

Chapter 6

Applications of Newton's Laws

1. Frictional Forces

A) Static friction

B) Kinetic friction

2. Strings & Springs

3. Translation Equilibrium

4. Circular Motion

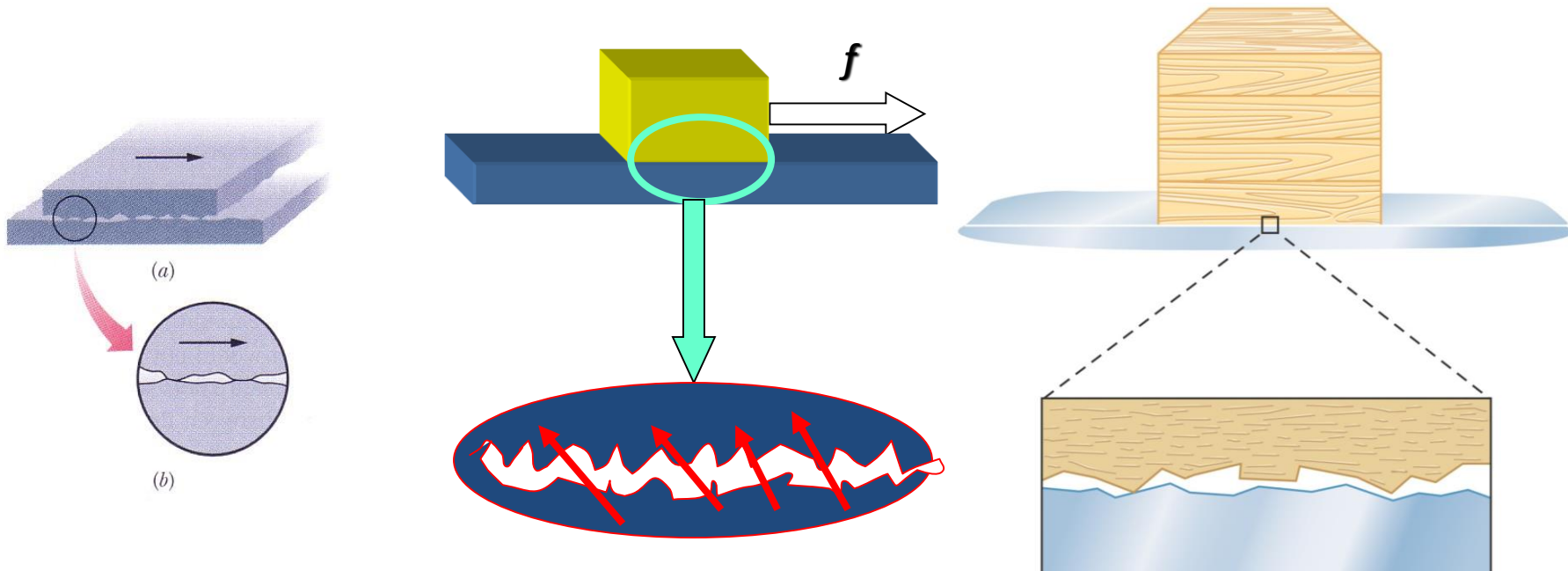
6-1 Frictional Forces

Even smooth surfaces have irregularities when viewed at the microscopic level.

This type of roughness contributes to friction.

No surface is perfectly smooth

- On the other hand, Friction can be helpful/indispensable in another situation.
- Ex: Walk, Run, Starting or Stopping a car,...etc.

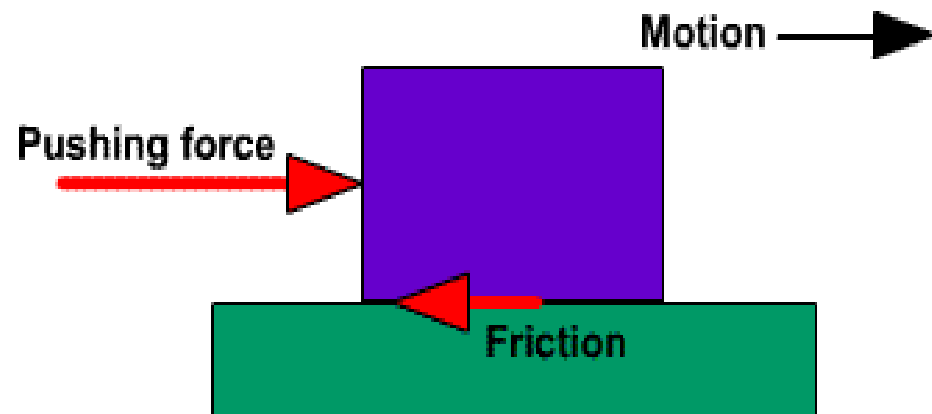


Definition: friction is the force that bodies can impart on each other when they are in contact.

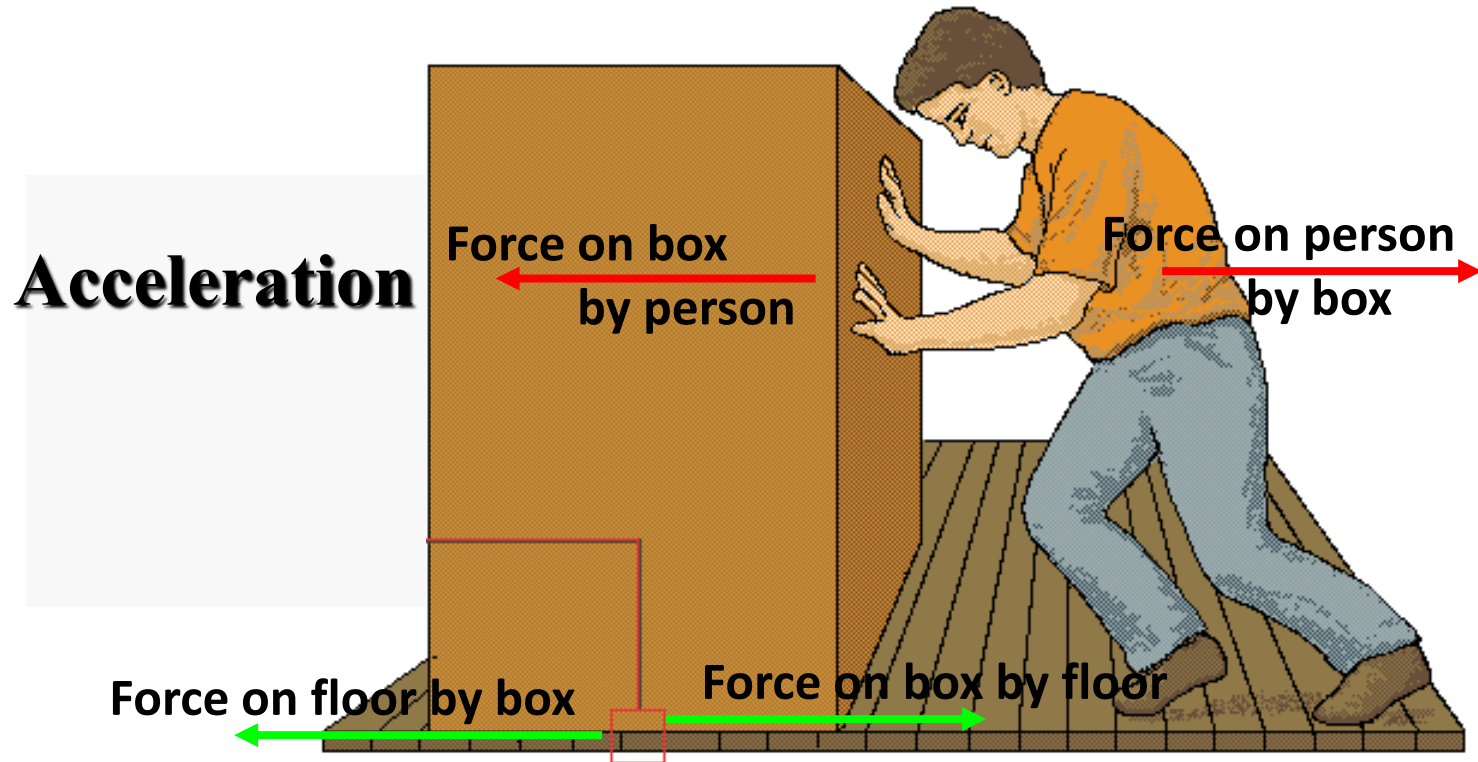
The friction force on an object is **opposite** to its motion or impending motion relative to the surface.

