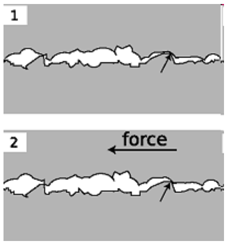
## PHY131H1F - Class 11

Today:

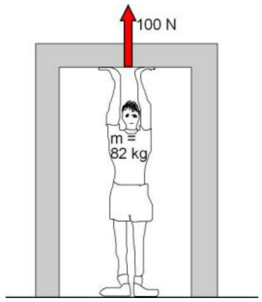
- Friction, Drag
- Rolling without slipping
- Examples of Newton's Second Law




Microscopic bumps and holes crash into each other, causing a frictional force.

Challenge Question

Bob stands under a low concrete arch, and presses upwards on it with a force of 100 N. Bob's mass is 82 kg. He is in equilibrium. What is the total **normal force** of the ground on Bob? (Note that 82 × 9.8 = 800.)




A. 800 N, upward
B. 800 N, downward
C. 900 N, upward
D. 700 N, upward
E. 900 N, downward

Last day I asked at the end of class:

Does friction always slow things down?

ANSWER: No!

Kinetic friction does oppose the relative motion of two surfaces. If the one of these surfaces is stationary, then it will tend to slow down the moving object.

Can friction ever speed things up?

ANSWER: Yes!

Static friction between your feet and the floor is what allows you to walk! Walking certainly involves speeding up, and this would not be possible if the floor were frictionless or covered in marbles!

How's that *reading* going?

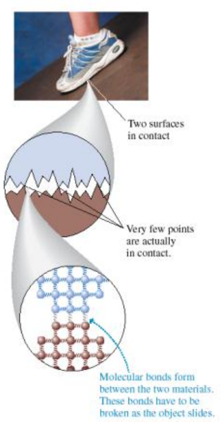
Which of the following types of friction is NOT part of your chapter 6 reading?

A. Drag
B. Internal friction
C. Kinetic friction
D. Rolling friction
E. Static friction

Why does friction exist?

Because at the microscopic level, ***nothing is smooth!***

FIGURE 6.19 An atomic-level view of friction.




## "Kinetic Friction" $\vec{f}_k$

- Also called "sliding friction"
- When two flat surfaces are in contact and sliding relative to one another, heat is created, so it slows down the motion (kinetic energy is being converted to thermal energy).
- Many experiments have shown the following approximate relation usually holds for the magnitude of $f_k$:

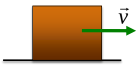

$$f_k = \mu_k n$$

where $n$ is the magnitude of the normal force.

The direction of $\vec{f}_k$ is opposite the direction of motion.

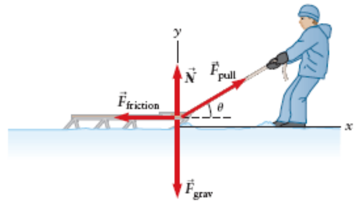
A wooden block weighs 100 N, and is sliding to the right on a smooth horizontal concrete surface at a speed of 5 m/s. The coefficient of kinetic friction between wood and concrete is 0.1.

A 5 N horizontal force is applied to the block, pushing toward the right. What is the force of kinetic friction of the concrete on the block?




A. 100 N, to the left
B. 10 N, to the left
C. 5 N, to the left
D. 10 N, to the right
E. 5 N, to the right

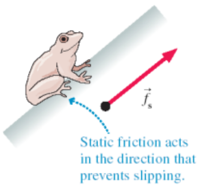
Example




- A sled of mass 5.0 kg is pulled at a constant velocity by a rope which makes an angle of 20.0° above the horizontal. The coefficient of kinetic friction between the sled and the snow is 0.030. What is the tension in the rope? ($F_{pull}$ in the diagram)

## "Static Friction" $\vec{f}_s$

- When two flat surfaces are in contact but are not moving relative to one another, they tend to resist slipping. They have "locked" together. This creates a force perpendicular to the normal force, called static friction.




There is no general equation for $f_s$.

The direction of $f_s$ is whatever is required to prevent slipping.

## Maximum Static Friction

There's a limit to how big $f_s$ can get. If you push hard enough, the object slips and starts to move. In other words, the static friction force has a *maximum* possible size $f_{s\,max}$.

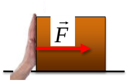
- The two surfaces don't slip against each other as long as $f_s \leq f_{s\,max}$.
- A static friction force $f_s > f_{s\,max}$ is not physically possible. Many experiments have shown the following approximate relation usually holds:

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

where $n$ is the magnitude of the normal force, and the proportionality constant $\mu_s$ is called the "coefficient of static friction".

A wooden block weighs 100 N, and is sitting stationary on a smooth horizontal concrete surface. The coefficient of static friction between wood and concrete is 0.2.

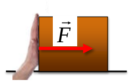
A 5 N horizontal force is applied to the block, pushing toward the right, but the block does not move. What is the force of static friction of the concrete on the block?




A. 100 N, to the left
B. 20 N, to the left
C. 5 N, to the left
D. 20 N, to the right
E. 5 N, to the right

A wooden block weighs 100 N, and is sitting stationary on a smooth horizontal concrete surface. The coefficient of static friction between wood and concrete is 0.2.

A horizontal force is applied to the block, pushing toward the right. What is the magnitude of the maximum pushing force you can apply and have the block remain stationary?

