Chapter 3
The Laws of motion

The Laws of motion

Chapter Outline:

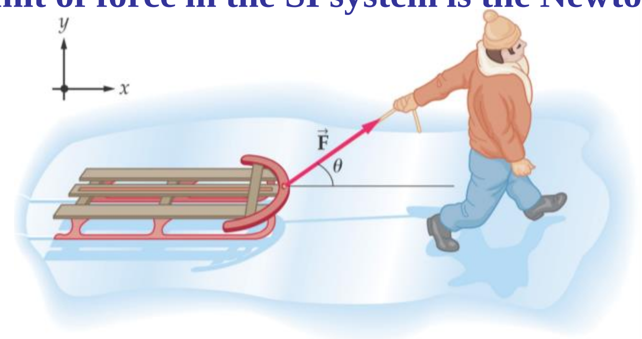
- *The Concept of Force.*
- *Newton's First Law.*
- *Newton's Second Law.*
- *Newton's Third Law.*
- *Some Applications of Newton's Laws.*

5.1 The Concept of Force

Force: push or pull

Force is a vector – it has magnitude and direction

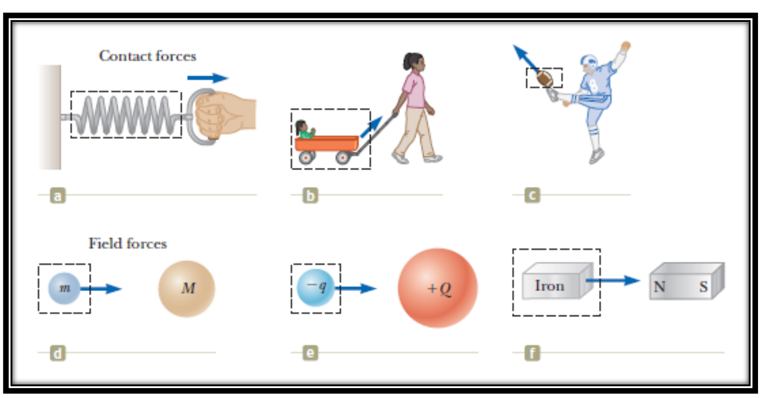
The unit of force in the SI system is the Newton (N).



5.1 The Concept of Force

**Contact forces* involve physical contact between two objects.

* *field forces,* does not involve physical contact between two objects.



5.1 The Concept of Force

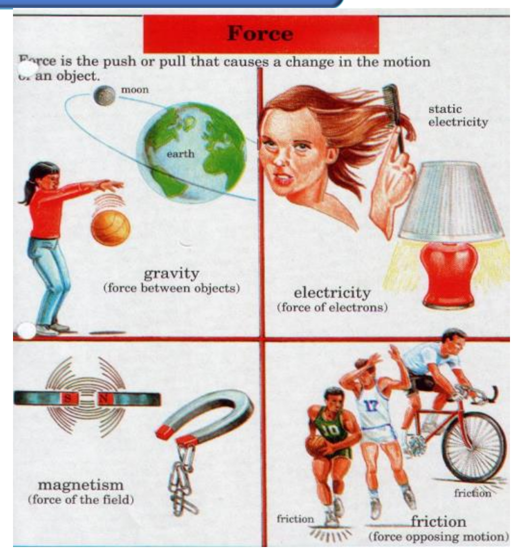
The only known *basic forces:*
in nature are all field forces:

