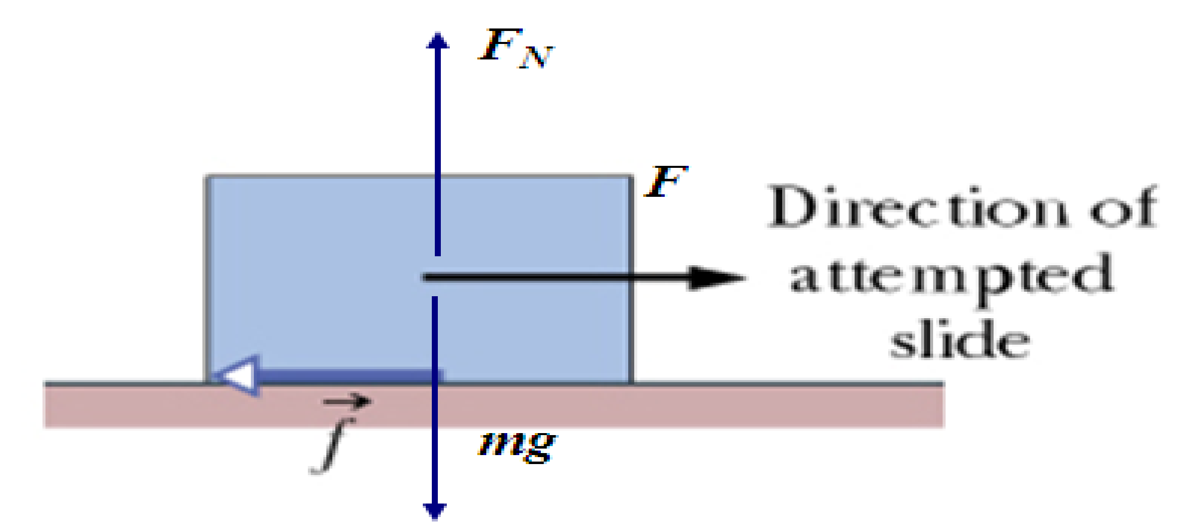
Kinetic Frictional Force

Property 3. Once the crate starts to move the frictional force $\vec{f}_k$ is known as kinetic friction. Its magnitude is constant and is given by the equation: $\boxed{f_k = \mu_k F_N}$

μ_k is known as the coefficient of kinetic friction. We note that: $f_k < f_{s,max}$

$$\boxed{f_k = \mu_k F_N}$$

Properties of friction: The frictional force is acting between two dry unlubricated surfaces in contact



$$\boxed{0 < f_s \le \mu_s F_N}$$

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

$$\boxed{f_k = \mu_k F_N}$$

Note 1: The static and kinetic friction acts parallel to the surfeces in contact The direction opposes the direction of motion (for kinetic friction) or of attempted motion (in the case of static friction)

Note 2: The coefficient μ_k does not depend on the speed of the sliding object

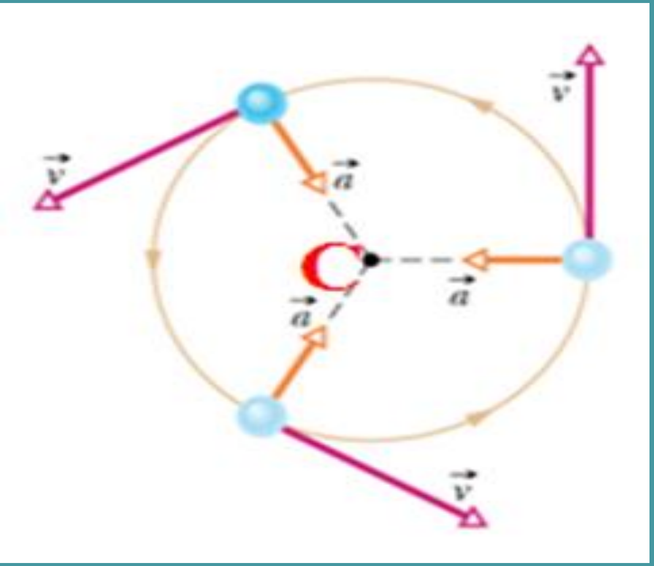
Coefficient of Friction

Material	μ_s static friction	μ_k kinetic friction
steel / steel	0.6	0.4
add grease to steel	0.1	0.05
metal / ice	0.022	0.02
brake lining / iron	0.4	0.3
tire / dry pavement	0.9	0.8
tire / wet pavement	0.8	0.7

Uniform Circular Motion

From Chapter 4 we know that *an object that moves on a circular path of radius r with constant speed* ***v*** *has an acceleration* ***a***.