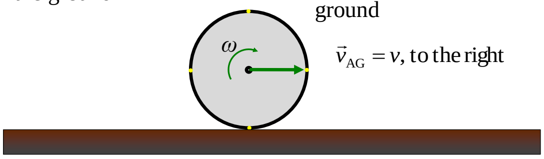



A. 200 N
B. 100 N
C. 20 N
D. 10 N
E. 5 N

## Rolling without slipping

Reference frame: the ground

The axle of the wheel moves relative to the ground




The wheel rotates with angular speed $\omega$.

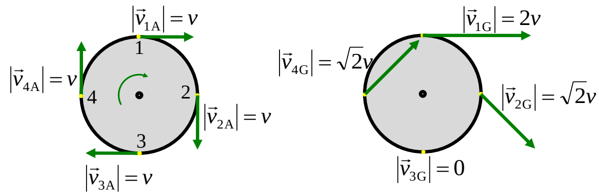
The tangential speed of a point on the rim is $v = \omega r$, relative to the axle.

In "rolling without slipping", the axle moves at speed $v$.

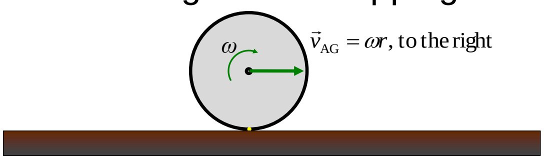
## Rolling without slipping

The axle reference frame

The ground reference frame




## Rolling without slipping




The wheel rotates with angular speed $\omega$.

The axle moves with linear speed $v = \omega r$., where $r$ is the radius of the wheel.

Since the bottom point is always at rest, it is *static friction* which acts between the ground and the wheel.

## Four points on this Ferrari are at rest!

## Rolling Friction (a type of kinetic friction)

- Due to the fact that the wheel is soft, and so is the surface upon which it is rolling. Plowing effect produces a force which slows down the rolling.
- Transportation engineers call $\mu_r$ the *tractive resistance*.
- Typical values of $\mu_r$ are 0.002 for steel wheels on steel rails, and 0.02 for rubber tires on concrete.

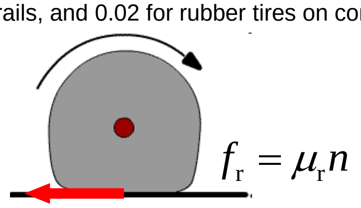



**TABLE 6.1** Coefficients of friction

| Materials | Static $\mu_s$ | Kinetic $\mu_k$ | Rolling $\mu_r$ |
|---|---|---|---|
| Rubber on concrete | 1.00 | 0.80 | 0.02 |
| Steel on steel (dry) | 0.80 | 0.60 | 0.002 |
| Steel on steel (lubricated) | 0.10 | 0.05 | |
| Wood on wood | 0.50 | 0.20 | |
| Wood on snow | 0.12 | 0.06 | |
| Ice on ice | 0.10 | 0.03 | |

- Problem 6.23: A 50,000 kg locomotive is traveling at 10 m/s when its engine and brakes both fail. How far will the locomotive roll before it comes to a stop?

# Drag force in a fluid, such as air

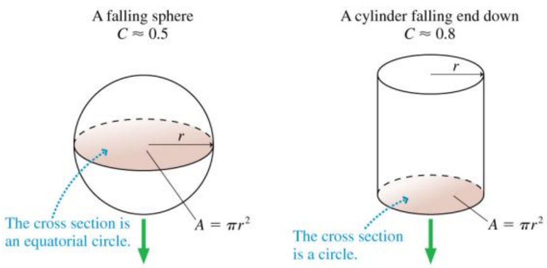
- Air resistance, or drag, is complex and involves fluid dynamics.
- For objects on Earth, with speeds between 1 and 100 m/s and size between 1 cm and 2 m, there is an approximate equation which predicts the magnitude of air resistance

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

where $A$ is the cross-sectional area of the object, $\rho$ is the density of the air, $C$ is the drag coefficient, and $v$ is the speed.

- The direction of air resistance, or Drag Force, is opposite to the direction of motion.
- It depends on size and shape, but not mass.

Cross Sectional Area depends on size, shape, and direction of motion.




…Consider the forces on a falling piece of paper, crumpled and not crumpled.

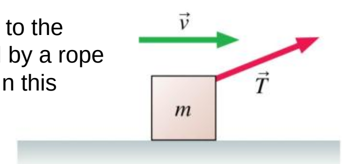
# Ch.6 force summary

Specific information about three important forces:

| | |
|---|---|
| Gravity | $\vec{F}_G = (mg, \text{downward})$ |
| Friction | $\vec{f}_s = (0 \text{ to } \mu_s n, \text{direction as necessary to prevent motion})$ |
| | $\vec{f}_k = (\mu_k n, \text{direction opposite the motion})$ |
| | $\vec{f}_r = (\mu_r n, \text{direction opposite the motion})$ |
| Drag | $\vec{D} \approx (\tfrac{1}{4} A v^2, \text{direction opposite the motion})$ |

# Challenge Question

A box is being pulled to the right at steady speed by a rope that angles upward. In this situation:




A. $n > mg$.
B. $n = mg$.
C. $n < mg$.
D. $n = 0$.
E. Not enough information to judge the size of the normal force.

# Before Class 12 on Monday

- Do the MasteringPhysics Problem Set by Friday evening!
- Please read Knight **Chapter 7.**
- Something to think about:

Consider the following reasoning, and identify the mistake:

"When you pull a wagon, Newton's 3rd Law states that the wagon pulls back on you with an equal and opposite force. These forces should cancel each other. So it is impossible to accelerate the wagon!"