Phys101 Lecture 5

Dynamics: Newton’s Laws of Motion

Key points:

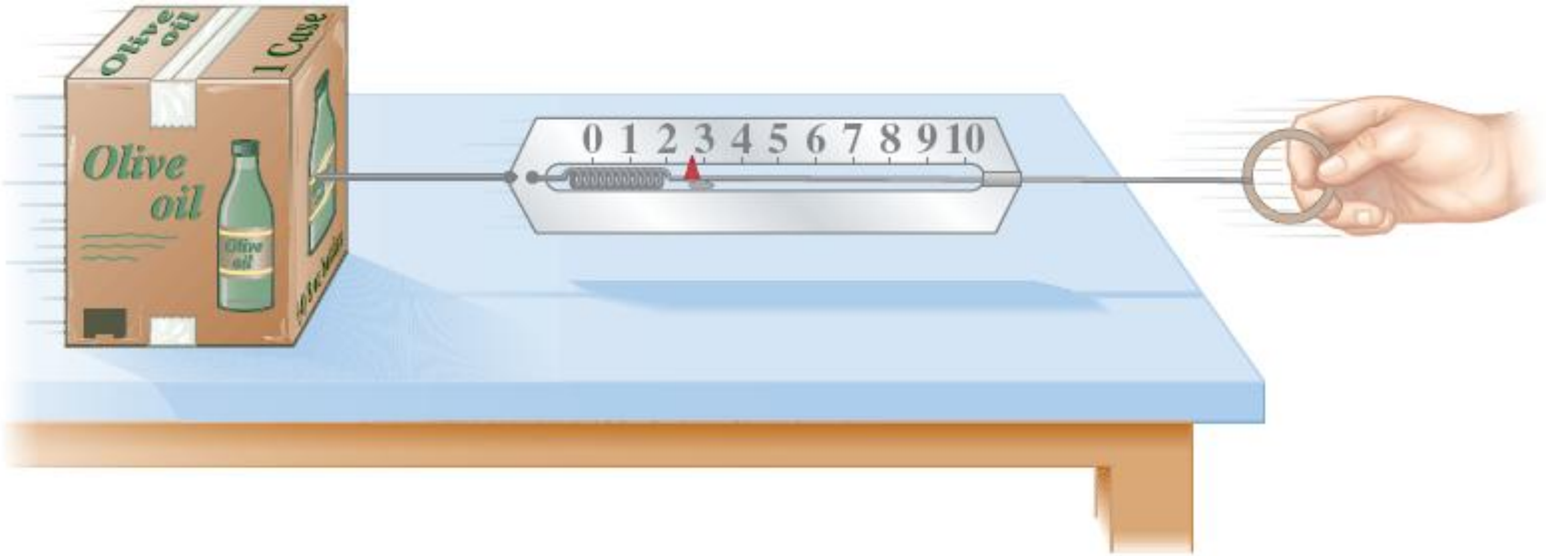
- **Newton’s second law is a vector equation**
- **Action and reaction are acting on different objects**
- **Free-Body Diagrams**
- **Friction**
- **Inclines**

Ref: 4-1,2,3,4,5,6,7,8,9.

Force

A **force** is a **push** or **pull**. An object at rest needs a force to get it **moving**; a moving object needs a force to change its **velocity**.

Force is a vector



Force is a vector, having both magnitude and direction. The magnitude of a force can be measured using a spring scale.

Newton’s First Law of Motion

This is Newton’s first law, which is often called the law of inertia:

Every object continues in its state of rest, or of uniform velocity in a straight line, as long as no net force acts on it.

Demo: Driving without a seat belt.

Inertial Reference Frames:

Newton's first law does not hold in every reference frame, such as a reference frame that is accelerating or rotating.

An inertial reference frame is one in which **Newton's first law** is valid. This excludes **rotating** and **accelerating** frames.

How can we tell if we are in an inertial reference frame? By checking to see if Newton's first law holds!

Newton’s Second Law of Motion

Newton’s second law is the relation between **acceleration** and **force**. Acceleration is **proportional** to force and **inversely** proportional to mass.

$$\sum \vec{\mathbf{F}} = m\vec{\mathbf{a}}$$

It takes a force to change either the direction or the velocity of an object. i.e., force is the cause of change of motion.