The direction of the ***centripetal acceleration*** vector always points towards the center of rotation C. Its magnitude is constant and is given by the equation: $\boxed{a = \dfrac{v^2}{r}}$



$$\boxed{a = \frac{v^2}{r}}$$

centripetal acceleration

CENTRIPETAL FORCE

If we apply Newton's law to analyze uniform circular motion we conclude that ***net force in the direction that points towards C*** must have magnitude:

F = m.a

$$\boxed{a = \frac{v^2}{r}}$$

$$\boxed{F = \frac{mv^2}{r}}$$

This force is known as **"centripetal force".**

Centripetal force is **not** a new kind of force. It is simply the **net force** that points from the rotating body to the rotation center.

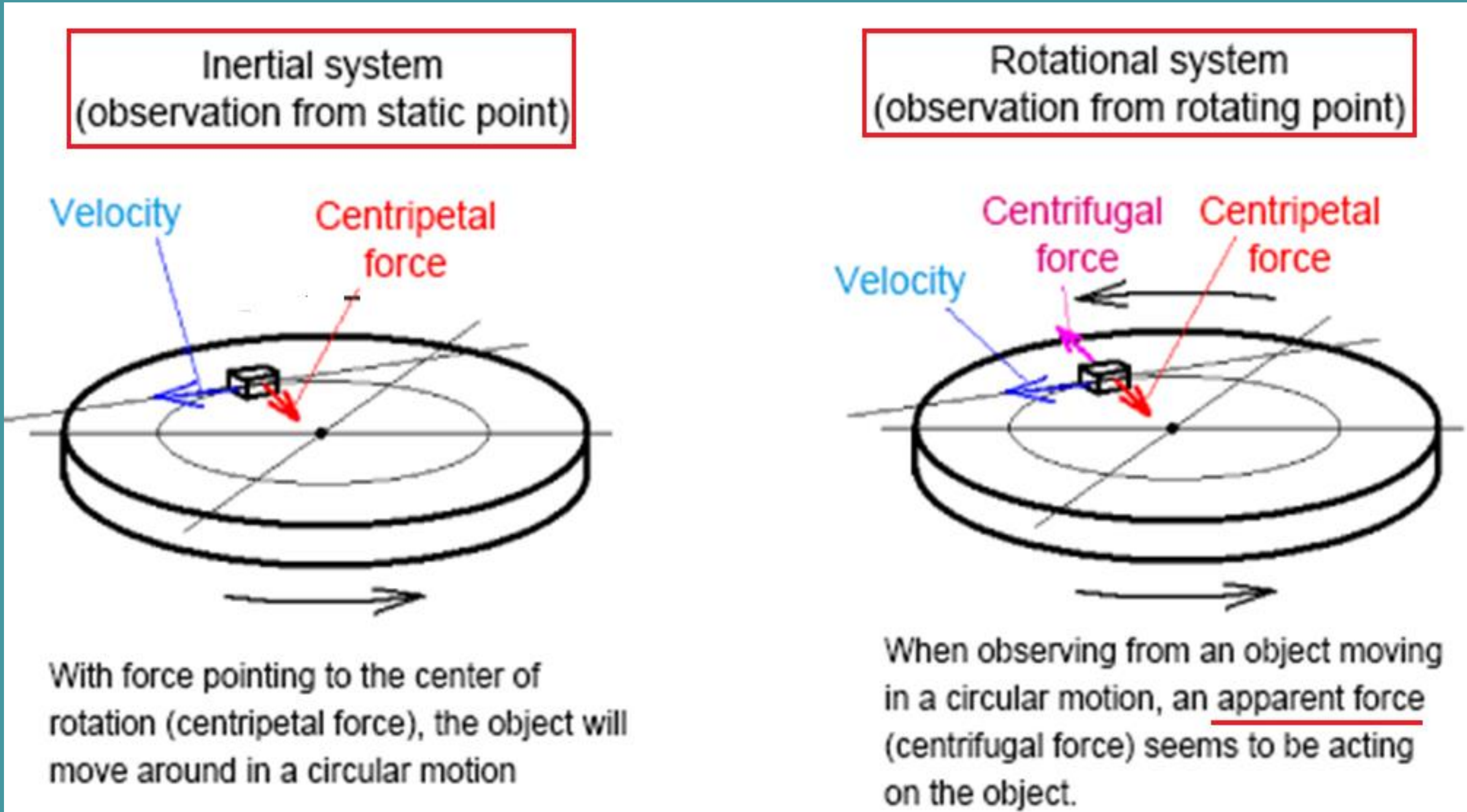
Depending on the situation the centripetal force can be **friction**, the **normal force** or **gravity**.