The direction of Friction Force is **parallel** to the surface in contact and occur when:

- ❖ One body slides over the other.
- ❖ They cling together despite external force.



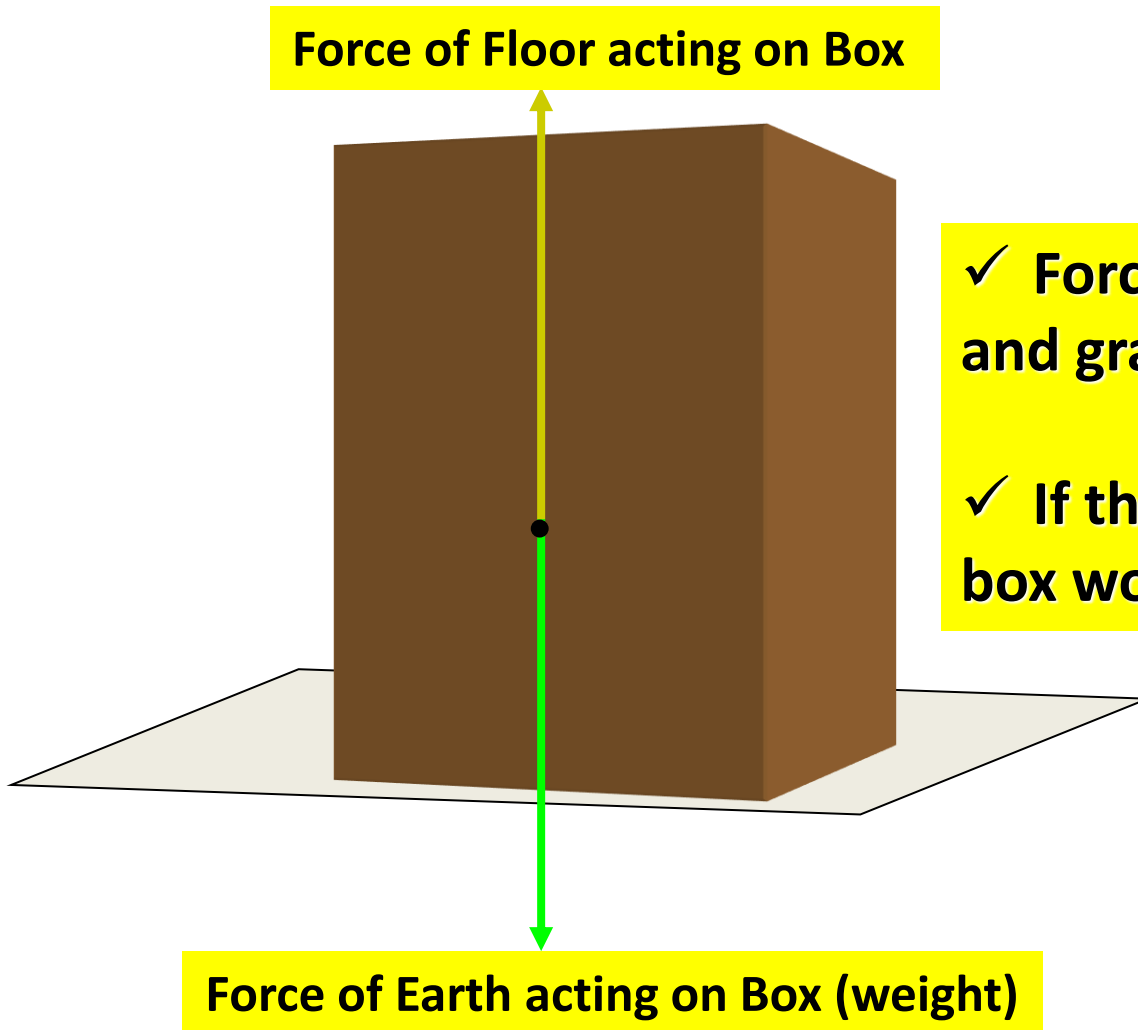
Friction opposes Motion



What kind of motion is created by Unbalanced Net Force?

**It's the sum of all the forces that determines the type of motion.
It's the sum of all the forces that determines the acceleration.
Every force has an equal & opposite partner.**

Why Doesn't Gravity Make the Box Fall?



✓ Force from floor on box
and gravity = Net Force of zero

✓ If the floor vanished, the
box would begin to fall

Types of friction

Static friction force:

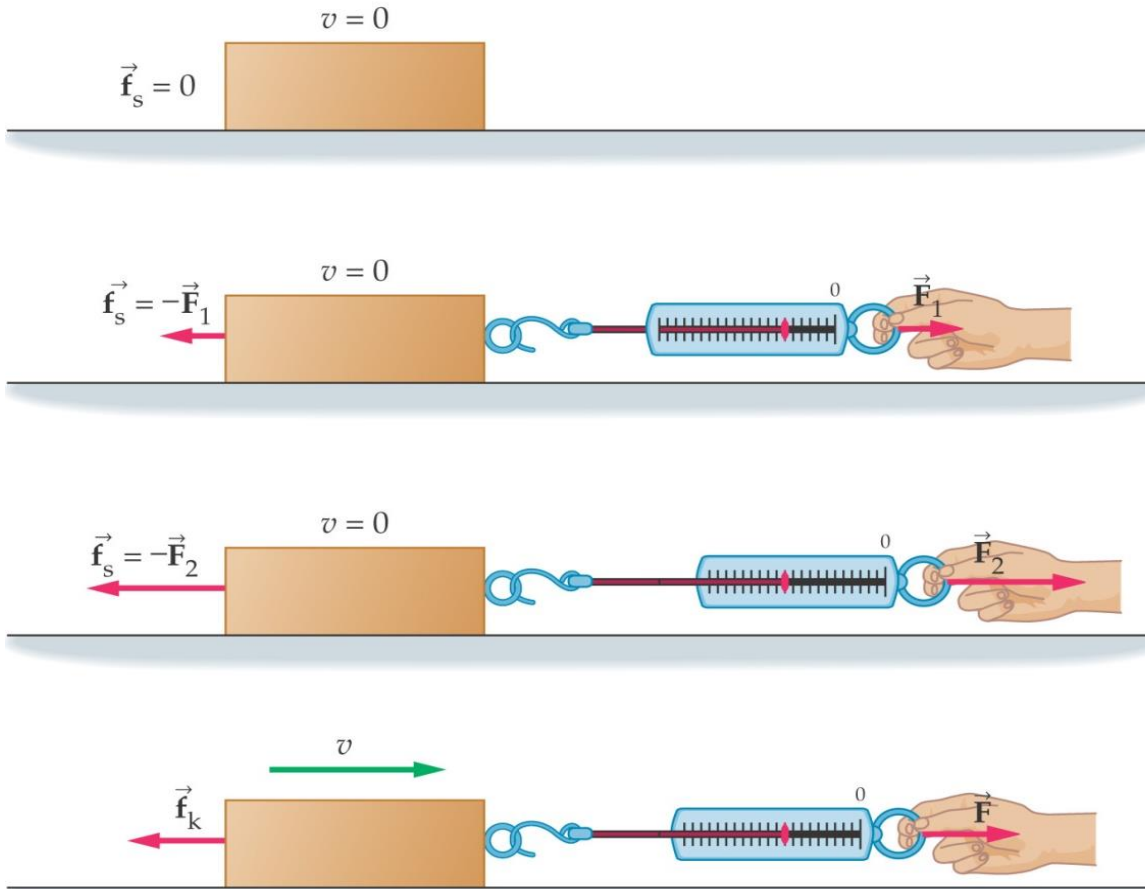
- There is no relative motion between the bodies, e.g., the box & tabletop

Kinetic friction force:

- Kinetic friction is the friction encountered when surfaces slide against one another with a finite relative speed
- Static friction is typically stronger than kinetic friction
- **Tow types of friction force, measured in (N)**

6-1 Frictional Forces

- ✓ **The static frictional force** keeps an object from **starting to move** when a force is applied.
- ✓ The static frictional force has a **maximum value**, but may take on any value **from zero to the maximum**