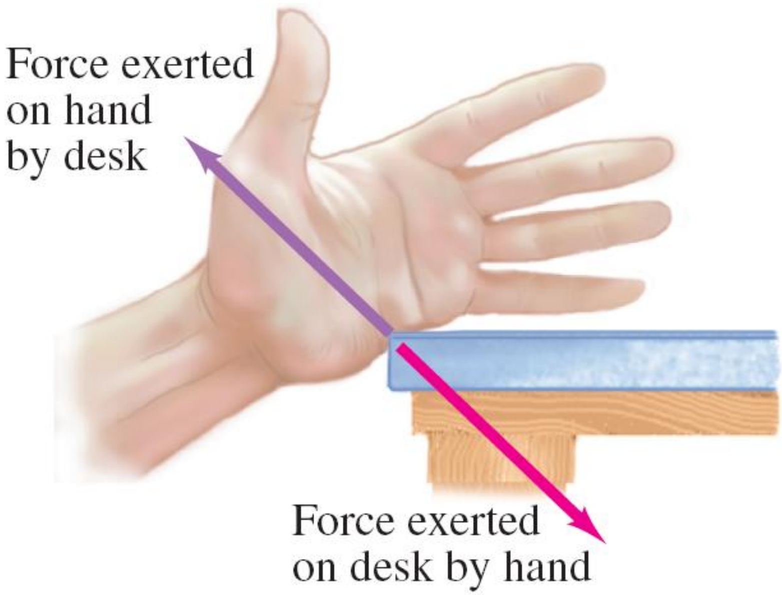
Note:

If we know the mass of an object and the net force acting on it, we will know its acceleration, but not the velocity (we don’t know how fast the object moves unless we have additional information).

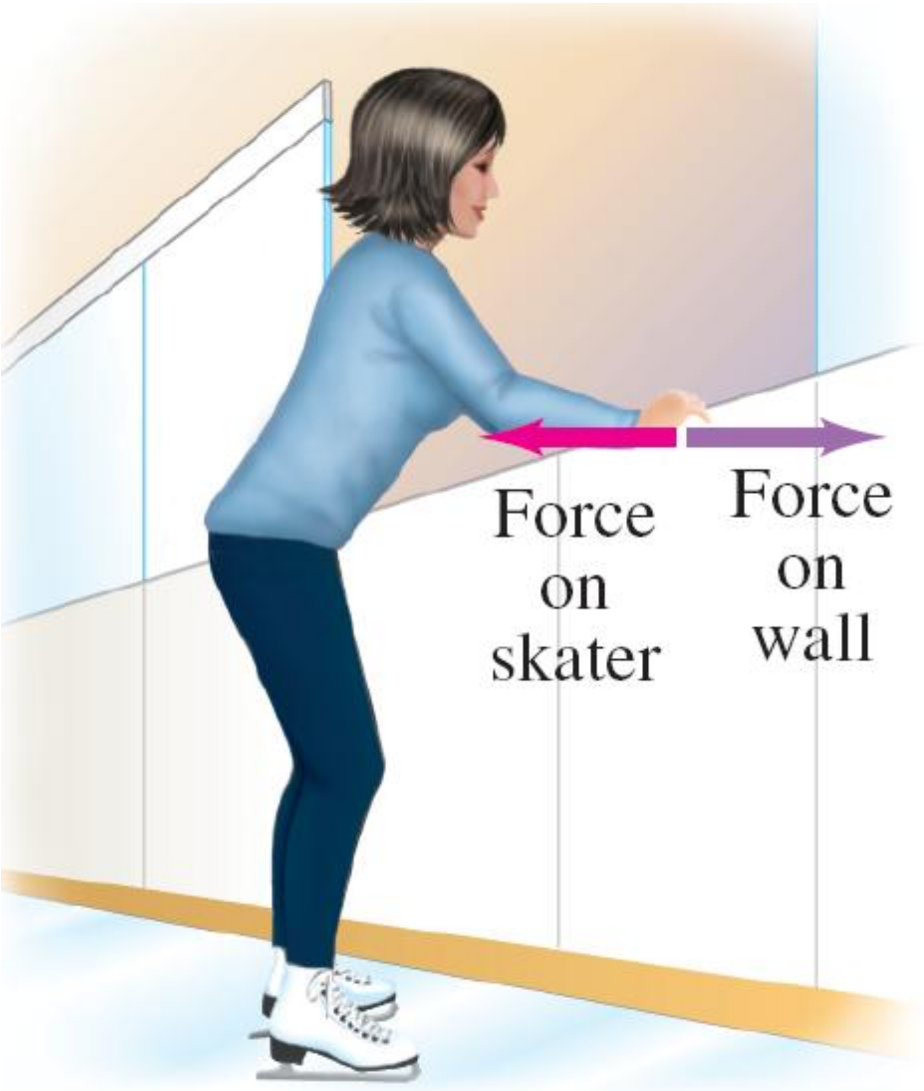
Newton's Third Law of Motion

Newton's third law:

Whenever one object exerts a force on a second object, the second exerts an equal force in the opposite direction on the first.



Newton's Third Law of Motion



A key to the correct application of the third law is that *the forces are exerted on different objects*. Make sure you don't use them as if they were acting on the *same* object.

