Phys101 Lecture 6, 7, 8

Friction; Circular Motion

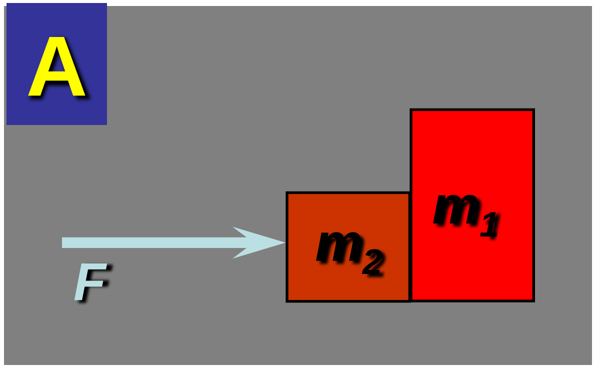
Key points:

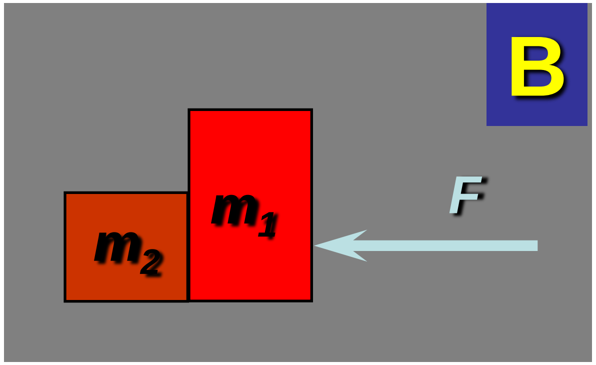
- **Kinetic friction and static friction**
- **Uniform Circular Motion - dynamics**

Ref: 5-1,2,3,4.

i-clicker question 6-1

If you push with force *F* on either the heavy box (m_1) or the light box (m_2), in which of the two cases is the contact force between the two boxes larger? Ignore friction.





1) **case A** ?
2) **case B**
3) **same in both cases**

Acceleration is the same for both cases $a=F/(m_1+m_2)$. Thus $m_1a > m_2a$

Kinetic Friction

Sliding friction is called **kinetic** friction. It's against the relative sliding motion.

$$F_{fr} = \mu_k F_N \,.$$

Here, F_N is the **normal** force, and μ_k is the **coefficient of kinetic friction**, which is different for each pair of surfaces.

Static Friction

Static friction applies when two surfaces are at rest with respect to each other. It's against the tendency of relative mition.

The static frictional force is as big as it needs to be to prevent slipping, up to a maximum value.

$$F_{\mathrm{fr}} \leq \mu_{s} F_{\mathrm{N}} .$$

Usually the coefficient of static friction is greater than the coefficient of kinetic friction.

Static and Kinetic Frictions

Note that, in general, $\mu_s > \mu_k$.

TABLE 5–1 Coefficients of Friction†

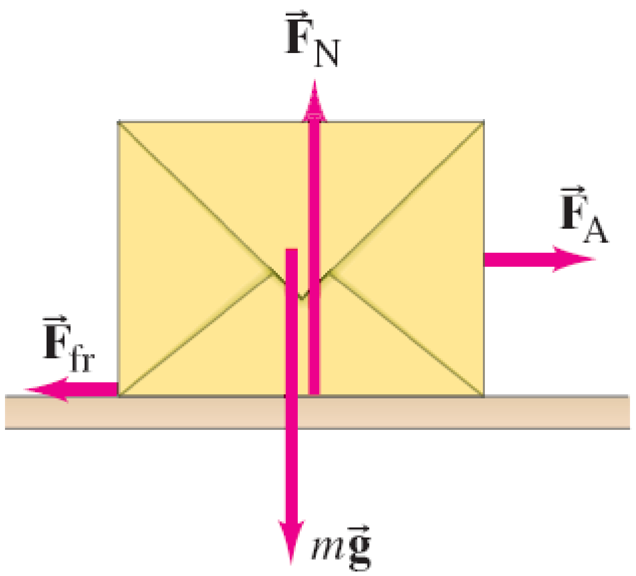
Surfaces	Coefficient of Static Friction, μ_s	Coefficient of Kinetic Friction, μ_k
Wood on wood	0.4	0.2
Ice on ice	0.1	0.03
Metal on metal (lubricated)	0.15	0.07
Steel on steel (unlubricated)	0.7	0.6
Rubber on dry concrete	1.0	0.8
Rubber on wet concrete	0.7	0.5
Rubber on other solid surfaces	1–4	1
Teflon® on Teflon in air	0.04	0.04
Teflon on steel in air	0.04	0.04
Lubricated ball bearings	<0.01	<0.01
Synovial joints (in human limbs)	0.01	0.01