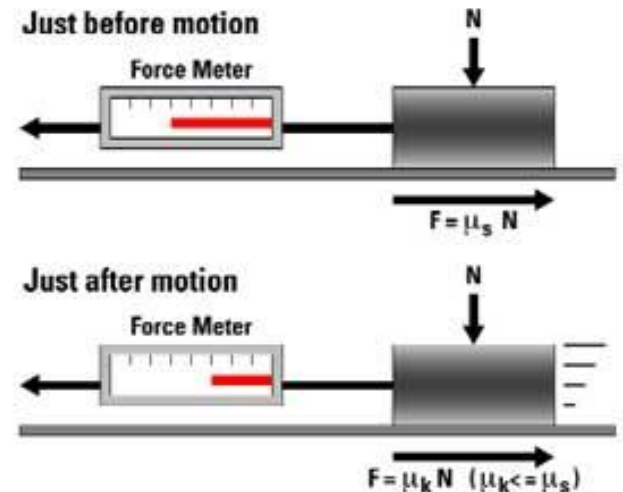
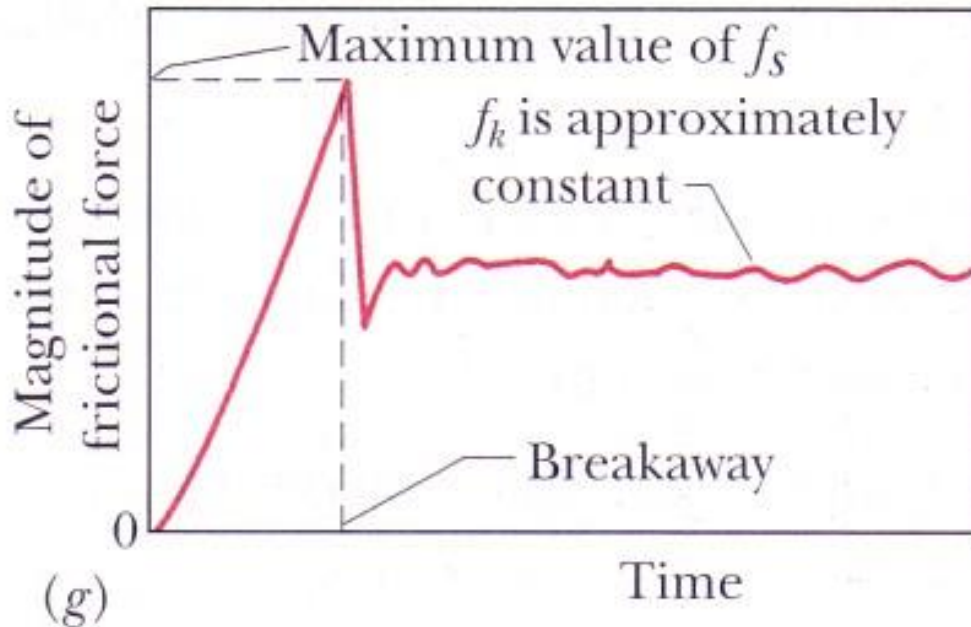
depending on
what is needed
to keep the sum
of forces zero

6-1 Frictional Forces

$$0 \leq f_s \leq f_{s,\max}$$

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

The static frictional force is also independent of the **area of contact** and the **relative speed of the surfaces**.



The Static Friction Force

The force of static friction between two surfaces has the following properties:

1. It takes any value between zero and the maximum possible force of static friction:

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

$$f_s \leq \mu_s N$$

$$0 \leq f_s \leq f_{s,\max}$$

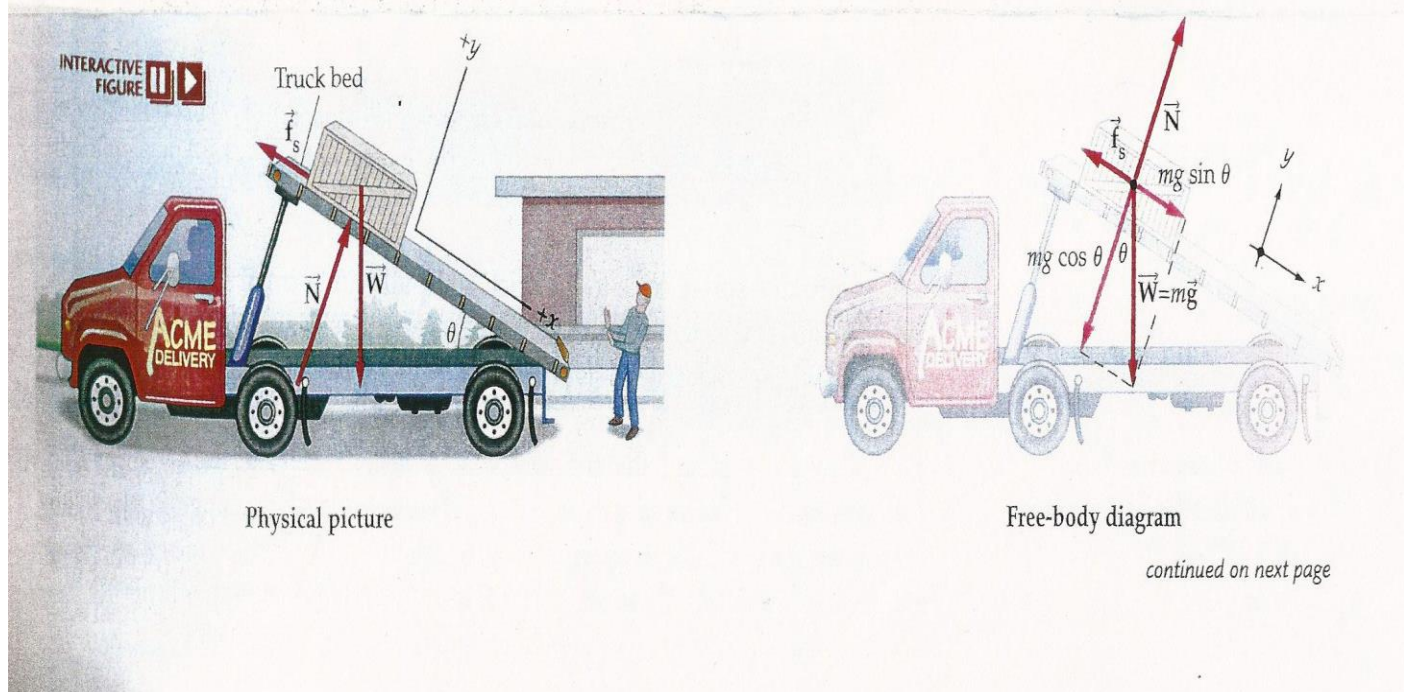
2. It is independent of the area of contact between the two surfaces.

3. It is parallel to the surface of contact, and in the direction that opposes relative motion.

Example - 3

A flatbed truck slowly tilts its bed upward to dispose of a 95 kg crate. For small angles of tilt, the crate stays put, but when the tilt angle exceeds 23.2° , the crate begins to slide. What is the coefficient of static friction between the bed of the truck and the crate.

Answer: $\mu_s = 0.429$



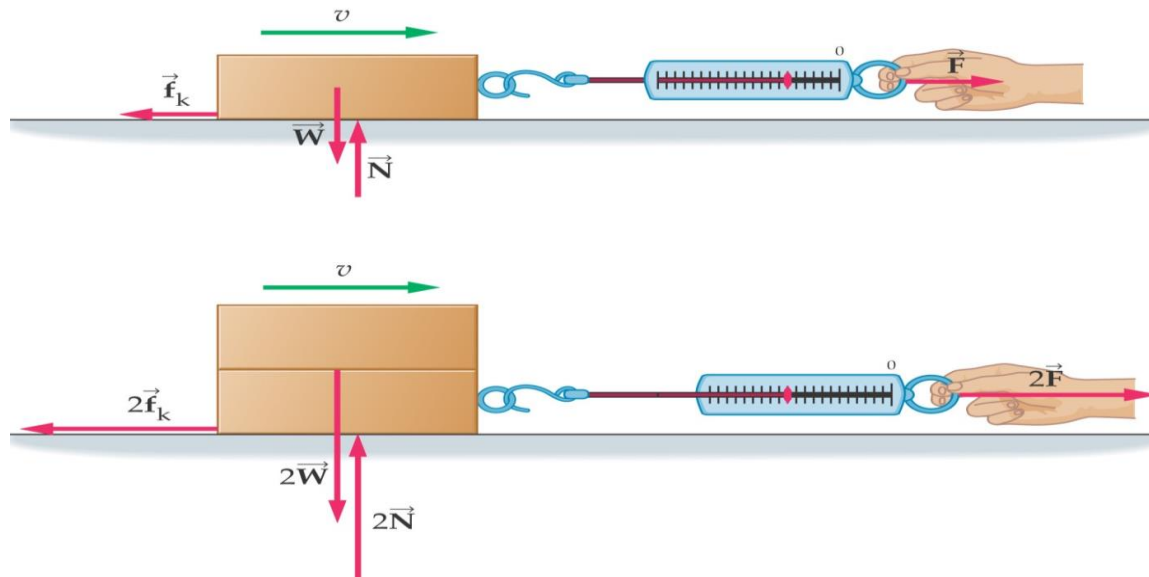
6-1 Frictional Forces

Kinetic Friction

- The friction experienced by surfaces sliding against one another
- The kinetic frictional force depends on the normal force:

$$f_k = \mu_k N$$

The constant μ_k is called the **coefficient of kinetic friction**.