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

$$F = \frac{mv^2}{r}$$

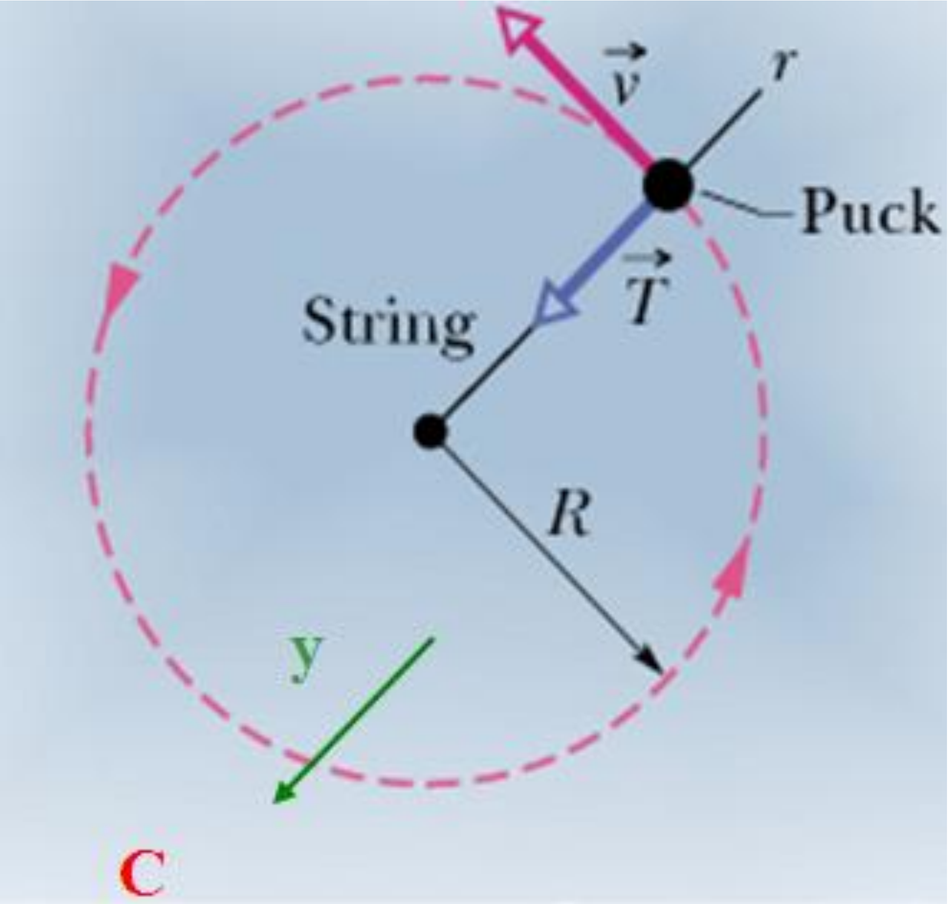
Centripetal forces keep these children moving in a circular path.

- ***Centripetal acceleration needs centripetal force***
  - Force is directed toward the circle’s center
  - Any centrally directed force is a centripetal force
- ***Centrifugal force???***
  - Acceleration is inward (toward center)
  - Centrifugal force is just an experience of inertia, not a real force!