Weight—the Force of Gravity

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 of an object of mass m is:

$$\vec{\mathbf{F}}_{G} = m\vec{\mathbf{g}},$$

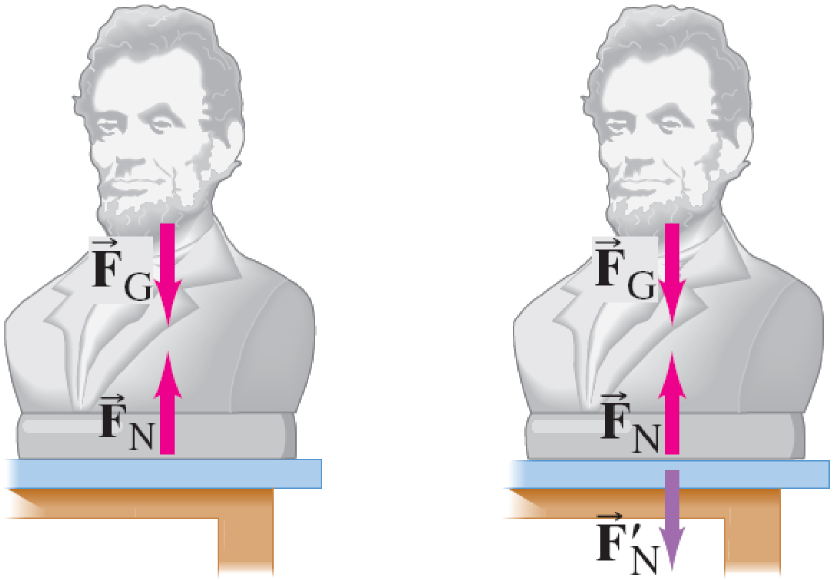
where

$$g = 9.80\ \mathrm{m/s^2}.$$

The Normal Force

An object at rest must have no **net force** on it. If it is sitting on a table, the force of gravity is still there; what other force is there?

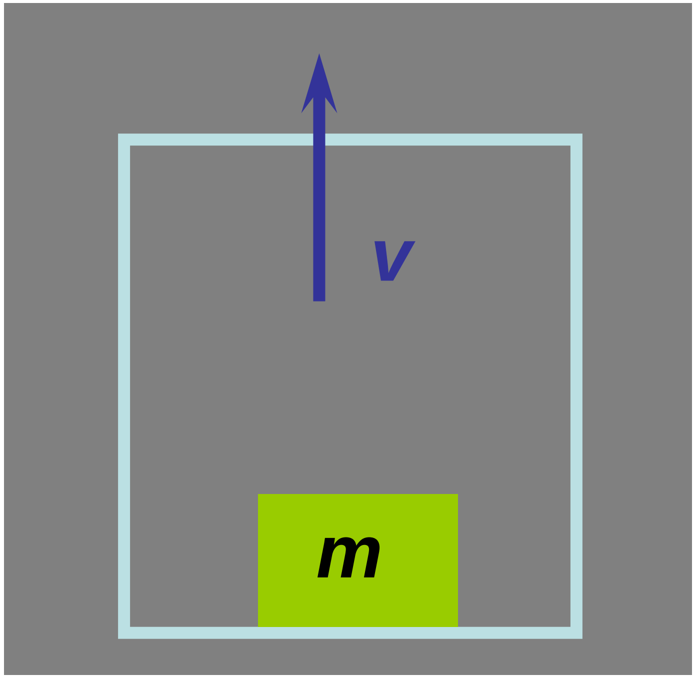
The force exerted perpendicular to a surface is called the **normal force**. It is exactly as large as needed to balance the force from the object. (If the required force gets too big, something breaks!)



i-clicker question 5-1

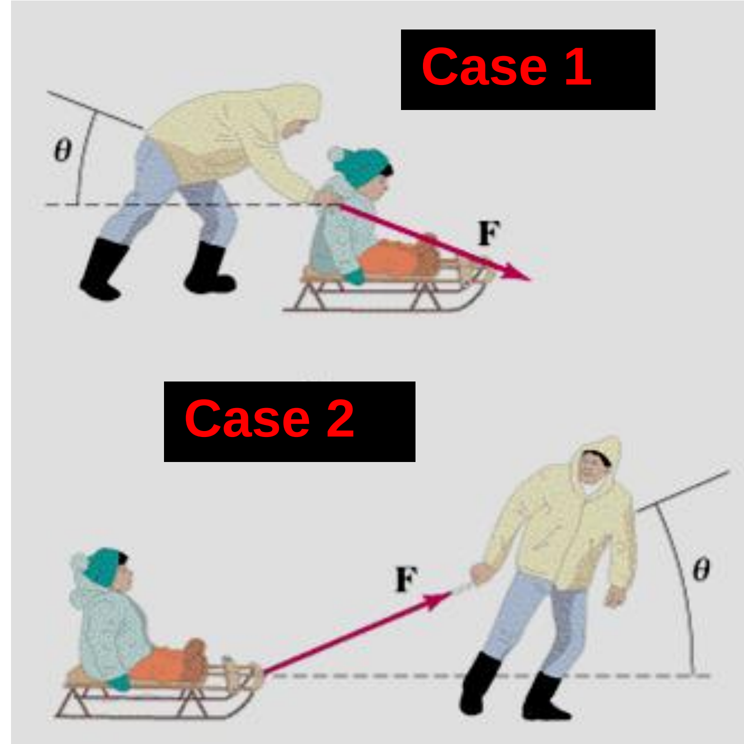
A block of mass *m* rests on the floor of an elevator that is moving upward at constant speed. What is the relationship between the force due to gravity and the normal force on the block?