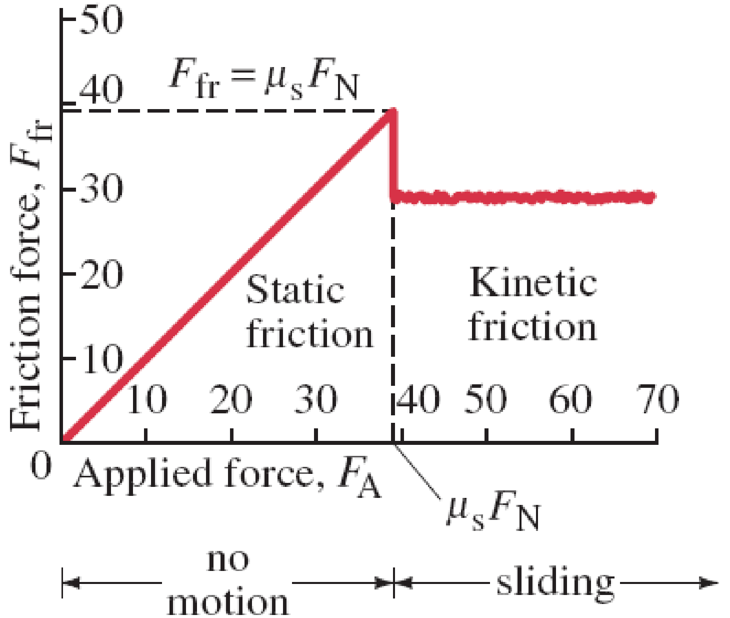
†Values are approximate and intended only as a guide.

Example 5-1: Friction: static and kinetic.

Our 10.0-kg mystery box rests on a horizontal floor. The coefficient of static friction is 0.40 and the coefficient of kinetic friction is 0.30. Determine the force of friction acting on the box if a horizontal external applied force is exerted on it of magnitude:

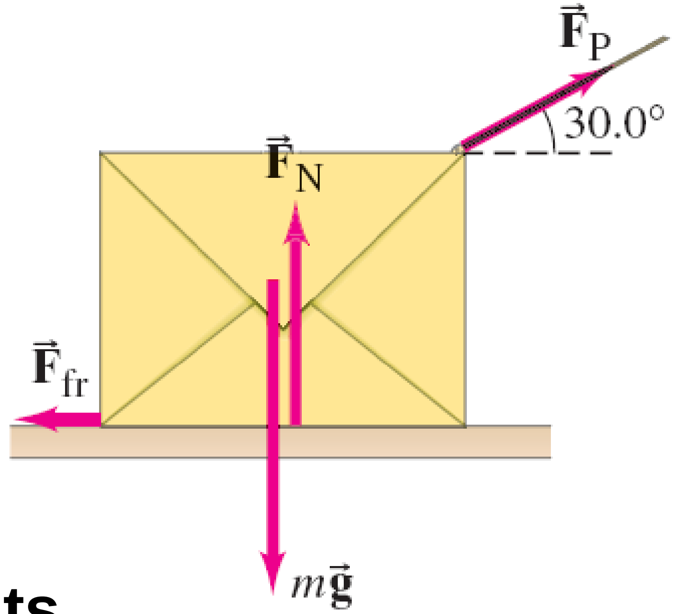
(a) 0, (b) 10 N, (c) 20 N, (d) 38 N, and (e) 40 N.