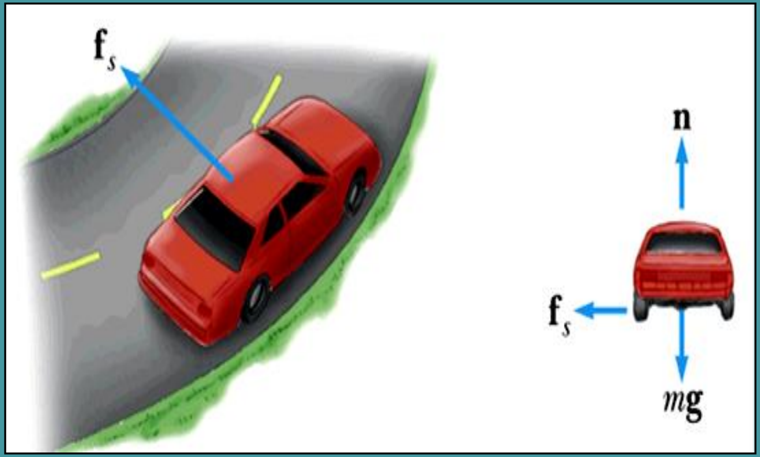
There is <u>no</u> centrifugal force. The car and the person only receive centripetal forces that create an acceleration pointing toward the center of rotation, so they follow a circular orbit.

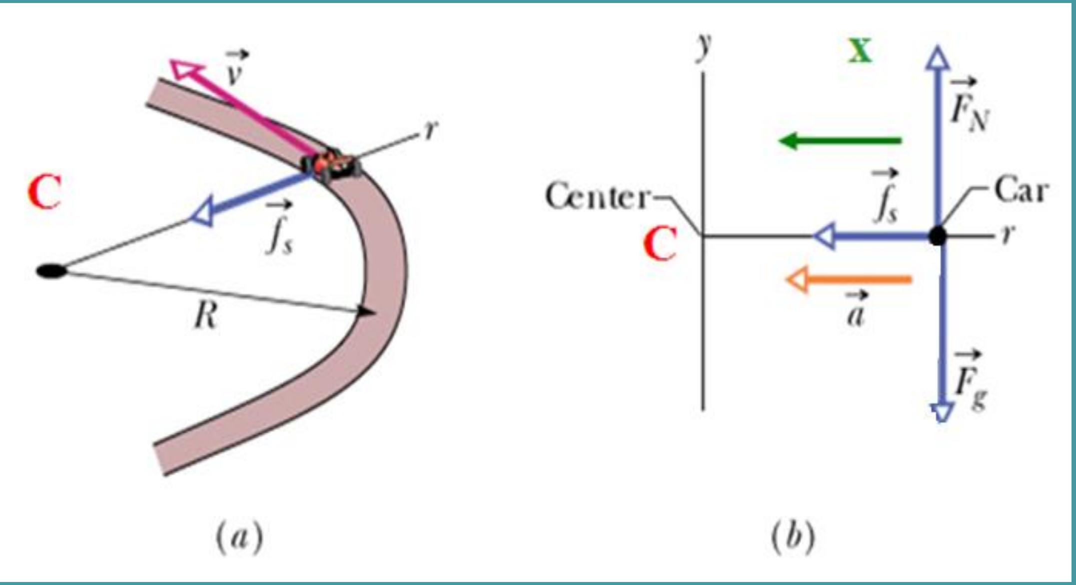
A centripetal force accelerates a body by changing the direction of the body's velocity without changing the body's speed.



$$F_{ynet} = T = \frac{mv^2}{r}$$

A race car of mass m travels on a flat circular race track of radius R with speed v. Because of the shape of the car the passing air exerts a downward force F_L on the car