1) $N > mg$
2) $N = mg$
3) $N < mg$ (but not zero)
4) $N = 0$
5) depends on the size of the elevator



i-clicker question 5-2

Here you see two cases: a physics student pulling or pushing a sled with a force *F* that is applied at an angle q. In which case is the normal force greater?



A) case 1

B) case 2

C) it's the same for both

D) depends on the magnitude of the force *F*

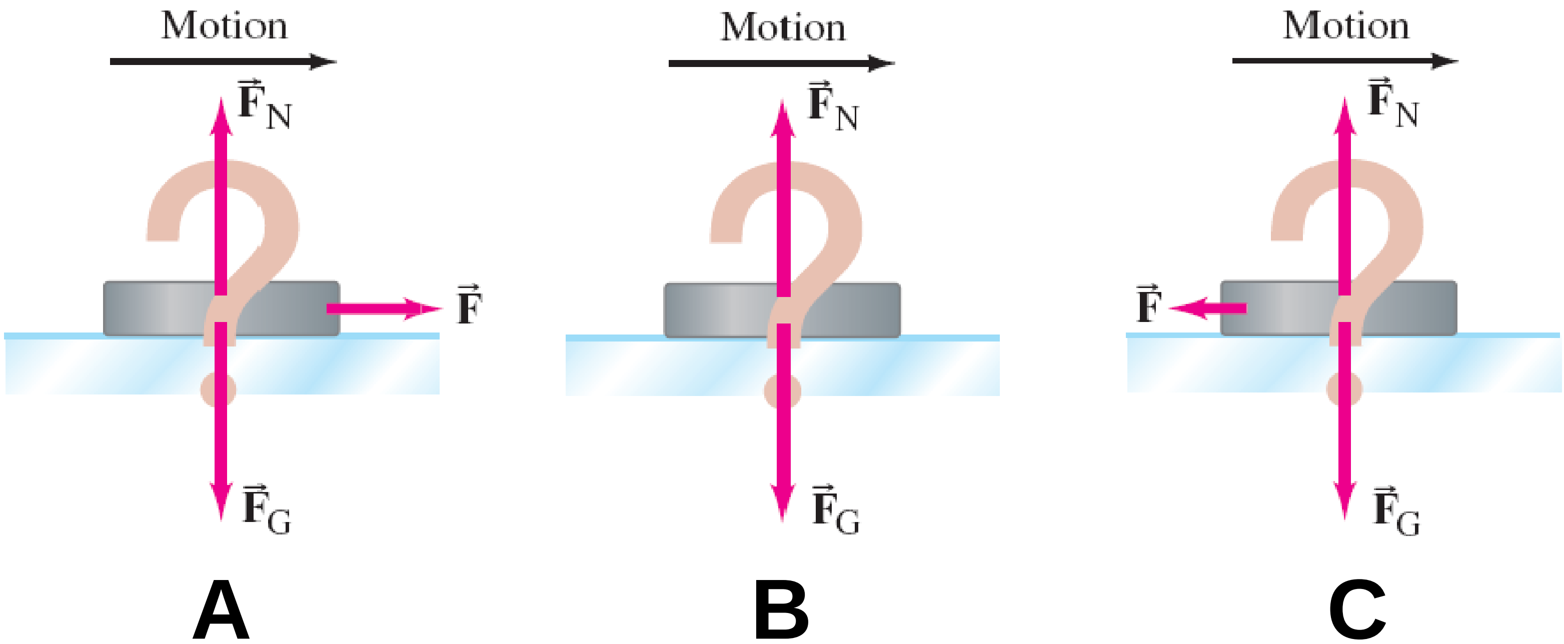
E) depends on the ice surface

Free-Body Diagram

A diagram showing all forces acting ***on*** an object.