Example 5-3: Pulling against friction

A 10.0-kg box is pulled along a horizontal surface by a force of 40.0 N applied at a 30.0° angle above horizontal. The coefficient of kinetic friction is 0.30. Calculate the acceleration.



FBD and Coordinates

Newton's law in x- and y- components

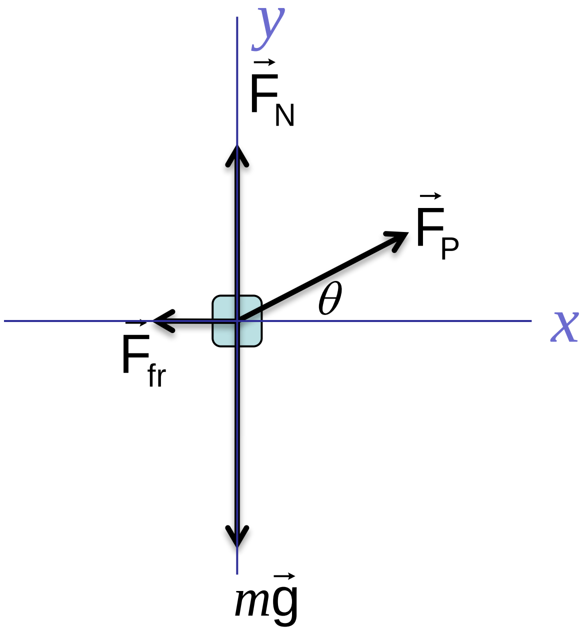
$$F_P \cos\theta - \mu_k F_N = ma_x \qquad (F_{fr} = \mu F_N)$$

$$F_N + F_P \sin\theta - mg = 0$$

Two unknowns, a_x and F_N. We can solve.

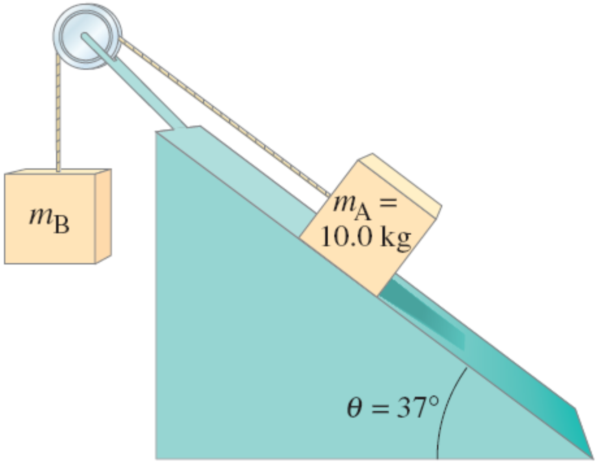
$$F_N = mg - F_P \sin\theta = 78N$$

$$a_x = \frac{F_P \cos\theta - \mu_k F_N}{m} = 1.1 m/s^2$$



Example 5-7: A ramp, a pulley, and two boxes.

Box A, of mass 10.0 kg, rests on a surface inclined at 37° to the horizontal. It is connected by a lightweight cord, which passes over a massless and frictionless pulley, to a second box B, which hangs freely as shown. (a) If the coefficient of static friction is 0.40, determine what range of values for mass B will keep the system at rest. (b) If the coefficient of kinetic friction is 0.30, and m_B = 10.0 kg, determine the acceleration of the system.