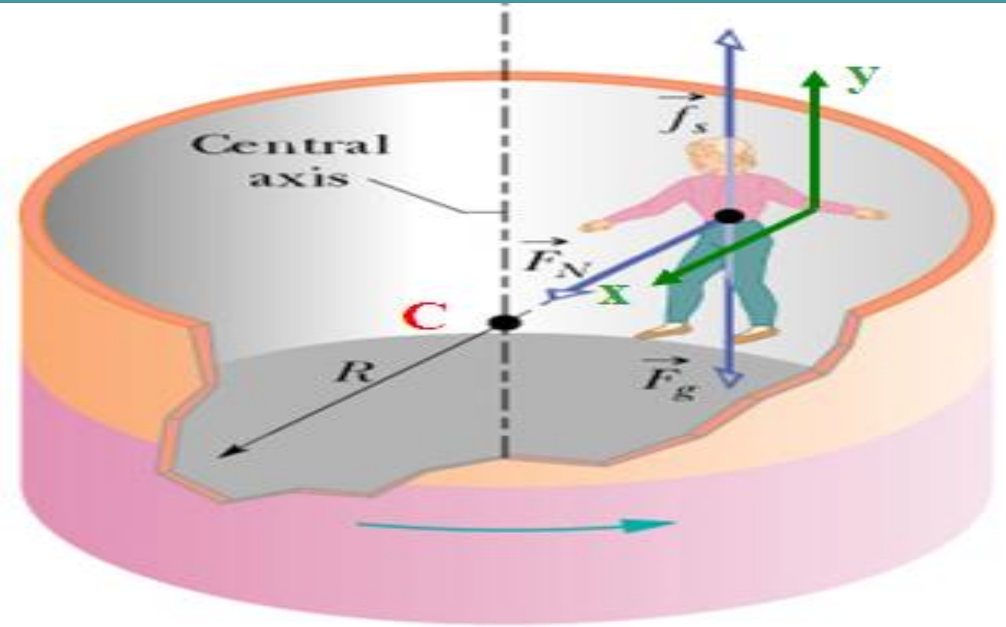




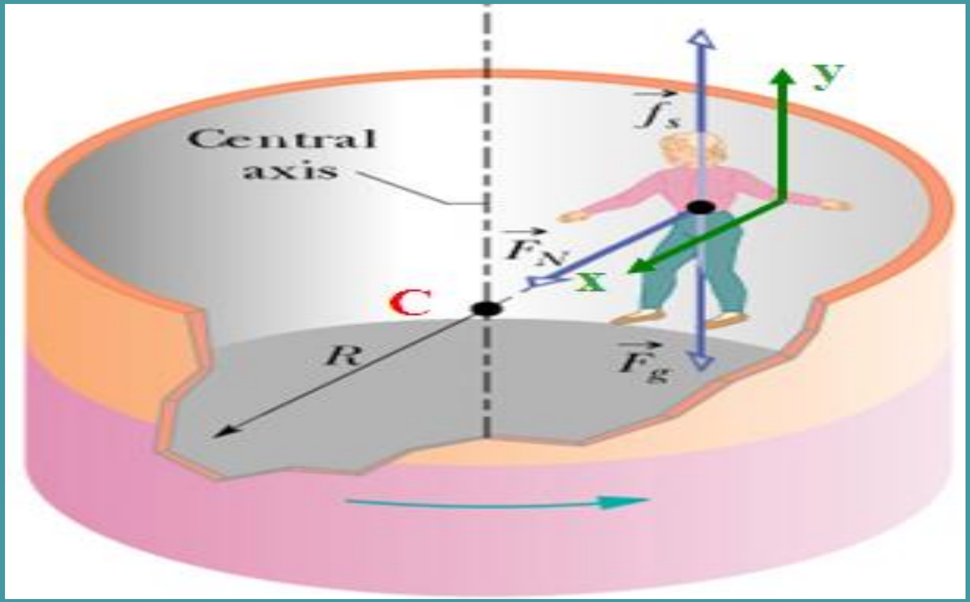
If we draw the free body diagram for the car we see that the net force along the x-axis is the static friction f_s. The frictional force f_s is the centripetal force.

$$F_{xnet} = f_s = \frac{mv^2}{R}$$

<u>Sample Problem</u>: ***<u>The Rotor</u>*** is a large hollow cylinder of radius *R* that is rotated rapidly around its central axis with a speed *v*. A rider of mass *m* stands on the Rotor floor with her back against the Rotor wall. Cylinder and rider begin to turn. When the speed *v* reaches some predetermined value, the Rotor floor abruptly falls away. *<u>The rider does not fall but instead remains pinned against the Rotor wall.</u>*