What does “free-body” mean?

i-clicker question 5-3 and 5-4

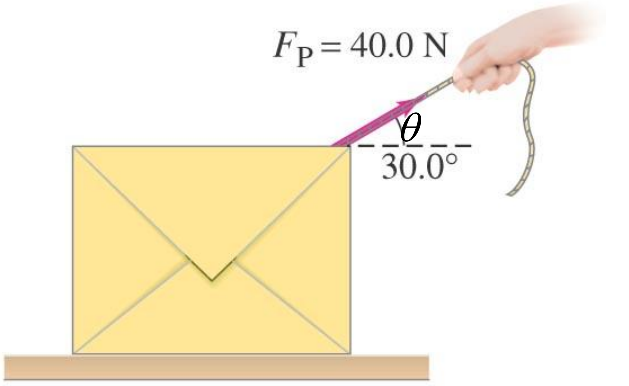


Conceptual Example: The hockey puck.

A hockey puck is sliding at constant velocity across a flat horizontal ice surface that is assumed to be frictionless. Which of these sketches is the correct free-body diagram for this puck? What would your answer be if the puck slowed down?

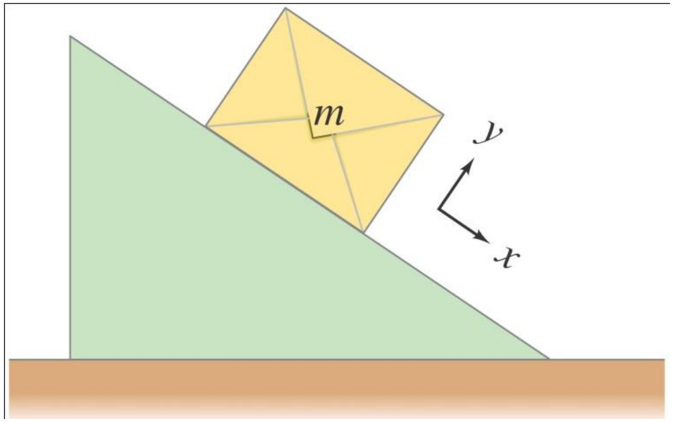
Example :

Tim pulls a 10-kg box by an attached cord on the smooth surface of a table. The magnitude of the force exerted by Tim is F_P = 40.0 N, and it is exerted at a 30.0° angle as shown. Calculate the acceleration of the box.



Example: Box slides down an incline.

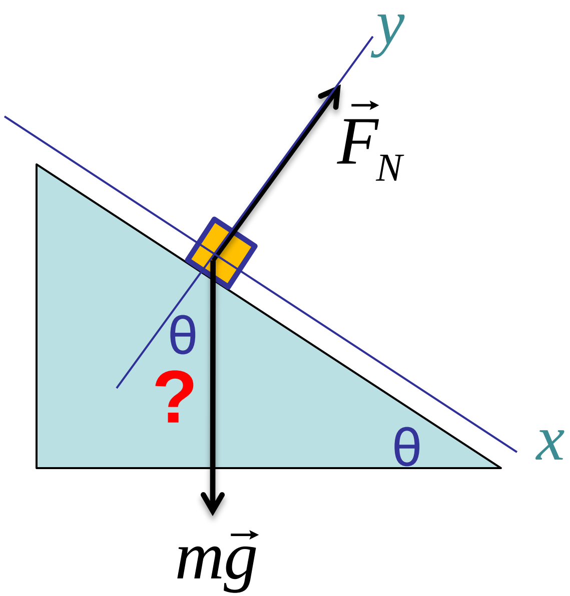
A box of mass m is placed on a smooth incline that makes an angle θ with the horizontal. (a) Determine the normal force on the box. (b) Determine the box's acceleration. (c) Evaluate for a mass m = 10 kg and an incline of θ = 30°.



[Solution]

First, FBD and x-y coordinates.

Then, Newton's law in component form:



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

$$x\text{-comp:}\quad mg\sin\theta = ma_x$$

$$y\text{-comp:}\quad F_N - mg\cos\theta = 0$$

(a) $F_N = mg\cos\theta$

(b) $a = a_x = g\sin\theta$

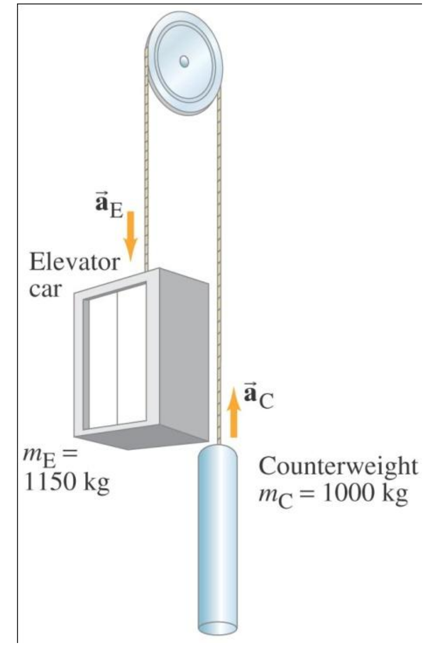
(c) $F_N = 85N,\quad a = 4.9m/s^2.$

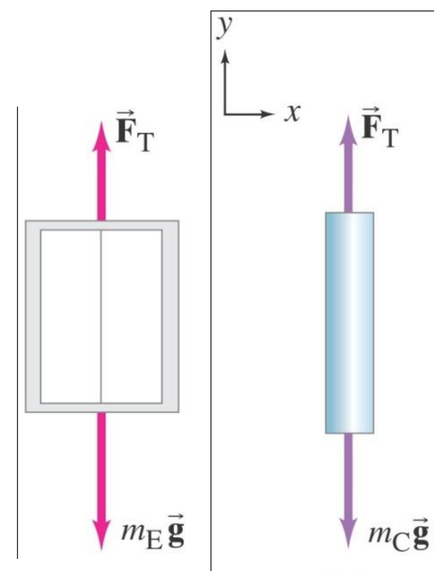
Again, two kinds of forces:

1. **Contact forces**
2. **Gravity.**

Example: Elevator and counterweight (Atwood’s machine).

A system of two objects suspended over a pulley by a flexible cable is sometimes referred to as an Atwood’s machine. Here, let the mass of the counterweight be 1000 kg. Assume the mass of the empty elevator is 850 kg, and its mass when carrying four passengers is 1150 kg. For the latter case calculate (a) the acceleration of the elevator and (b) the tension in the cable.

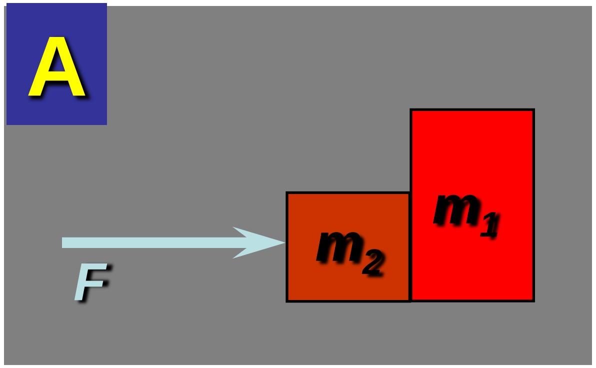


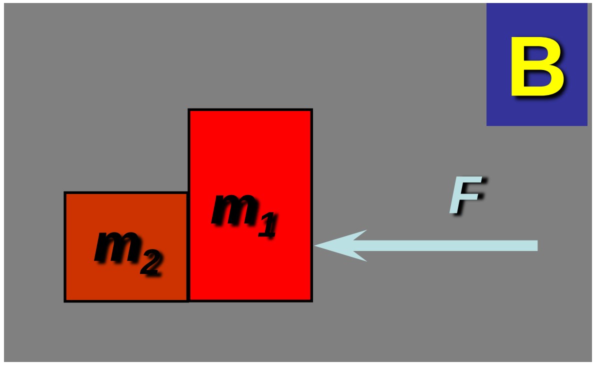


i-clicker question 5-5

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.

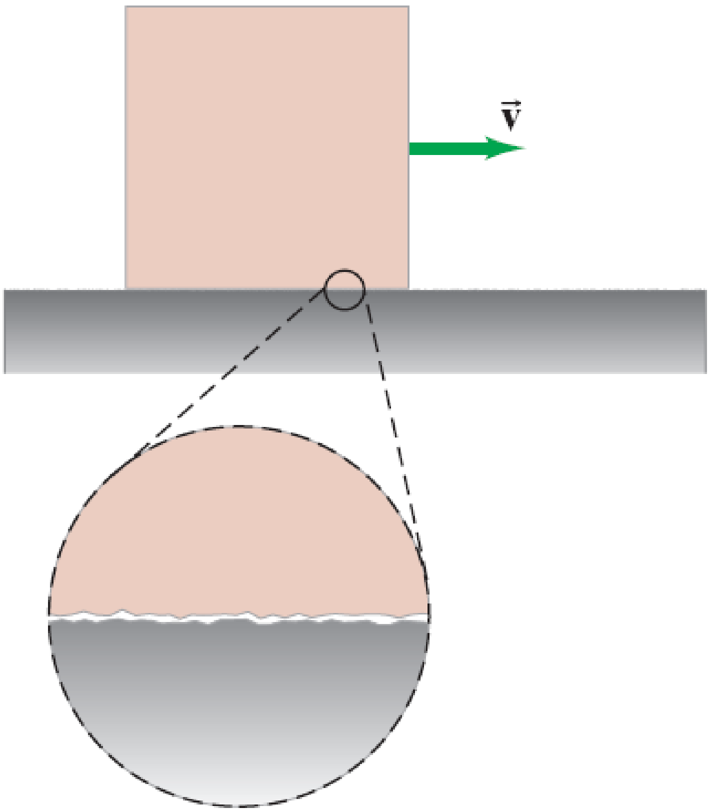
1) case A
2) case B
3) same in both cases





Friction

Friction is always present when two solid surfaces slide along each other.