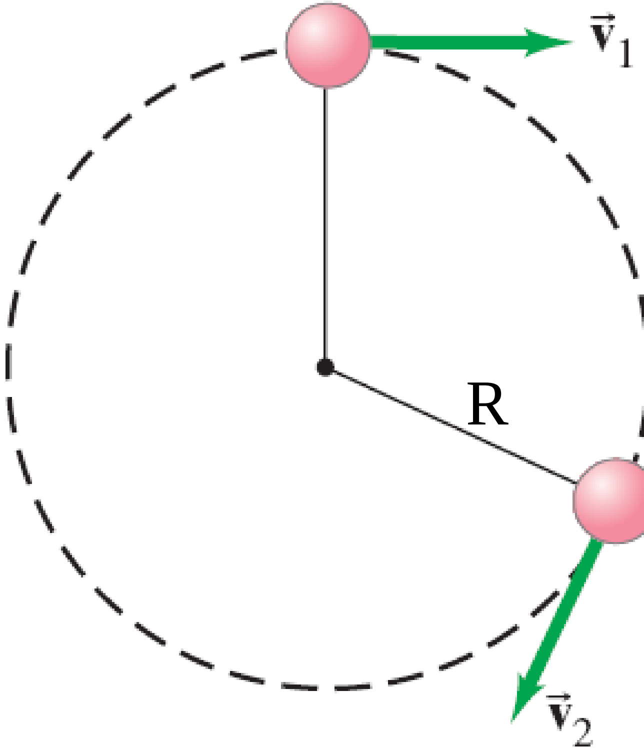
Uniform Circular Motion—Kinematics

Uniform circular motion: motion in a circle of constant radius at constant speed

Instantaneous velocity is always tangent to the circle.

The magnitude of the velocity is constant:

$$v_1 = v_2 = v$$

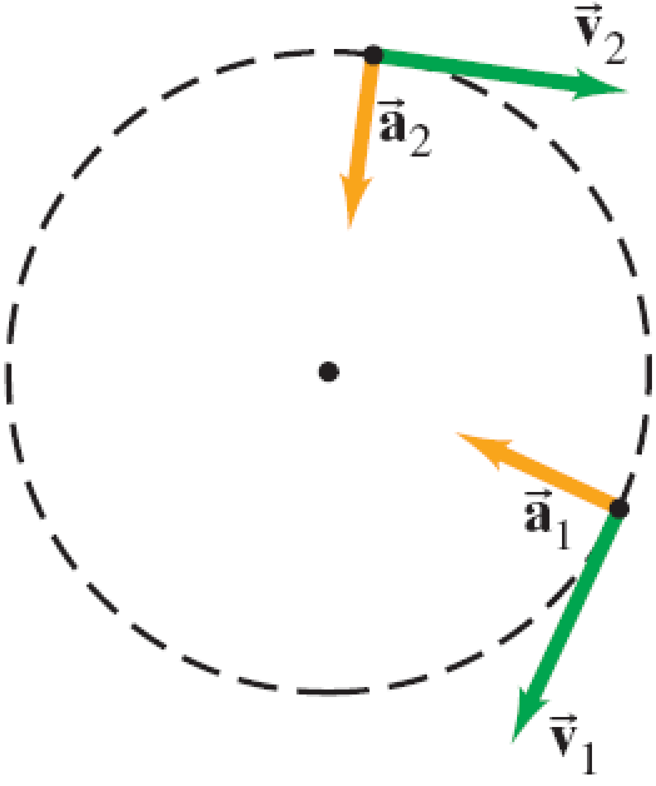


Centripetal acceleration

The acceleration, called the centripetal acceleration, points toward the center of the circle.