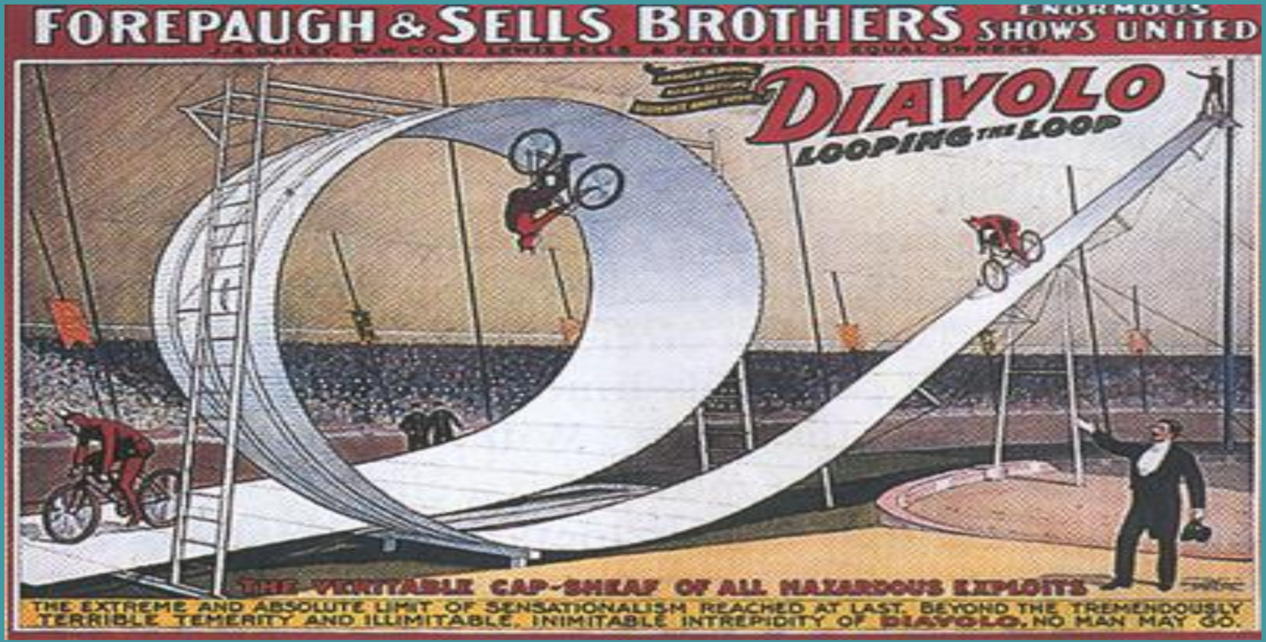
We draw *a free body diagram* for the rider using the axes shown in the figure. The normal reaction ***<u>F_N</u>*** **<u>is the centripetal force</u>**.

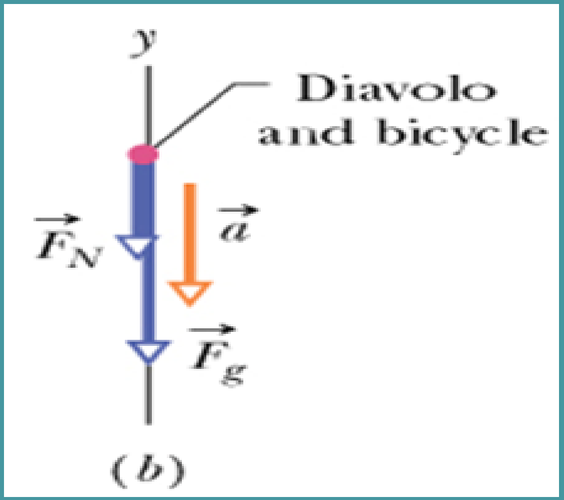


$$\boxed{F_{x,net} = F_N = ma = \frac{mv^2}{R}} \text{ (eqs.1)} \quad ,$$

$$\boxed{F_{y,net} = f_s - mg = 0} \ , \quad f_s = \mu_s F_N \rightarrow mg = \mu_s F_N \text{ (eqs.2)}$$

If we combine eqs.1 and eqs.2 we get: $mg = \mu_s \dfrac{mv^2}{R} \rightarrow v^2 = \dfrac{Rg}{\mu_s} \rightarrow \boxed{v_{min} = \sqrt{\dfrac{Rg}{\mu_s}}}$