(1) gravitational forces between objects

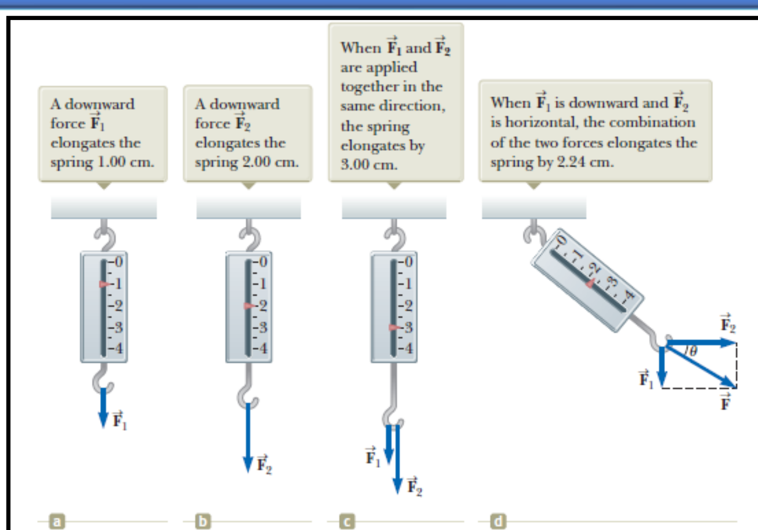
(2) electromagnetic forces between electric charges

(3) strong forces between subatomic particles

(4) weak forces that arise in certain radioactive decay processes.



5.1 The Concept of Force



5.1 The Concept of Force

What happened if there are several forces?

*The **net force** acting on an object is defined as **the vector sum of all forces acting on the object**.*

the **net force** *= the* **total force** *=the* **resultant force**

*If the net force exerted on an object is **zero**, then **the acceleration** of the object is **zero** and its **velocity** remains **constant**.*

*That is, if the net force acting on the object is zero, then the object either remains **at rest** or **continues to move with constant velocity**.*

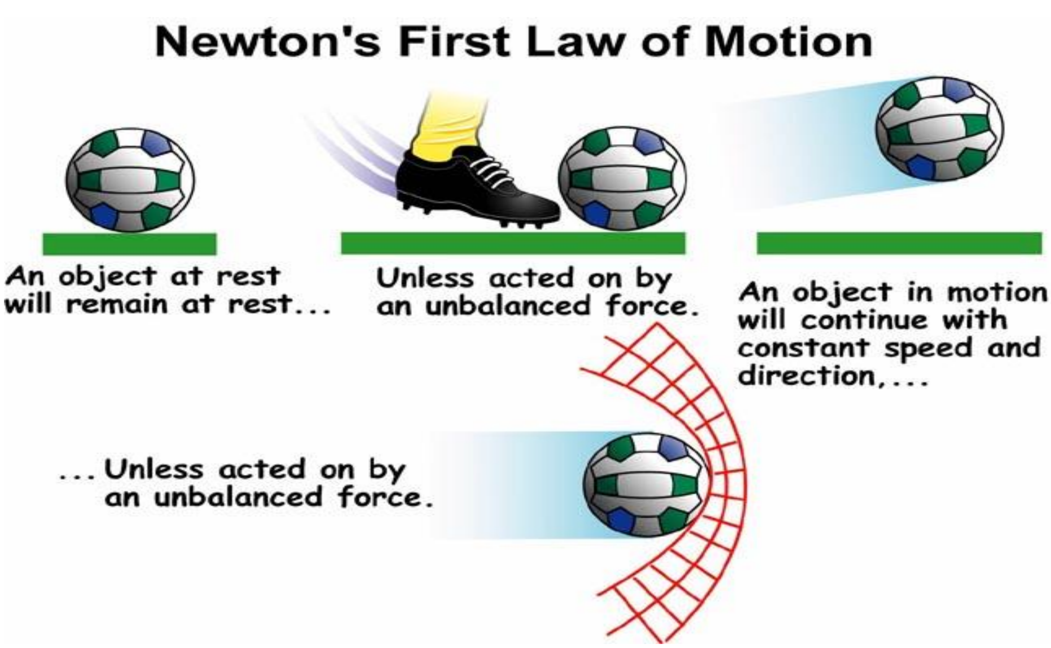
What is the law of motion ?

Newton's laws of motion are three physical laws which provide relationships between the forces acting on a body and the motion of the body.