Kinetic Friction Force

The force of kinetic friction between two surfaces has the following properties:

1. It is proportional to the magnitude of the normal force N :

$$f_k = \mu_k N$$

2. It is independent of the area of contact between the two surfaces.

3. It is parallel to the surface of contact, and in the direction that opposes relative motion.

4. It is independent of the relative speed of the surfaces.

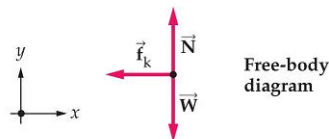
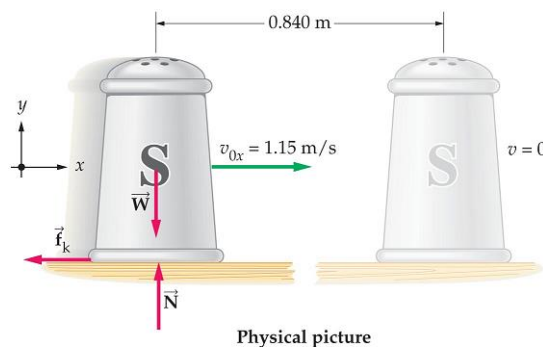
Example-1

Someone at the other end of table asks you to pass the salt. Feeling quiet dashing you slide the 50g saltshaker in their direction, giving it an initial speed of 1.15m/s.

(a) If the shaker comes to rest with constant acceleration in 0.840 m , what is the coefficient of kinetic friction between the shaker and the table?

(b) How much time is required for the shaker to come to rest if you slide it with an initial speed of 1.32 m/s?

- Answer : $a_x = -0.787 \text{ m/s}^2$, $\mu_k = 0.0802$, $t=1.68\text{s}$



6-1 Frictional Forces

TABLE 6–1 Typical Coefficients of Friction

Materials	Kinetic, μ_k	Static, μ_s
Rubber on concrete (dry)	0.80	1–4
Steel on steel	0.57	0.74
Glass on glass	0.40	0.94
Wood on leather	0.40	0.50
Copper on steel	0.36	0.53
Rubber on concrete (wet)	0.25	0.30
Steel on ice	0.06	0.10
Waxed ski on snow	0.05	0.10
Teflon on Teflon	0.04	0.04
Synovial joints in humans	0.003	0.01

COEFFICIENT OF FRICTION cont.

$$\mu_k < \mu_s$$

- ❑ f_k --- is the **kinetic friction** force that exists once the object begins to move. Its value remains fairly constant, as the **velocity of the object increases**.
- ❑ The coefficient of kinetic friction μ_k is always **positive** and typical values range between **zero and 1**.
- ❑ The coefficient of static friction μ_s is always **positive** can have any value between **0 and greater than > 1**
- ❑ μ_s and μ_k Are dimensionless.

Friction Strength

The magnitude of the friction force is proportional to:

1. How hard the two bodies are pressed together (the normal force, N).
2. The materials from which the bodies are made (the coefficient of friction).

Attributes that have little or no effect:

- Sliding speed
- Contact area



Photo 8.1 The coefficient of static friction between a package and the inclined conveyer belt must be sufficiently large to enable the package to be transported without slipping.

Problems

(A) A box of mass 5 kg is on a floor where $\mu_s = 0.4$ and $\mu_k = 0.3$.

- Find the static friction force
- Find the kinetic friction force
- What is the acceleration of the box if the applied force is:

1) $F_a = 16\text{N}$

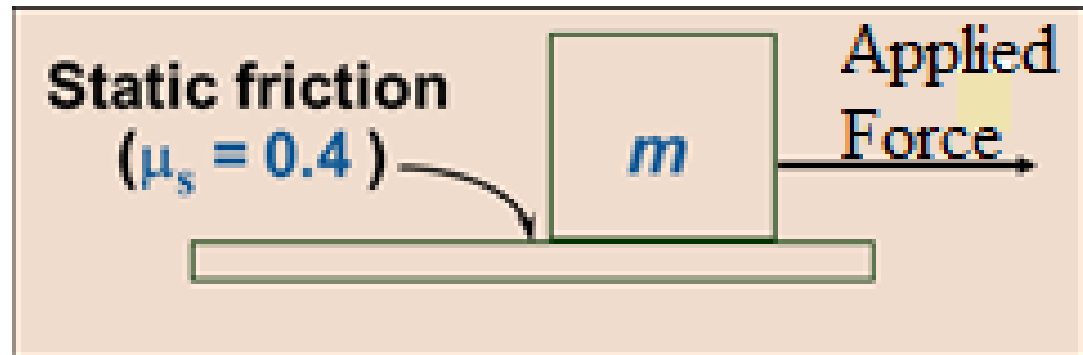
2) $F_a = 24\text{N}$

Answers:

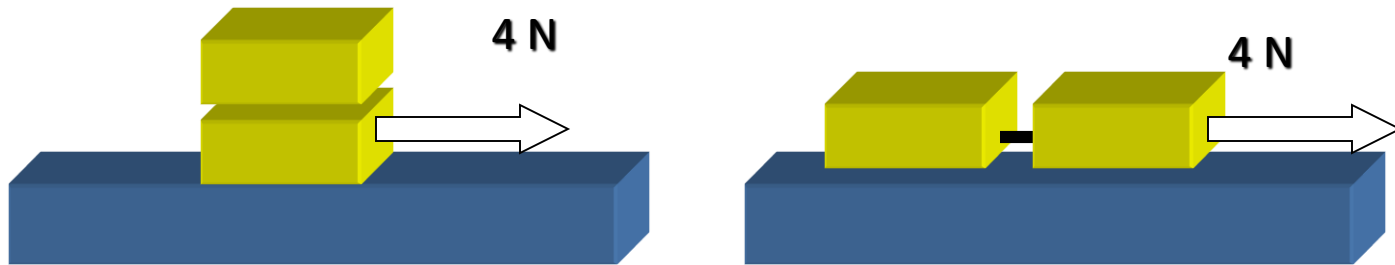
$F_{s,\max} = 20\text{ N}$

$F_k = 15\text{ N}$

1) $a = 0$ 2) $a = 1.8\text{ m/s}^2$



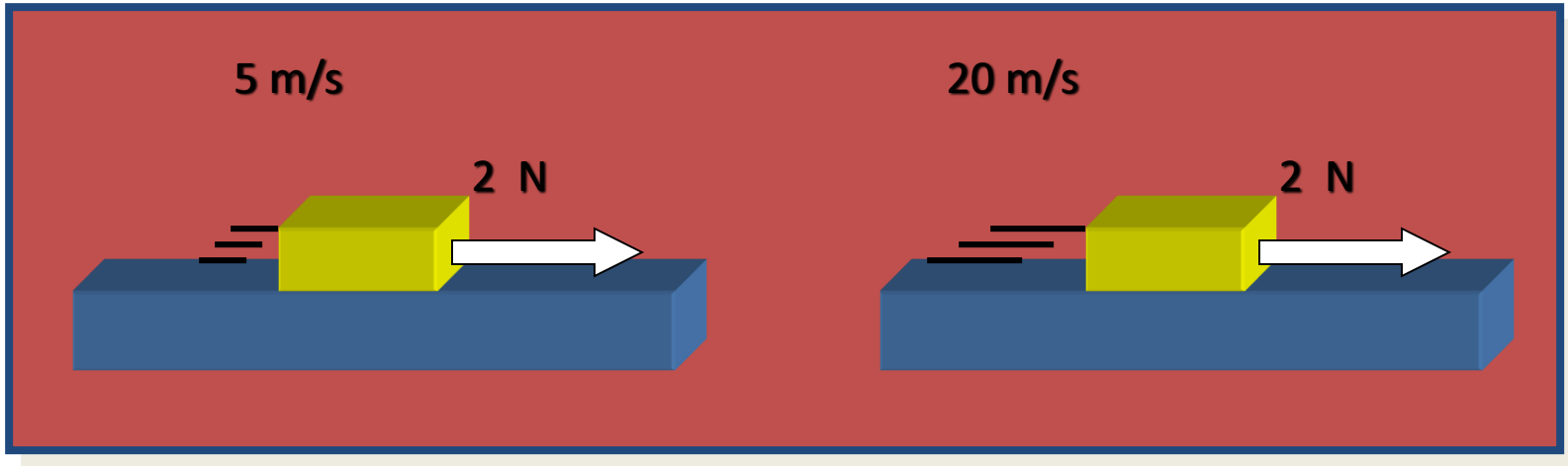
Friction forces are independent of area



If the total mass pulled is constant, the same force (4 N) is required to overcome friction even with twice the area of contact.

For this to be true, it is essential that
ALL other variables be rigidly controlled

Friction forces are independent of speed



The force of kinetic friction is the same at 5 m/s as it is for 20 m/s. Again, we must assume that there are no chemical or mechanical changes due to speed.

STATIC AND KINETIC FRICTION

- Play the videos



static kinetic friction ÇáÇÍÊßÇß ÇáÓßæäí æÇáÇÍÊßÇß ÇáÑßí - YouTube2.wmv



Alicia's Physics Shoe Commercial - YouTube.wmv



static kinetic friction ÇáÇÍÊßÇß ÇáÓßæäí æÇáÇÍÊßÇß ÇáÑßí - YouTube2.wmv

The force of friction depends upon both surfaces in contact and the normal force. A mathematical relationship can be created here.

The diagram illustrates three scenarios of a wood block on different surfaces, showing the forces acting on it and the resulting friction coefficient.

Scenario 1: Wood on Wood
 A wood block is shown on a wood surface. The forces acting on it are: Normal force (F_N) pointing up, weight (w) pointing down, and friction force (f_k) pointing left. The friction coefficient is given as $\frac{f_k}{F_N} = 0.4$.

Scenario 2: Wood on Wood
 A wood block is shown on a wood surface. The forces acting on it are: Normal force (F_N) pointing up, weight (w) pointing down, and friction force (f_k) pointing left. The friction coefficient is given as $\mu_k = \frac{f_k}{F_N}$.

Scenario 3: Wood on Asphalt
 A wood block is shown on an asphalt surface. The forces acting on it are: Normal force (F_N) pointing up, weight (w) pointing down, and friction force (f_k) pointing left. The friction coefficient is given as $\mu_k = 0.6$.

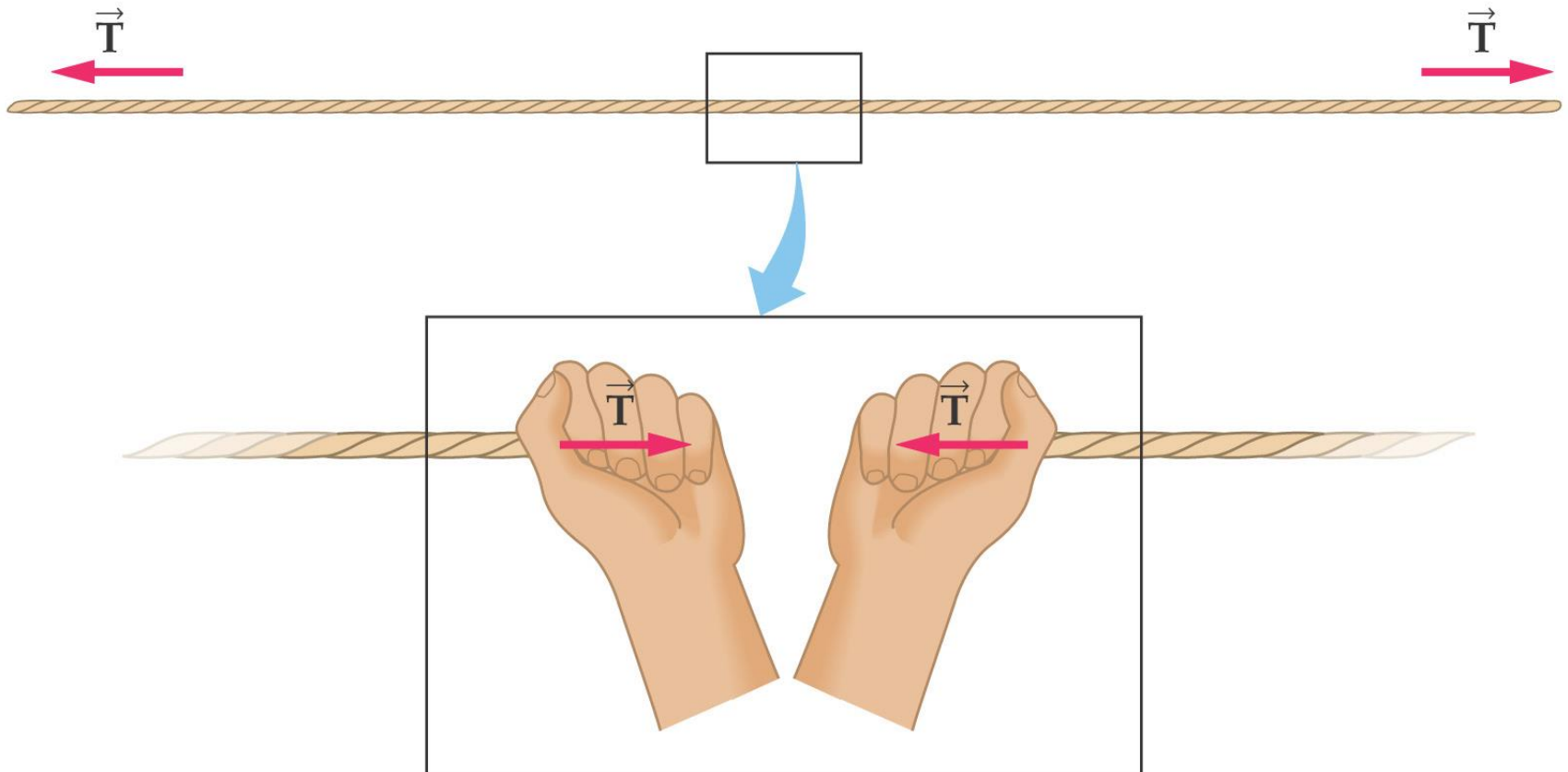
Friction Coefficient Formula
 The maximum static friction coefficient is given by the formula: $\mu_s = \frac{f_{s_{max}}}{F_N}$.

Force Diagram
 A separate diagram shows a red block on a blue inclined plane. The forces acting on the block are: Normal force (yellow arrow pointing perpendicular to the surface), Friction force (green arrow pointing up the surface), and Weight force (teal arrow pointing vertically down).

6-2 Strings and Springs

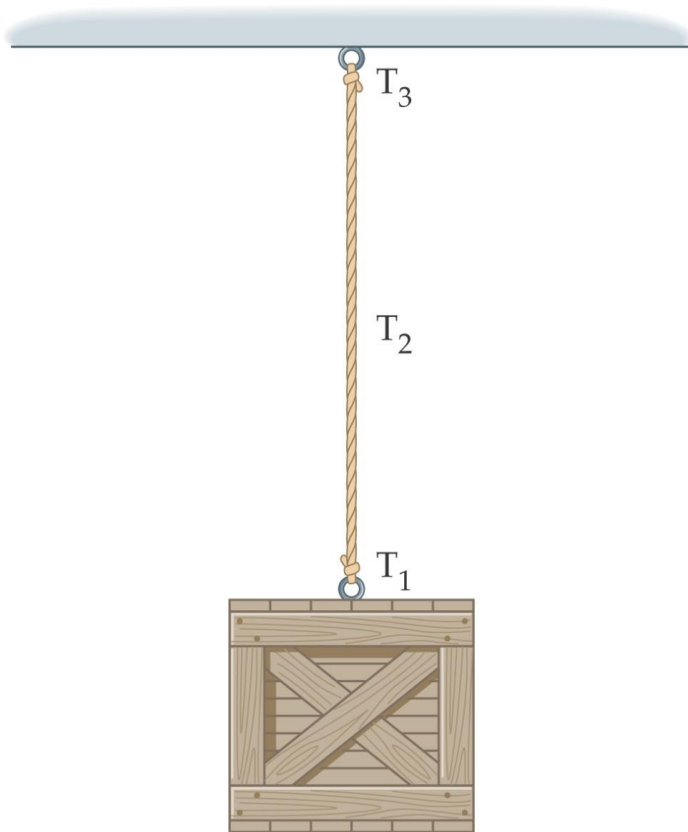
(Tension Force)

When you pull on a string or rope, it becomes taut. We say that there is tension in the string.