The magnitude of centripetal acceleration is:

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

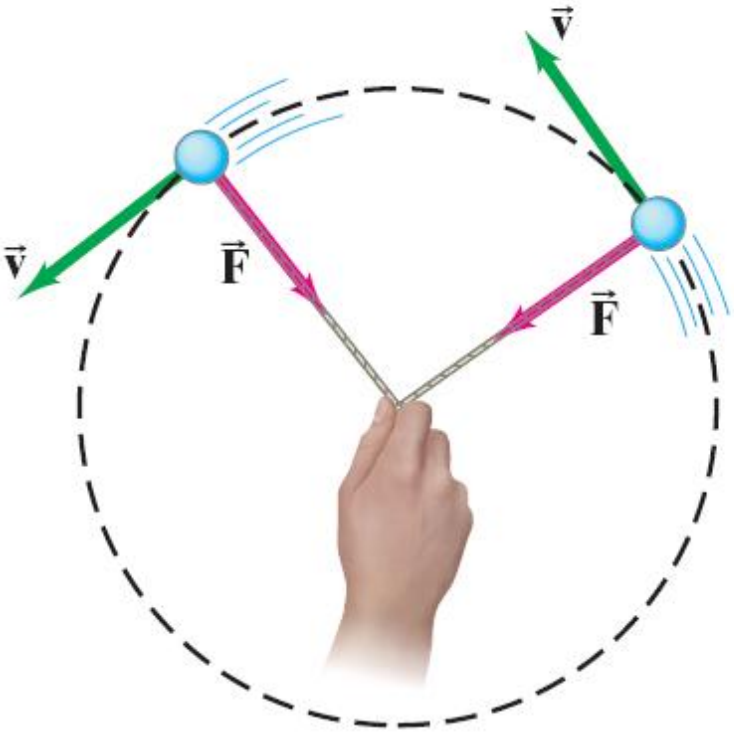


Dynamics of Uniform Circular Motion

For an object to be in uniform circular motion, Newton's 2nd law requires a net force acting on it. This net force is called centripetal force:

$$\Sigma F_R = m a_R = m \frac{v^2}{r}.$$

Physically, the centripetal force can be the tension in a string, the gravity on a satellite, the normal force of a ring, etc.



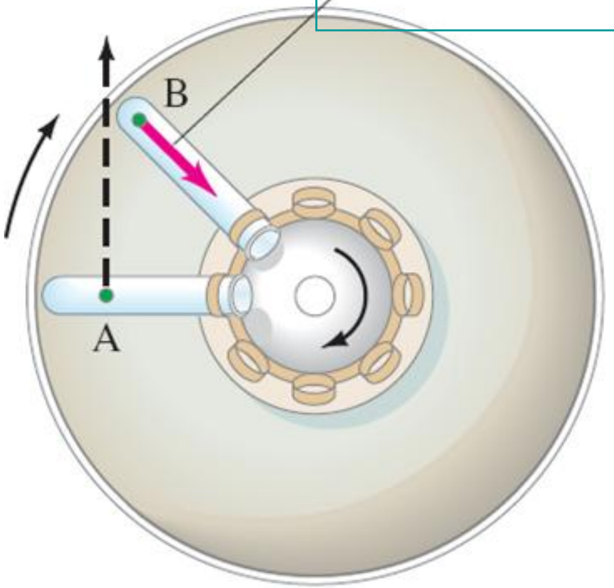
Note: Don't count the centripetal force as an additional force in the free-body-diagram! It refers to the required net force for circular motion.

Centrifuge

A centrifuge works by spinning very fast. A small object in the tube requires a large centripetal force. When the liquid can't provide such a large force, the object will move (sink) to the end of the tube.

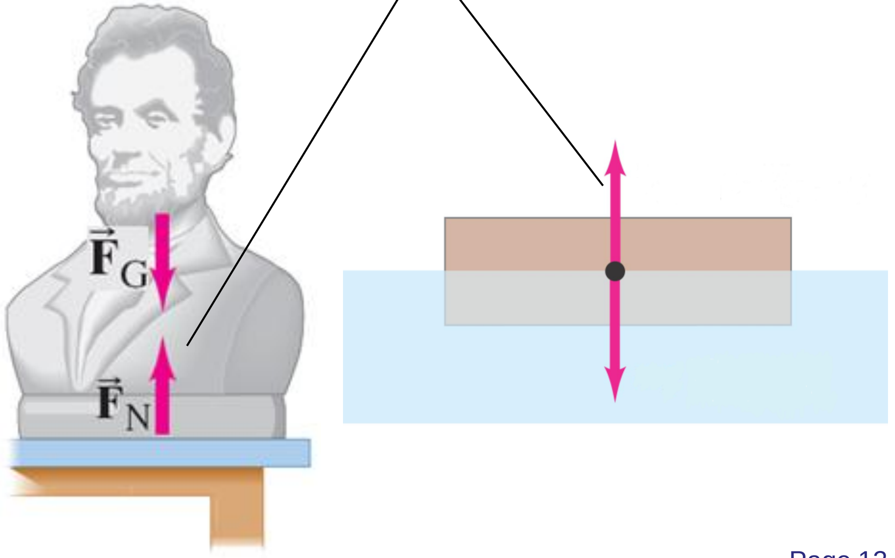
Force reuired for circular motion:

$$F_R = ma_R = \frac{mv^2}{R}$$



Force reuired for staying in position:

$$F_N = mg$$

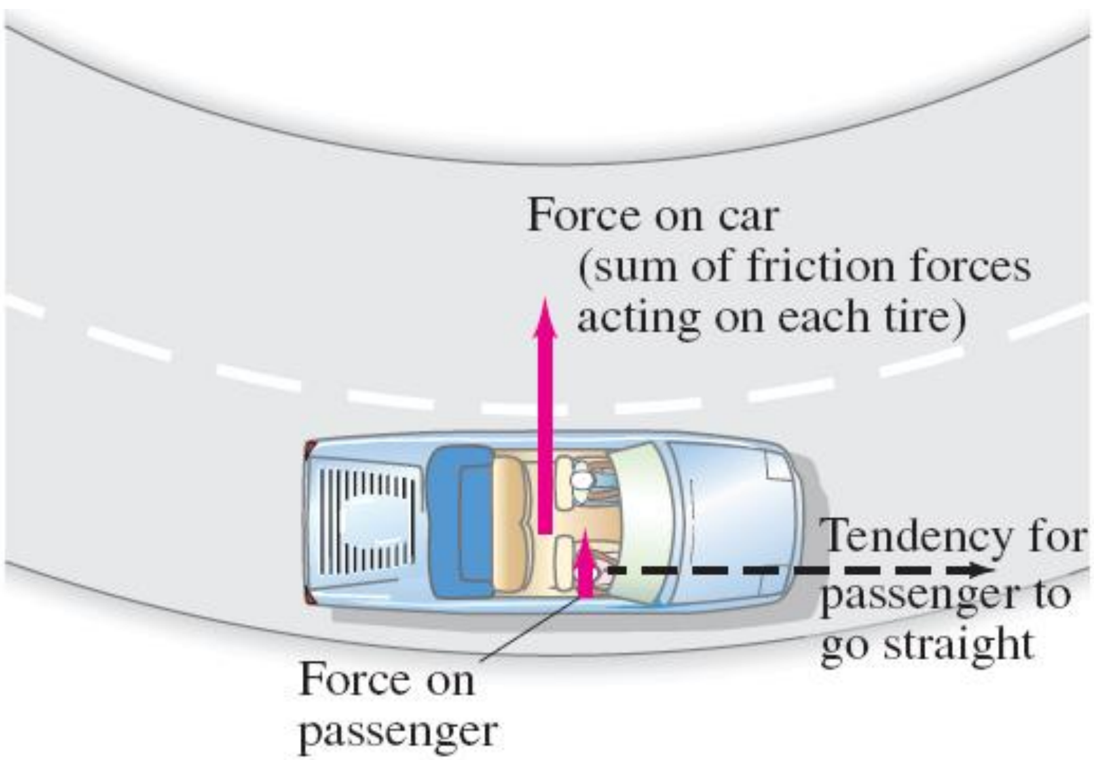


Example 5-10: Ultracentrifuge.

The rotor of an ultracentrifuge rotates at 50,000 rpm (revolutions per minute). A particle at the top of a test tube is 6.00 cm from the rotation axis. Calculate its centripetal acceleration, in "*g*'s."