5.2 Newton's First Law and Inertial Frames:

An object at rest will stay at rest, and an object in motion will stay in motion at constant velocity, unless acted upon by an unbalanced force.

$$\sum \vec{F} = 0$$



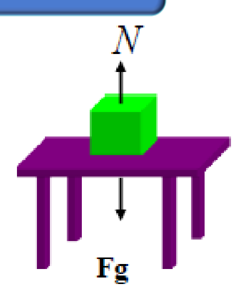
5.3 Mass and Weight

Mass is that property of an object that specifies how much resistance an object exhibits to changes in its velocity,
* The SI unit of mass is the kilogram.
*mass is a scalar quantity.
*Mass and weight are two different quantities.
*Weight is the force exerted on an object by gravity. Close to the surface of the Earth, where the gravitational force is nearly constant, the weight is:

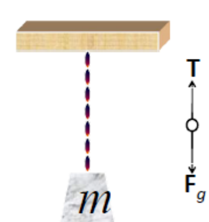
$$F_g=mg$$

5.3 Weight, Normal Force and Tension

An object at rest must have no net force on it. If it is sitting on a table, the force of gravity (Fg) is still there; what other force is there?
The force exerted perpendicular to a surface is **N= called the normal force**



Tension force T (such as in a stretched rope or string), arises because each small element of the string pulls on the element next to it.



Tension

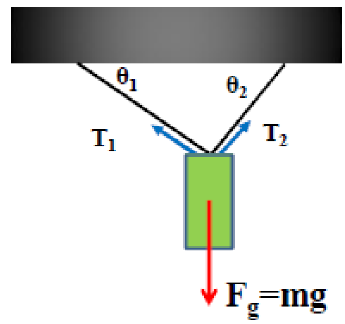
The reactionary force by a stringy object against an external force exerted on it.

x comp.

$$|T_{1x}| = |T_{2x}|$$
$$T_1 \cos\theta_1 = T_2 \cos\theta_2$$

y comp.

$$|T_{1y} + T_{2y}| = |F_g|$$
$$T_1 \sin\theta_1 + T_2 \sin\theta_2 = mg$$



5.4 Newton's Second Law:

If an external force acts on the body, the body will ***accelerate***. The ***direction of acceleration*** is the same as the ***direction of the net force***.
The net force vector is equal to the mass of the body times the acceleration of the body.

$$\Sigma\vec{F} = m\vec{a}$$

*The acceleration is due to the *net force* $\Sigma\vec{F}$ acting on an object.
*The **net force** on an object is the vector sum of all forces acting on the object.
*Many forces may be acting on an object, but there is only one acceleration.

$$\Sigma F_x = ma_x \quad \Sigma F_y = ma_y \quad \Sigma F_z = ma_z$$

*The SI unit of force is the **newton** (N).
*A force of 1 N is the force that, when acting on an object of mass 1 kg, produces an acceleration of 1 m/s^2.

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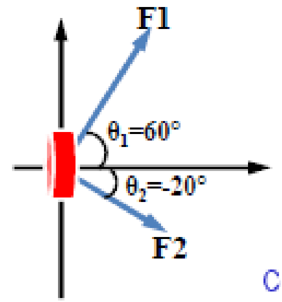
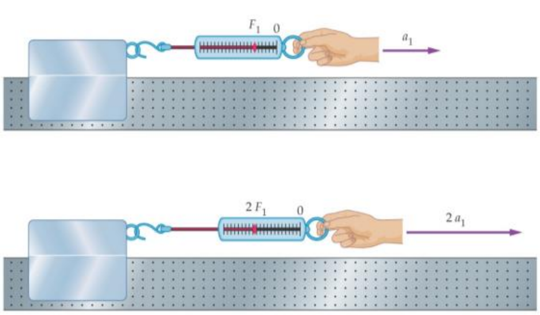
5.4 Newton's Second Law:

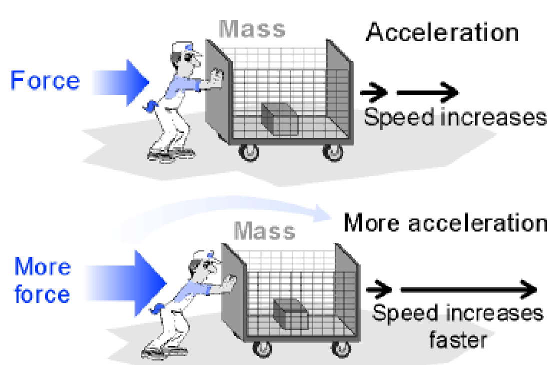
Determine the magnitude and the direction of acceleration of the puck whose mass is 0.30kg and is being pulled by two forces, **F1** and **F2,** as shown in the **figure**, whose magnitudes of the forces are 8.0 N and 5.0 N, respectively.



5.4 Newton's Second Law:

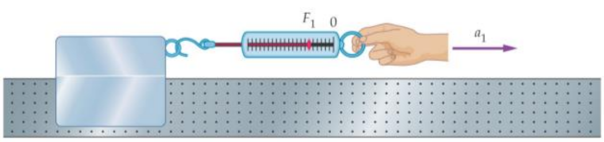
If you apply more force to an object, it accelerates at a higher rate.

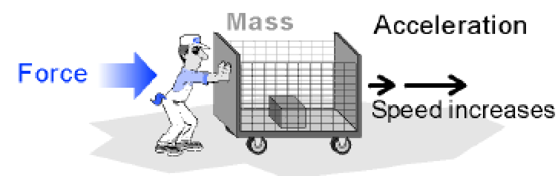


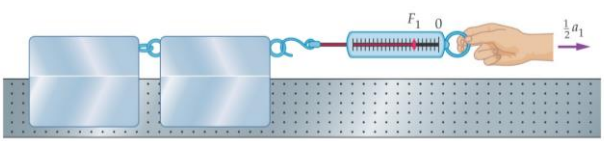


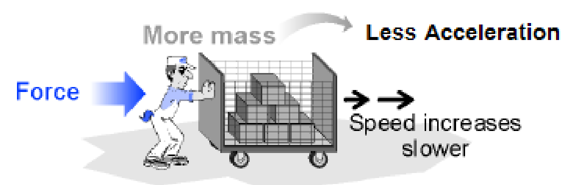
5.4 Newton’s Second Law:

If an object has <u>more</u> mass it accelerates at a lower rate









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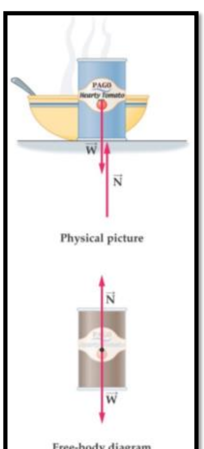
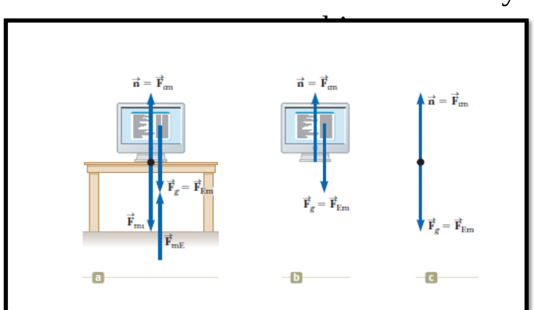
5.6 Newton’s Third Law:



If two objects interact, the force $\vec{F}_{12}$ exerted by object 1 on object 2 is equal in magnitude and opposite in direction to the force $\vec{F}_{21}$ exerted by object 2 on object 1:

$$\vec{F}_{12} = -\vec{F}_{21}$$

* The normal force is the force exerted by a surface on



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5.7 Analysis Models Using Newton's Second Law:

Free Body Diagrams and Solving Problems

Free-body diagram: A diagram of vector forces acting on an object

A great tool to solve a problem using forces or using dynamics

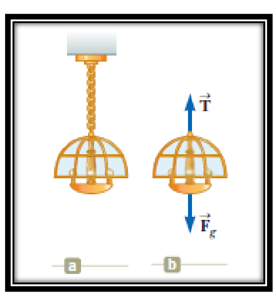
1. Select a point on an object in the problem
2. Identify all the forces acting only on the selected object
3. Define a reference frame with positive and negative axes specified
4. Draw arrows to represent the force vectors on the selected point
5. Write down net force vector equation
6. Write down the forces in components to solve the problems

5.7 Analysis Models Using Newton's Second Law:

Analysis Model: The Particle in Equilibrium:

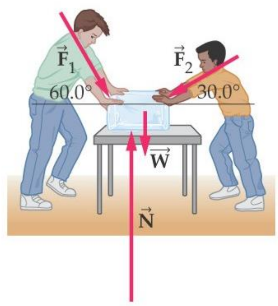
If the acceleration of an object modeled as a particle **is zero**, the object is treated with the **particle in equilibrium** model. In this model, the net force on the object is zero:

$$\sum \vec{F} = 0$$

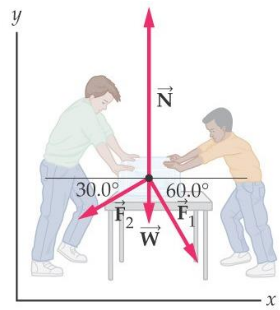


5.7 Analysis Models Using Newton’s Second Law:

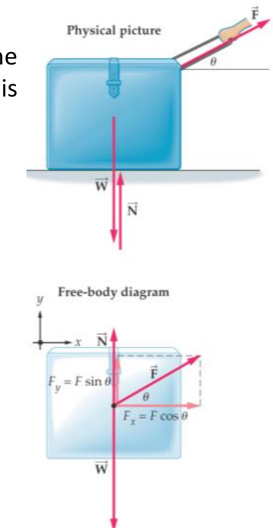
Analysis Model: The Particle Under a Net Force:
If an object experiences an acceleration, its motion can be analyzed with the **particle under a net force** model. The appropriate equation for this model is Newton’s second law, Equation (2): $\sum \vec{F} = m\vec{a}$ (8)



Physical picture

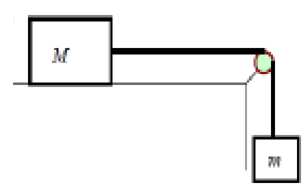


Free-body diagram



5.7 Analysis Models Using Newton’s Second Law:

Two blocks are attached by a rope as shown below. Assume that the surface is
frictionless and the pulley and string are massless.
(1)Show the free body diagram
(2)Find the acceleration of the system
(3)Find the tension in the string

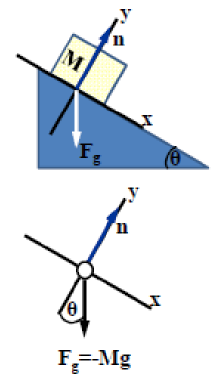


5.7 Analysis Models Using Newton's Second Law:

A crate of mass M is placed on a frictionless inclined plane of angle θ.

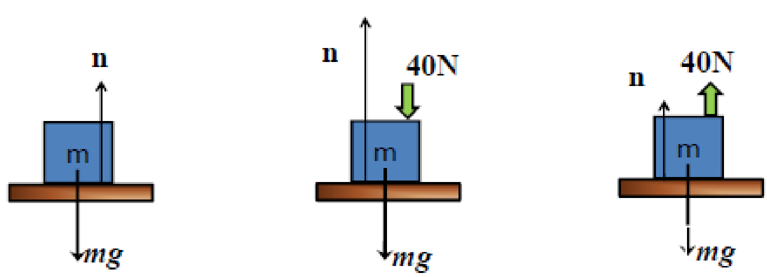
a) Determine the acceleration of the crate after it is released.

B) How long does it take for the crate to reach the bottom and what is its speed at the bottom?