6-2 Strings and Springs

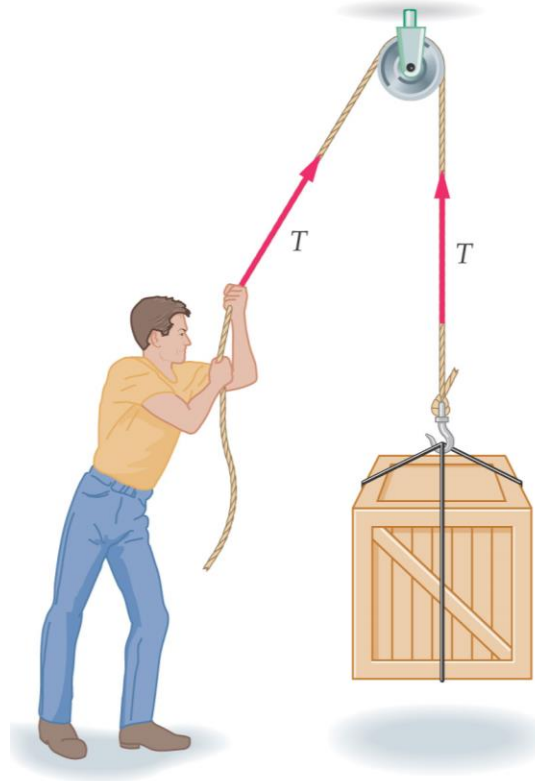
The tension in a real rope will vary along its length, due to the weight of the rope.



Here, we will assume that all ropes, strings, wires, etc. are massless unless otherwise stated

6-2 Strings and Springs

- ❖ An ideal pulley is one that simply changes the direction of the tension:
- ❖ Assume: All ropes, wires, strings are **massless** and hence, that the tension is the **same** throughout their length.



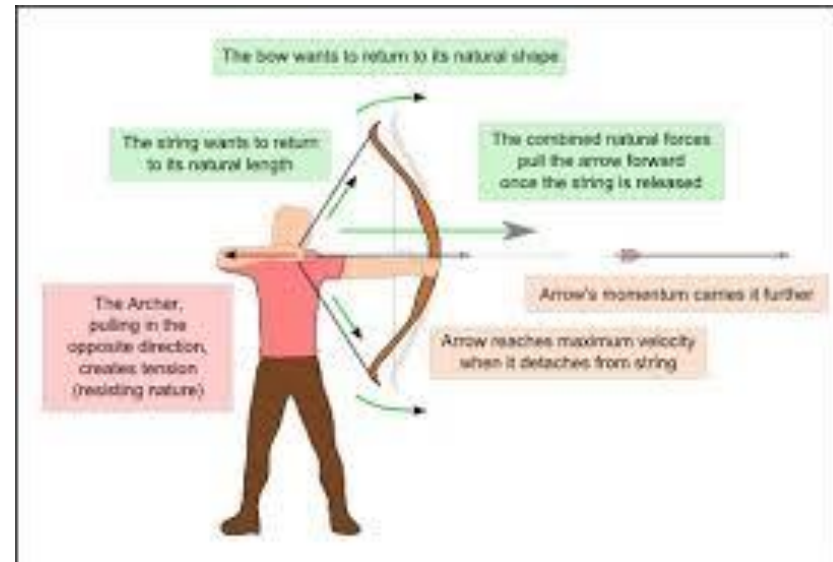
Problems

20. Pulling up on a rope, you lift a 4.35 kg bucket of water from a well with an acceleration of 1.78 m/s^2 . What is the tension in the rope?

$$T=50.4 \text{ N}$$

34. Pulling a string on a bow back with a force of 28.7 lb, an archer prepares to shoot an arrow. If the archer pulls in the center of the string, and the angle between the two halves is 138° , what is the tension in the string?

$$\theta= 69.0^\circ \quad T=40.0 \text{ lb}$$



6-2 Strings and Springs

(Spring Force)

Hooke's law for springs states that the force increases with the amount the spring is stretched or compressed, the spring force:

$$F = -kx$$

If F is the **magnitude** of the spring: $F = kx$

The constant of proportionality is

called the spring constant (k)

k is measured in (N/m) in SI.



Problems

21. When a 9.09 kg mass is placed on top of a vertical spring, the spring compresses 4.18 cm. Find the force constant of the spring.

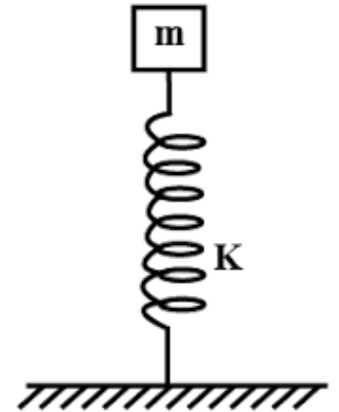
$$k=2.13 \text{ kN/m}$$

24. A backpack full of books weighing 52.0 N rests on a table in a physics laboratory classroom. A spring with a force constant of 150 N/m is attached to the backpack and pulled horizontally.

(a) If the spring is pulled until it stretches 2.00 cm and the pack remains at rest, what is the force of friction exerted on the backpack by the table?

$$F_s=3.0 \text{ N}$$

(b) Does your answer to part (a) change if the mass of the backpack is doubled? Explain.



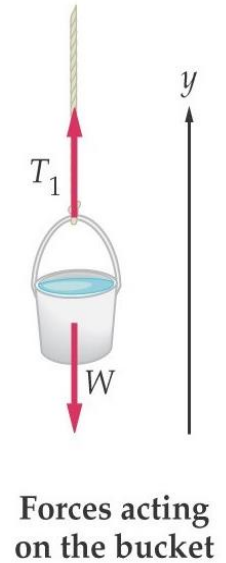
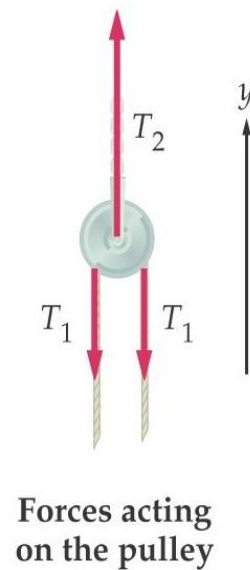
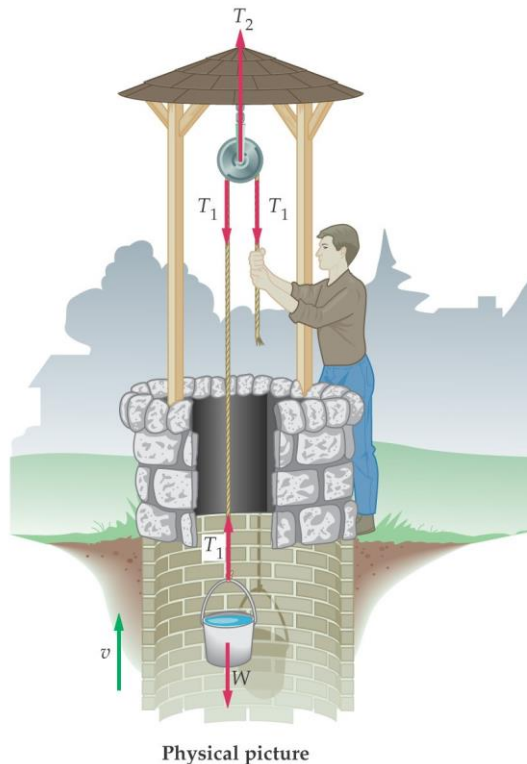
6-3 Translational Equilibrium

When an object is in translational equilibrium, the net force on it is zero:

$$\sum \vec{F} = 0 \quad (6-5)$$

This allows the calculation of unknown forces.