The microscopic details are not yet fully understood.

Kinetic Friction

Sliding friction is called **kinetic** friction.

Approximation of the frictional force:

$$F_{\mathrm{fr}} = \mu_{\mathrm{k}} F_{\mathrm{N}}.$$

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 (such as a book sitting on a table).

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

$$F_{\mathrm{fr}} \le \mu_s F_{\mathrm{N}} .$$

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†

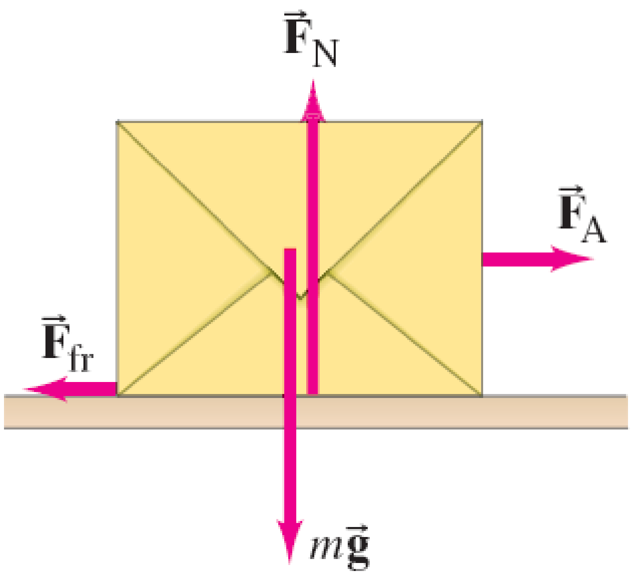
Surfaces	Coefficient of Static Friction, μ_s	Coefficient of Kinetic Friction, μ_k
Wood on wood	0.4	0.2
Ice on ice	0.1	0.03
Metal on metal (lubricated)	0.15	0.07
Steel on steel (unlubricated)	0.7	0.6
Rubber on dry concrete	1.0	0.8
Rubber on wet concrete	0.7	0.5
Rubber on other solid surfaces	1–4	1
Teflon® 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

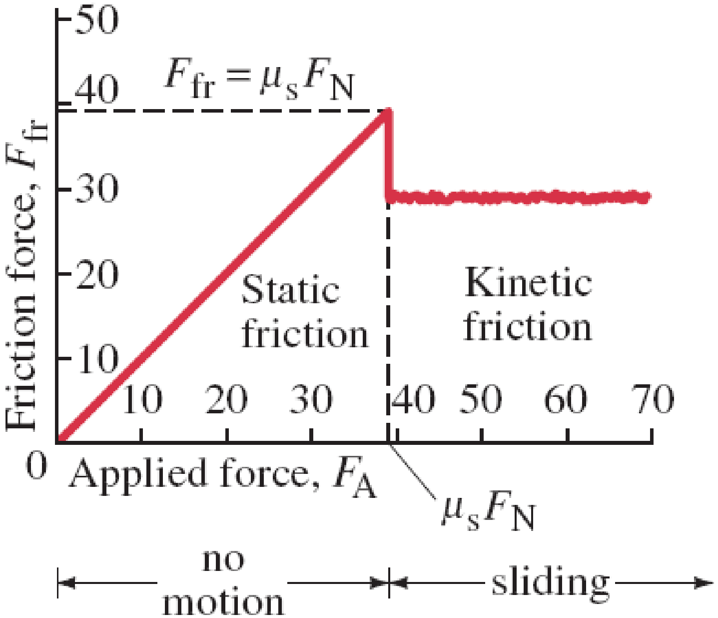
†Values are approximate and intended only as a guide.

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.