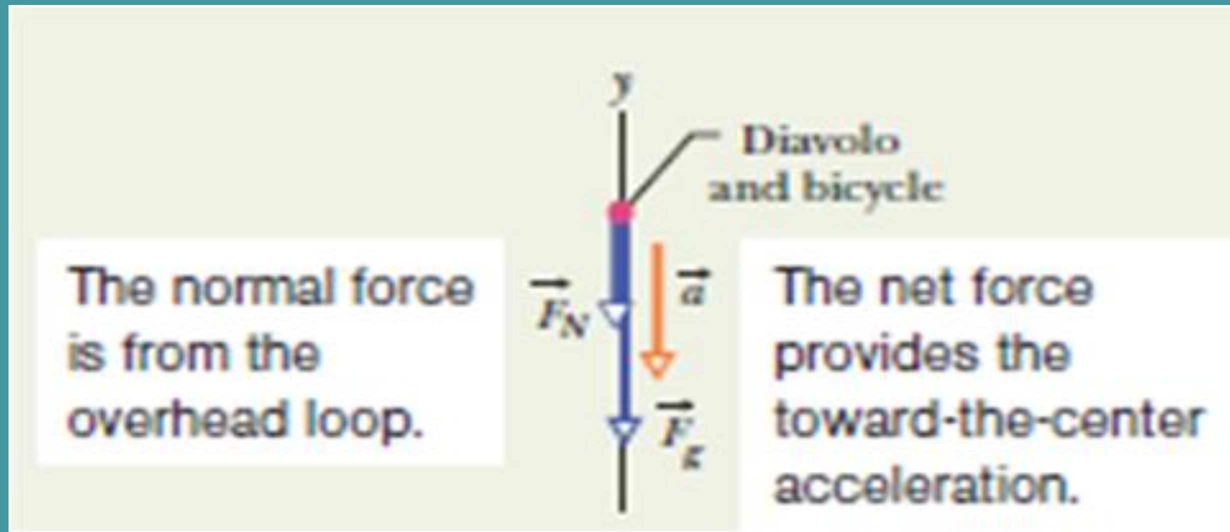




Sample Problem: In a 1901 it is introduced the stunt of riding a bicycle in a looping-the-loop by Diavolo. The loop is a circle of radius R. *What is the minimum speed v of Diavolo should have at the top of the loop and not fall?*

Two forces are acting along the y-axis: Gravitational force $\boldsymbol{F_g}$ and the normal reaction $\boldsymbol{F_N}$ from the loop. When Diavolo has the minimum speed v, he has just lost contact with the loop and thus $\boldsymbol{F_N = 0}$. The only force acting on Diavolo is F_g.

The gravitational force F_g is the centripetal force.



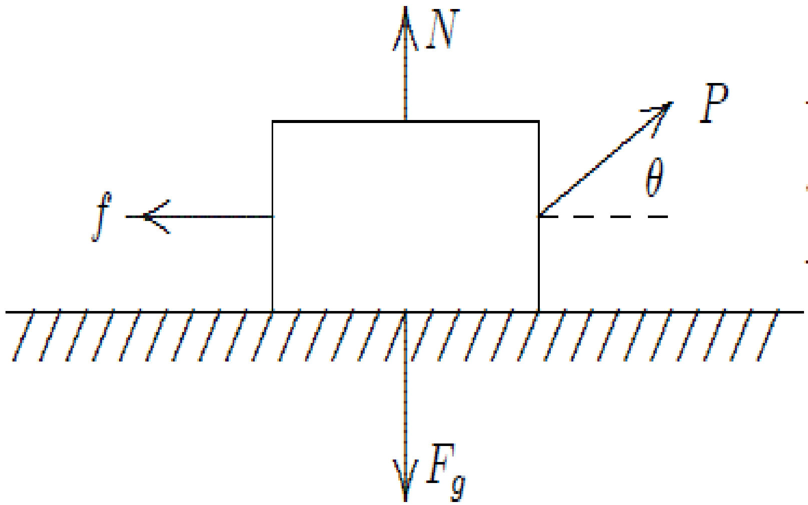
$$-F_N - F_g = m(-a)$$

$$-F_N - mg = m\left(-\frac{v^2}{R}\right).$$

$(F_N = 0)$

$$F_{ynet} = mg = \frac{mv_{\min}^2}{R} \rightarrow v_{\min} = \sqrt{Rg}$$

15. A boy pulls a wooden box along a rough horizontal floor at constant speed by means of a force $\vec{P}$ as shown. In the diagram f is the magnitude of the force of friction, N is the magnitude of the normal force, and F_g is the magnitude of the force of gravity. Which of the following must be true?



$\vec{F}_g$: force of gravity
$\vec{f}$: frictional force
$\vec{N}$: normal force

A. $P = f$ and $N = F_g$
B. $P = f$ and $N > F_g$
C. $P > f$ and $N < F_g$
D. $P > f$ and $N = F_g$
E. none of these

ans: C

13. A car is traveling at 15 m/s on a horizontal road. The brakes are applied and the car skids to a stop in 4.0 s. The coefficient of kinetic friction between the tires and road is:

A. 0.38

B. 0.69

C. 0.76

D. 0.92

E. 1.11

ans: A

43. A 1000-kg airplane moves in straight flight at constant speed. The force of air friction is 1800 N. The net force on the plane is:

A. zero

B. 11800 N

C. 1800 N

D. 9800 N

E. none of these

ans: A