Find T_1 and T_2 ?

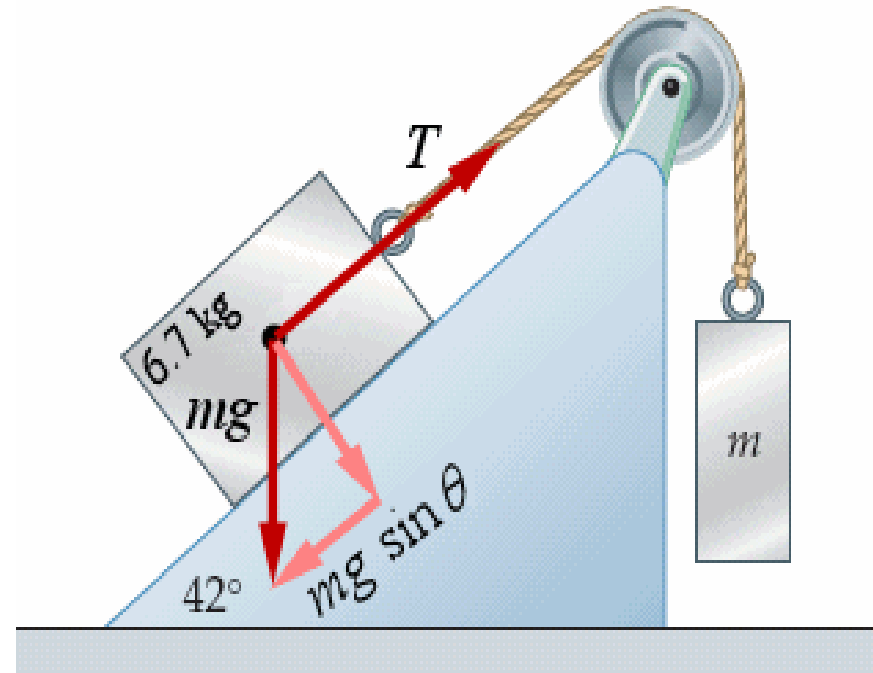


Problems

37. Two blocks are connected by a string as shown. The smooth inclined surface makes an angle of 42° with the horizontal, and the block on the incline has a mass of 6.7 kg. Find the mass of the hanging block that will cause the system to be in equilibrium.

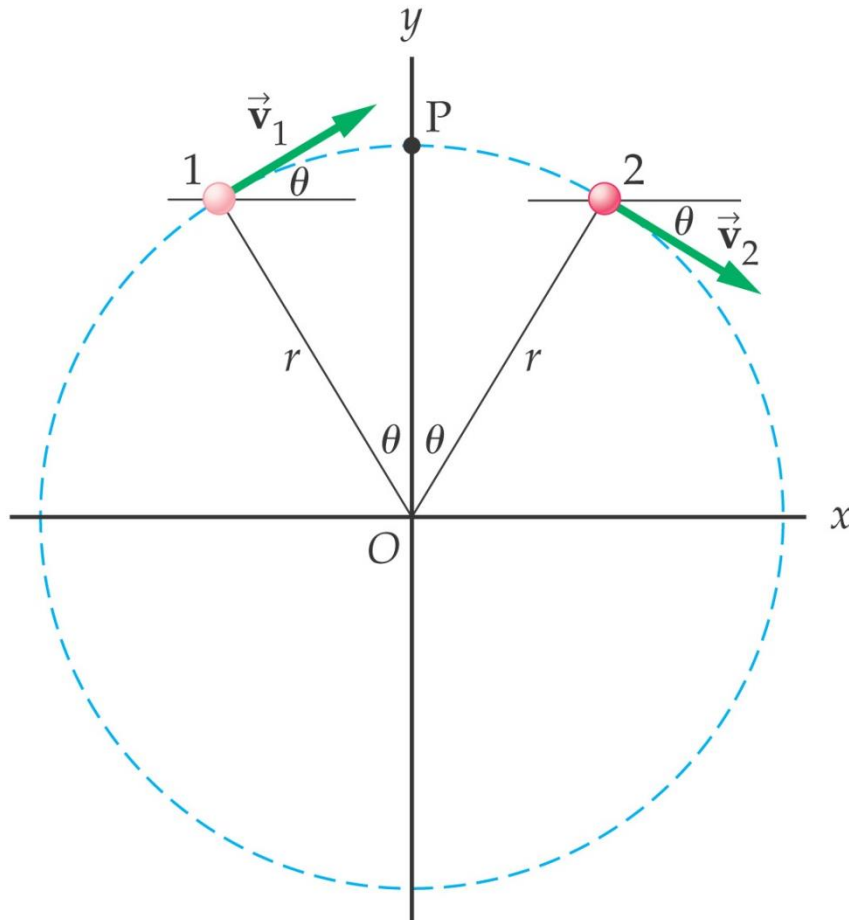
(The pulley is assumed to be ideal)

Answer: $m = 4.5 \text{ kg}$

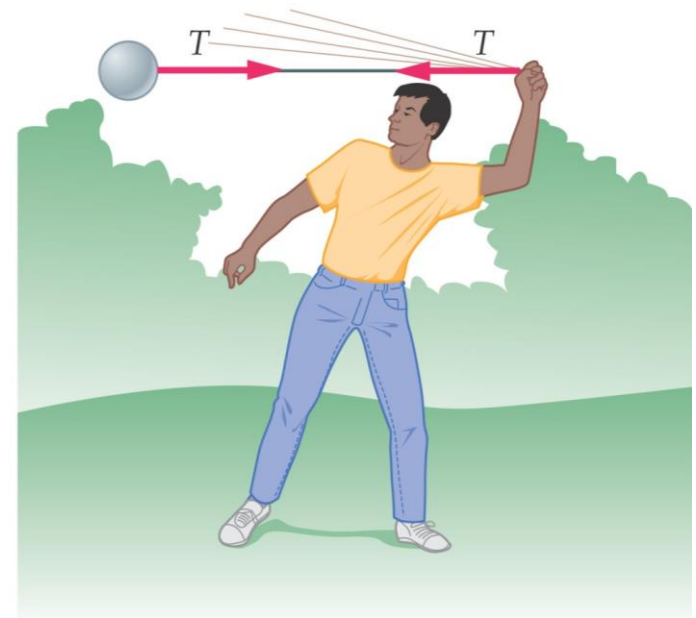


6-5 Circular Motion

An object moving in a **circle must have a force acting on it**; otherwise it would move in a straight line.



The direction of the force is **towards the center of the circle**.



6-5 Circular Motion

The magnitude of the acceleration, and therefore the force, required to keep an object of mass m moving in a circle of radius r are related by the following equation:

$$f_{\text{cp}} = ma_{\text{cp}} = m \frac{v^2}{r}$$

Prob. 1

A 2 kg ball on a string is rotated about a circle of radius 10 m. The maximum tension allowed in the string is 50 N. What is the maximum speed of the ball?

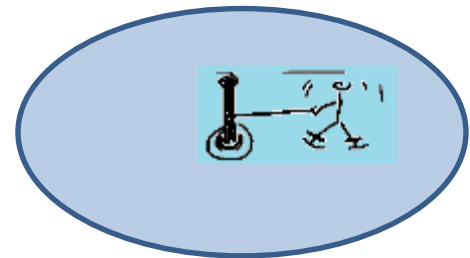
Answer: $V = 15.8 \text{ m/s}$

Prob. 2

A 55.0-kg ice skater is moving at 4.00 m/s when she grabs the loose end of a rope, the opposite end of which is tied to a pole. She then moves in a circle of radius 0.800 m around the pole.

- Determine the force exerted by the horizontal rope on her arms.
- Compare this force with her weight.