Highway Curves: Banked and Unbanked

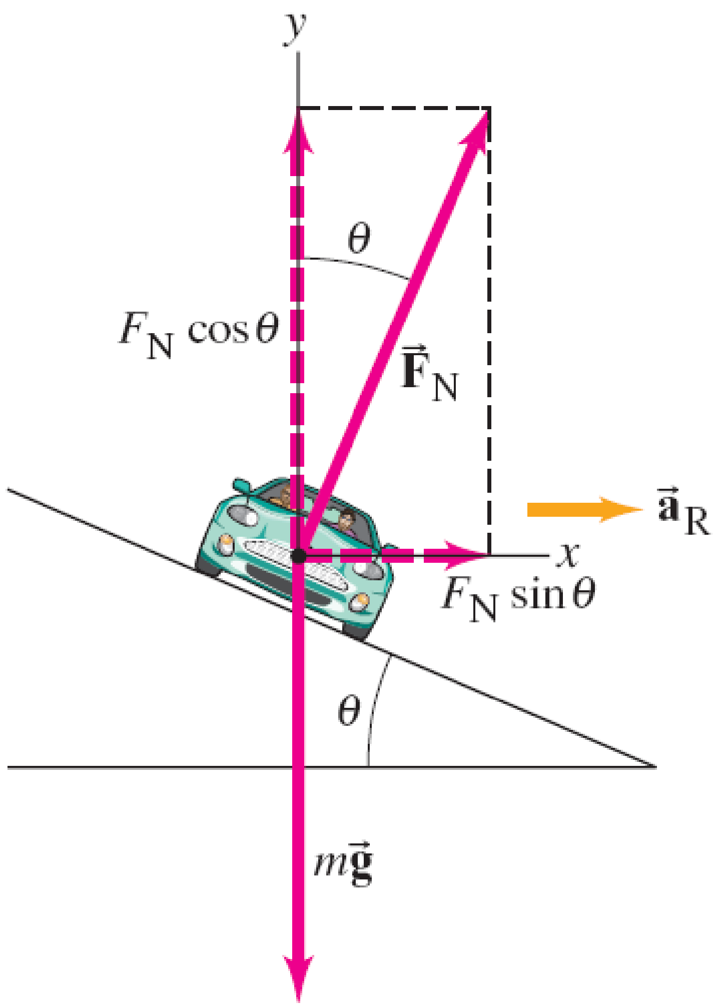
When a car goes around a **curve**, there must be a net force toward the center of the circle of which the curve is an arc. If the road is flat, that force is supplied by **friction**.



Highway Curves: Banked and Unbanked

If the frictional force is insufficient, the car will tend to move more nearly in a straight line, as the skid marks show.

Highway Curves: Banked and Unbanked



Banking the curve can help keep cars from skidding. When the curve is banked, the centripetal force can be supplied by the horizontal component of the **normal** force. In fact, for every banked curve, there is one speed at which the entire centripetal force is supplied by the horizontal component of the **normal** force, and no friction is required.

Example 5-15: Banking angle.

(a) For a car traveling with speed v around a curve of radius r, determine a formula for the angle at which a road should be banked so that no friction is required. (b) What is this angle for an expressway off-ramp curve of radius 50 m at a design speed of 50 km/h?

Drag: a Velocity-Dependent Force

When an object moves through a fluid, it experiences a drag force that depends on the velocity of the object. The faster the speed, the larger the drag force.

When there is no turbulence (slow), the drag force is approximately proportional to the velocity; when there is turbulence (usually fast), the drag force is approximately proportional to the square of the velocity.