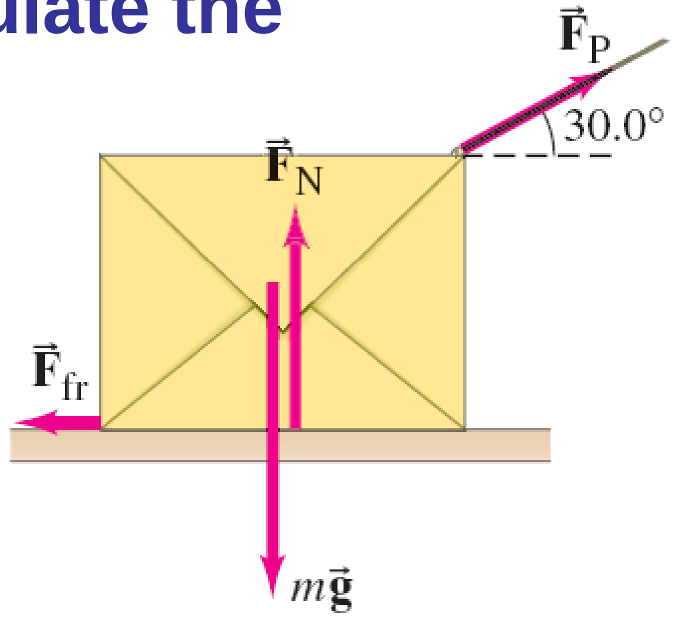




Applications of Newton's Laws Involving Friction

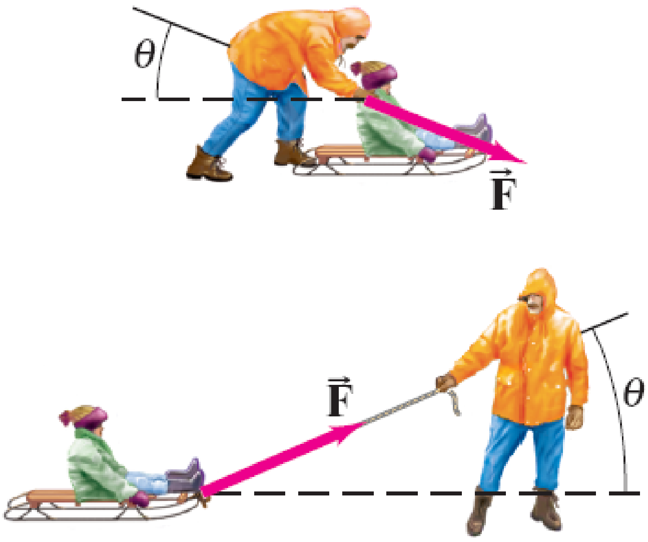
Example: Pulling against friction.

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.



i-clicker question 5-6

To push or to pull a sled?



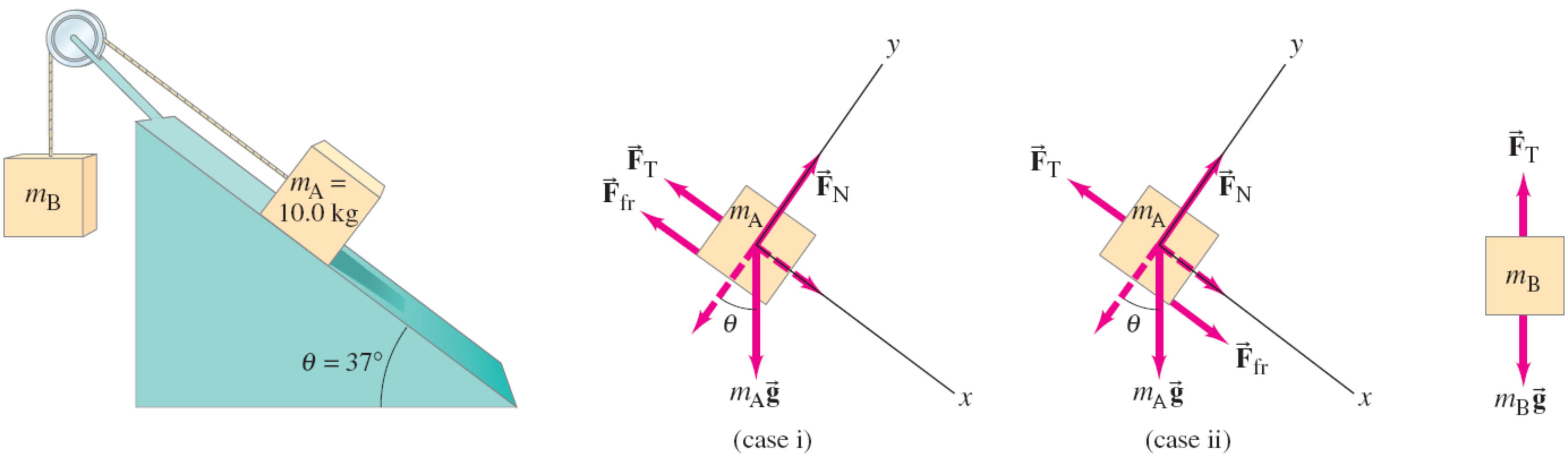
Your little sister wants a ride on her sled. If you are on flat ground, will you exert less force if you push her or pull her? Assume the same angle θ in each case.

A) Push
B) Pull
C) No difference

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

Example : 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.



Summary of Chapter 4

- Newton's first law: If the net force on an object is zero, it will remain either at rest or moving in a straight line at constant speed.

- Newton's second law: $\Sigma \vec{\mathbf{F}} = m\vec{\mathbf{a}}.$

- Newton's third law: $\vec{\mathbf{F}}_{\mathrm{AB}} = -\vec{\mathbf{F}}_{\mathrm{BA}}.$

- Weight is the gravitational force on an object.

- Free-body diagrams are essential for problem-solving. Do one object at a time, make sure you have all the forces, pick a coordinate system and find the force components, and apply Newton's second law along each axis.