Answers: $T = F_{cp} = 1100 \text{ N}$
 $W = mg = 540 \text{ N}$

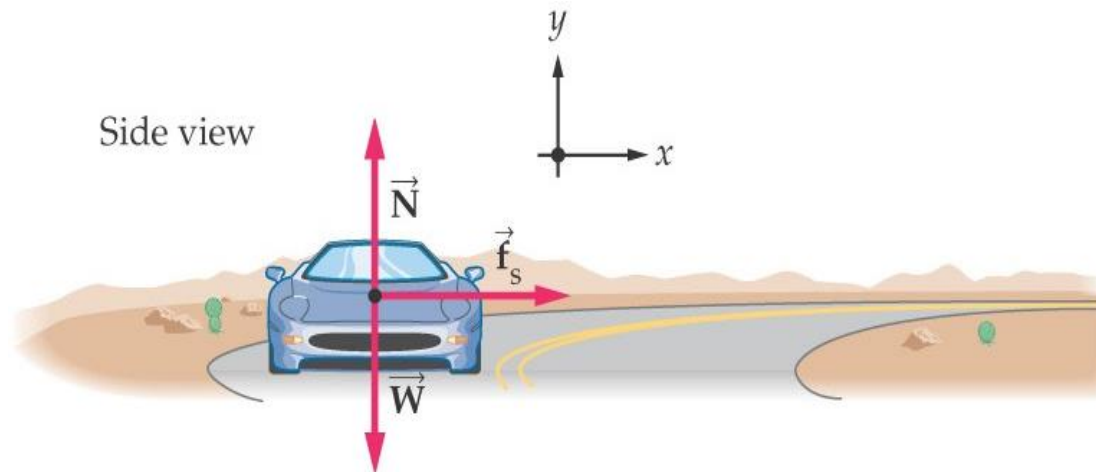


6-5 Circular Motion

This force may be provided by the tension in a string, the normal force, or friction, among others.

Example 8: A 1200 kg car rounds a corner of radius 45 m. If the coefficient of static friction between the tires and the road is 0.82, what is the greatest speed the car can have in the corner without skidding? $m = 1200\text{kg}$, $r = 45\text{ m}$, $\mu_s = 0.82$, $v = ???$

Answer: $v = 19\text{ m/s}$

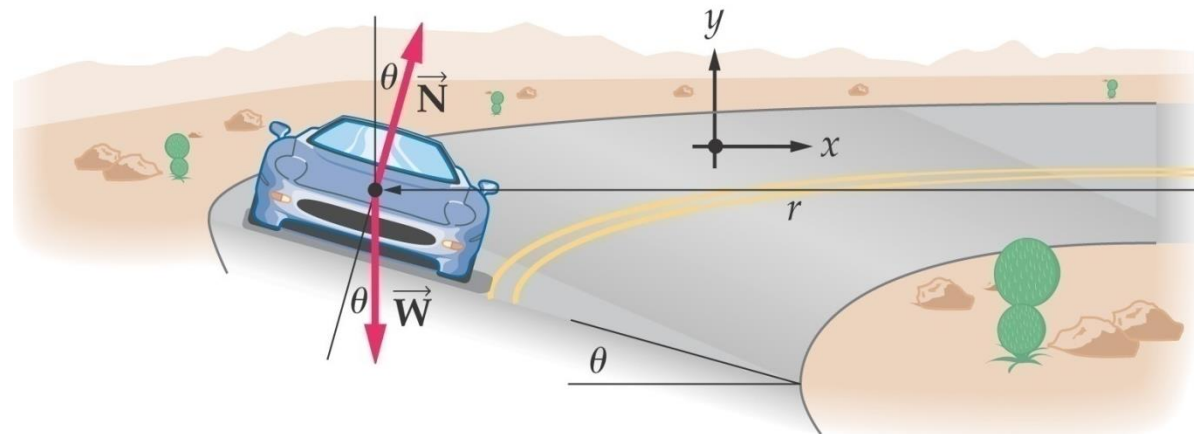




Example 9. If a roadway is banked at the proper angle, a car can round a corner without any assistance from friction between the tires and the road. Find the appropriate banking angle for a 900kg car traveling at 20.5 m/s in a turn of radius 85 m?

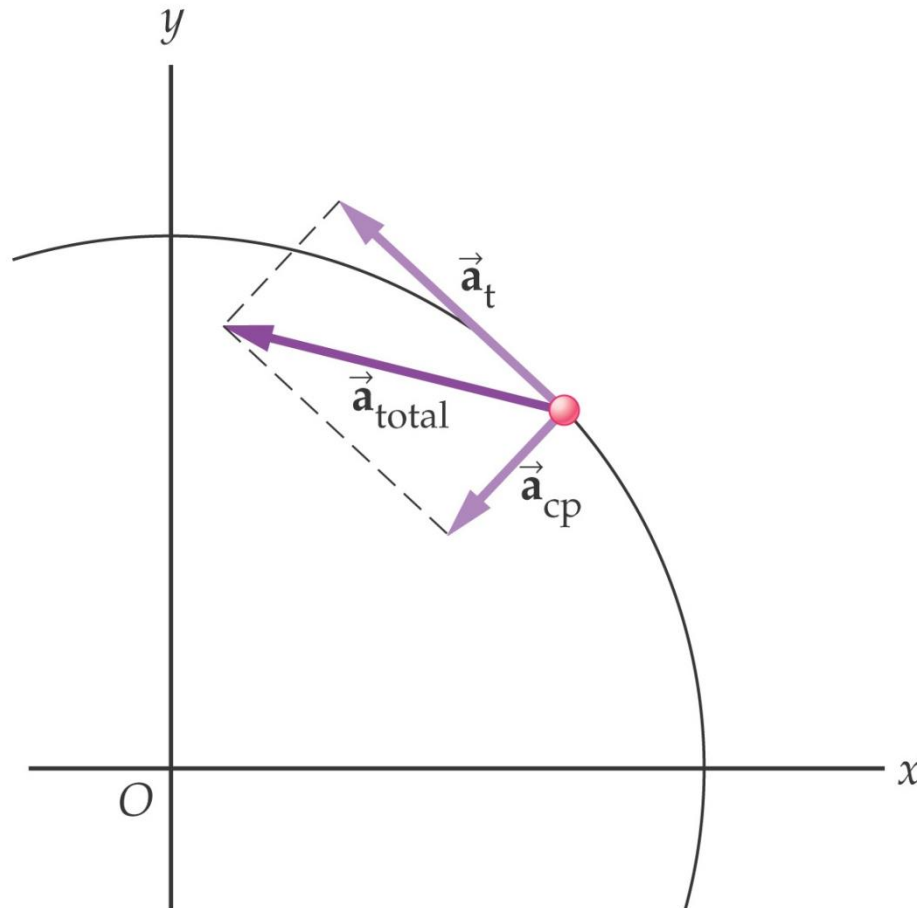
$$m = 900\text{kg}, \quad r = 85\text{ m}, \quad v = 20.5\text{m/s}, \quad \theta = ??$$

Answer: $\theta = 26.7^\circ$



6-5 Circular Motion

An object may be changing its speed as it moves in a circle; in that case, there is a tangential acceleration as well: $|\mathbf{a}| = \sqrt{a_{cp}^2 + a_t^2}$ $\theta = \tan^{-1}(a_{cp}/a_t)$



Summary of Chapter 6

- Friction is due to microscopic roughness.
- Kinetic friction: $f_k = \mu_k N$
- Static friction: $f_{s,\max} = \mu_s N$
- An object is in translational equilibrium if the net force acting on it is zero.
- The force required to move an object of mass m in a circle of radius r is:

$$f_{\text{cp}} = ma_{\text{cp}} = m \frac{v^2}{r}$$

Summary of Chapter 6

- Tension: the force transmitted through a string.
- Force exerted by an ideal spring:

$$F_x = -kx$$

Exercises

3. A baseball player slides into third base with an initial speed of 4.0 m/s. If the coefficient of kinetic friction between the player and the ground is 0.46, how far does the player slide before coming to rest. (Answer: 1.8 m)
4. A child goes down a playground slide with an acceleration of 1.26 m/s². Find the coefficient of kinetic friction between the child and the slide if the slide is inclined at an angle of 33° below the horizontal. (Answer: 0.496)
5. Hoping into your Porsche, you floor it and accelerate at 12 m/s² without spinning the tires. Determine the minimum coefficient of static friction between the tires and the road needed to make this possible. (Answer: 1.2)
6. A 4 kg ball on a string is rotated about a circle of radius 10 m. The maximum tension allowed in the string is 52 N. What is the maximum speed of the ball? (Answer : 11.4 m/s.)