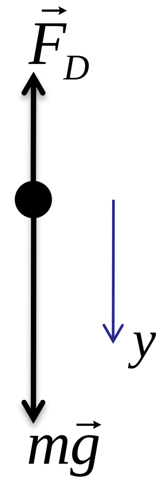
No turbulence: $F_D = b_1 v$

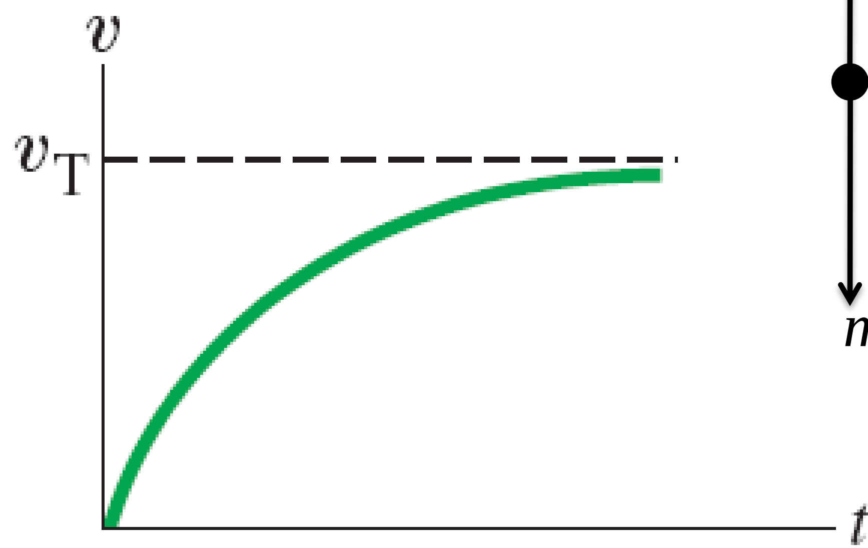
With turbulence: $F_D = b_2 v^2$

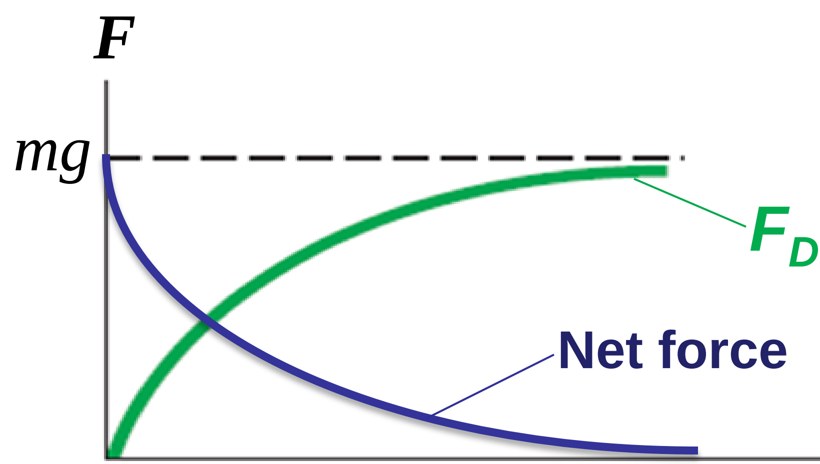
b_1 and b_2 depend on the size and shape of the object as well as the viscosity of the fluid.

Terminal Velocity

When an object falls, the drag force increases with increasing speed until it equals to the gravitational force. Then the net force on the object becomes zero and the object will fall with constant velocity, called the terminal velocity.







Net force: $\vec{F} = \vec{F}_D + m\vec{g}$

magnitude: $F = mg - F_D$

Summary of Chapter 5

- Kinetic friction: $F_{\mathrm{fr}} = \mu_{\mathrm{k}} F_{\mathrm{N}}.$

- Static friction: $F_{\mathrm{fr}} \leq \mu_{\mathrm{s}} F_{\mathrm{N}}.$
- An object moving in a circle at constant speed is in uniform circular motion.
- It has a centripetal acceleration of $a_{\mathrm{R}} = \frac{v^2}{r}.$
- There is a centripetal force given by

$$\Sigma F_{\mathrm{R}} = m a_{\mathrm{R}} = m \frac{v^2}{r}.$$