5.7 Analysis Models Using Newton's Second Law:

Calculate (surface) normal forces n for the following cases.



$|mg| = -|F_N|$

$\sum \vec{F} = \vec{F}_N - m\vec{g} = m\vec{a} = 0$

$|mg + 40N| = -|F_N|$

$\sum \vec{F} = \vec{F}_N - m\vec{g} - 40N = 0$

$|mg| = -|F_N + 40N|$

$\sum \vec{F} = m\vec{g} - \vec{F}_N - 40N = 0$

5.7 Analysis Models Using Newton's Second Law:

Example 5.4 A Traffic Light at Rest

A traffic light weighing 122 N hangs from a cable tied to two other cables fastened to a support as in Figure 5.10a. The upper cables make angles of 37.0° and 53.0° with the horizontal. These upper cables are not as strong as the vertical cable and will break if the tension in them exceeds 100 N. Does the traffic light remain hanging in this situation, or will one of the cables break?

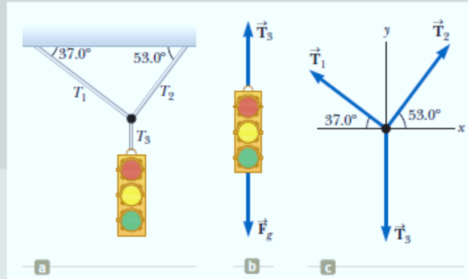


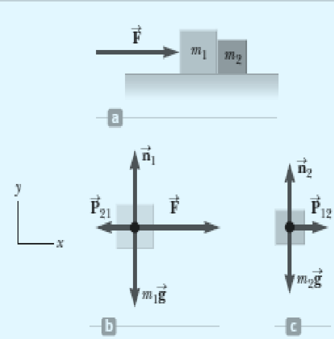
Figure 5.10 (Example 5.4) (a) A traffic light suspended by cables. (b) The forces acting on the traffic light. (c) The free-body diagram for the knot where the three cables are joined.

5.7 Analysis Models Using Newton's Second Law:

Example 5.7 One Block Pushes Another

Two blocks of masses m_1 and m_2, with $m_1 > m_2$, are placed in contact with each other on a frictionless, horizontal surface as in Active Figure 5.12a. A constant horizontal force $\vec{F}$ is applied to m_1 as shown.

(A) Find the magnitude of the acceleration of the system.



ACTIVE FIGURE 5.12

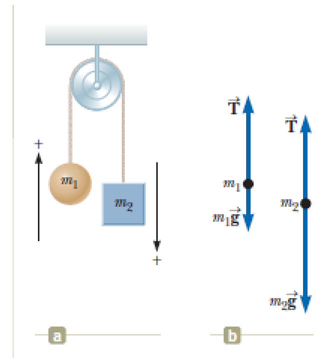
(Example 5.7) (a) A force is applied to a block of mass m_1, which pushes on a second block of mass m_2. (b) The forces acting on m_1. (c) The forces acting on m_2.

(B) Determine the magnitude of the contact force between the two blocks.

5.7 Analysis Models Using Newton's Second Law:

Example 5.9 **The Atwood Machine**

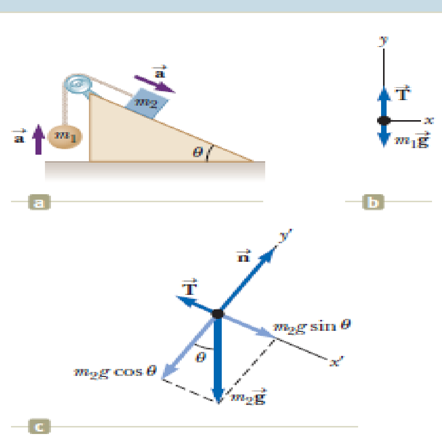
When two objects of unequal mass are hung vertically over a frictionless pulley of negligible mass as in Active Figure 5.14a, the arrangement is called an *Atwood machine.* The device is sometimes used in the laboratory to determine the value of *g.* Determine the magnitude of the acceleration of the two objects and the tension in the lightweight cord.



5.7 Analysis Models Using Newton's Second Law:

Example 5.10 **Acceleration of Two Objects Connected by a Cord**

A ball of mass m_1 and a block of mass m_2 are attached by a lightweight cord that passes over a frictionless pulley of negligible mass as in Figure 5.15a. The block lies on a frictionless incline of angle θ. Find the magnitude of the acceleration of the two objects and the tension in the cord.



5.8 Forces of Friction:

Force of Friction

The force of kinetic friction

where μ_k is the **coefficient of kinetic friction.**

$$f_k = \mu_k n$$

The force of static friction

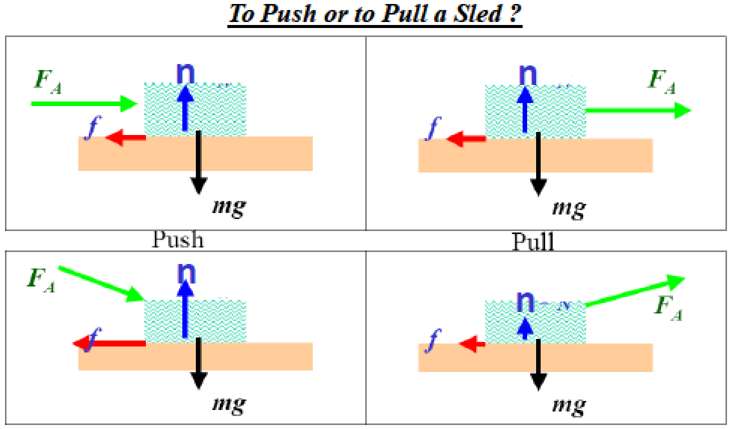
where the dimensionless constant μ_s is the **coefficient of static friction**

$$f_s \leq \mu_s n$$

- The values of μ_k and μ_s depend on the n, but μ_k is generally less than μ_s.
- The direction of the friction force on an object is parallel to the surface and opposite to the actual motion

5.8 Forces of Friction:

To Push or to Pull a Sled ?

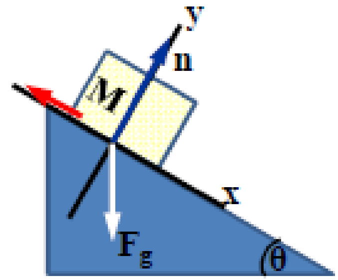


$$n - mg \pm F_A \sin\theta = ma_y = 0 \qquad n = mg \pm F_A \sin\theta$$

$$F_A \cos\theta - f = F_A \cos\theta - \mu n = ma_x$$

5.8 Forces of Friction:

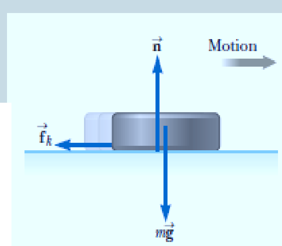
Suppose a block is placed on a rough surface inclined relative to the horizontal. The inclination angle is increased till the block starts to move. Show that by measuring this critical angle, θc, one can determine coefficient of static friction, μs.



5.8 Forces of Friction:

Example 5.12 The Sliding Hockey Puck

A hockey puck on a frozen pond is given an initial speed of 20.0 m/s. If the puck always remains on the ice and slides 115 m before coming to rest, determine the coefficient of kinetic friction between the puck and ice.



5.8 Forces of Friction:

Example 5.13 Acceleration of Two Connected Objects When Friction Is Present

A block of mass m_2 on a rough, horizontal surface is connected to a ball of mass m_1 by a lightweight cord over a lightweight, frictionless pulley as shown in Figure 5.20a. A force of magnitude F at an angle θ with the horizontal is applied to the block as shown, and the block slides to the right. The coefficient of kinetic friction between the block and surface is μ_k. Determine the magnitude of the acceleration of the two objects.