# #12 Equilibrium, Dynamics Pre-class

Due: 11:00am on Wednesday, September 19, 2012

***Note: You will receive no credit for late submissions.*** To learn more, read your instructor's Grading Policy

## The Normal Force

When an object rests on a surface, there is always a force perpendicular to the surface; we call this the normal force, denoted by $\vec{n}$. The two questions to the right will explore the normal force.

### Part A

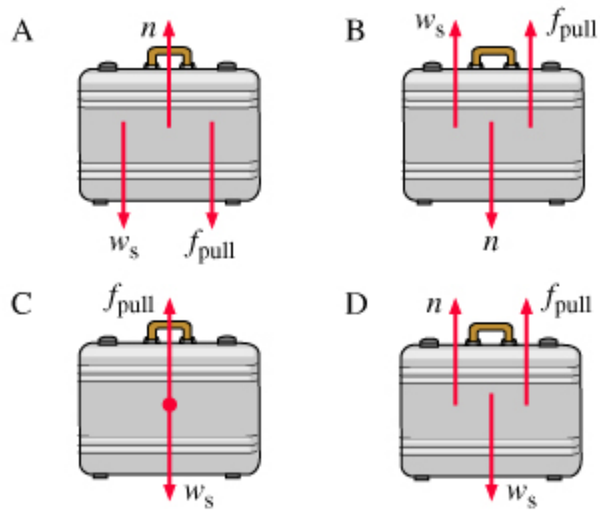
A man attempts to pick up his suitcase of weight $w_s$ by pulling straight up on the handle. However, he is unable to lift the suitcase from the floor. Which statement about the magnitude of the normal force $n$ acting on the suitcase is true during the time that the man pulls upward on the suitcase?

**Hint 1.** How to approach this problem

First, identify the forces that act on the suitcase and draw a free-body diagram. Then use the fact that the suitcase is in equilibrium, $\sum \vec{F} = 0$, to examine how the forces acting on the suitcase relate to each other.

**Hint 2.** Identify the correct free-body diagram

Which of the figures represents the free-body diagram of the suitcase while the man is pulling on the handle with a force of magnitude $f_{\rm pull}$?




ANSWER:

- A
- B
- C
- D

ANSWER:

- The magnitude of the normal force is equal to the magnitude of the weight of the suitcase.
- The magnitude of the normal force is equal to the magnitude of the weight of the suitcase minus the magnitude of the force of the pull.
- The magnitude of the normal force is equal to the sum of the magnitude of the force of the pull and the magnitude of the suitcase's weight.
- The magnitude of the normal force is greater than the magnitude of the weight of the suitcase.

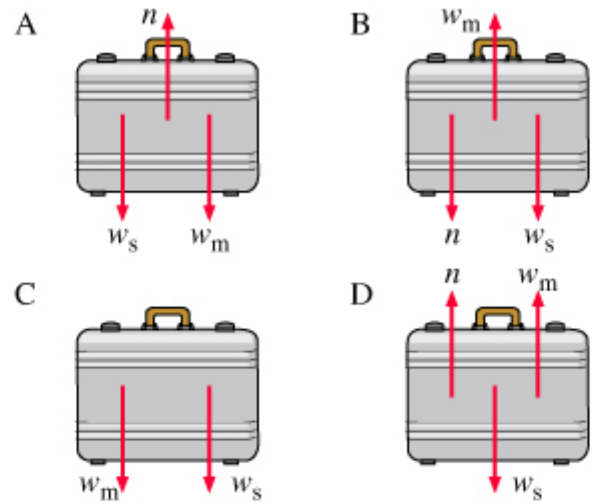
**Correct**

## Part B

Now assume that the man of weight $w_{\rm m}$ is tired and decides to sit on his suitcase. Which statement about the magnitude of the normal force $n$ acting on the suitcase is true during the time that the man is sitting on the suitcase?

**Hint 1.** Identify the correct free-body diagram.

Which of the figures represents the free-body diagram while the man is sitting atop the suitcase? Here the vector labeled $w_{\rm m}$ is a force that has the same magnitude as the man's weight.




ANSWER:

- A
- B
- C
- D

ANSWER:

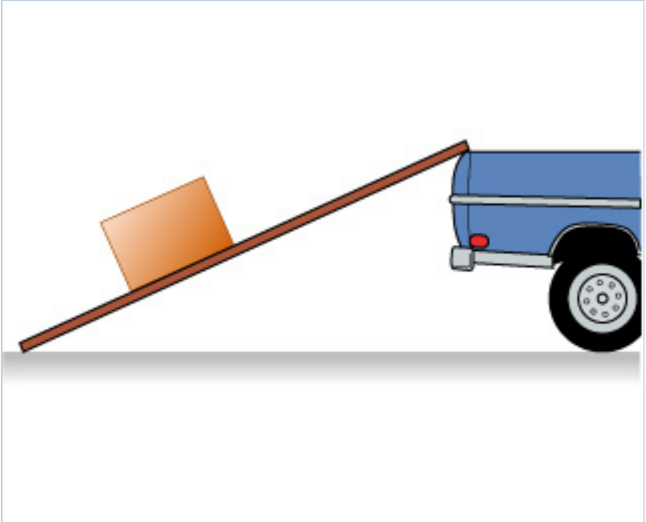
- The magnitude of the normal force is equal to the magnitude of the suitcase's weight.
- The magnitude of the normal force is equal to the magnitude of the suitcase's weight minus the magnitude of the man's weight.
- The magnitude of the normal force is equal to the sum of the magnitude of the man's weight and the magnitude of the suitcase's weight.
- The magnitude of the normal force is less than the magnitude of the suitcase's weight.

**Correct**

Recognize that the normal force acting on an object is *not* always equal to the weight of that object. This is an important point to understand.

## Comparing Friction Forces with Gravity Conceptual Question

A large crate filled with physics laboratory equipment must be moved up an incline onto a truck.



### Part A

The crate is at rest on the incline. What can you say about the force of friction acting on the crate?

**Hint 1.** Determining the direction of the frictional force

The frictional force points in the direction that opposes the relative motion between two surfaces. If, however, the two surfaces are not in relative motion, imagine the direction of relative motion that would result if friction did not exist. Friction then will act in opposition to this hypothetical relative motion.

ANSWER:

- (selected) The frictional force points up the incline.
- The frictional force points down the incline.
- The frictional force is zero.

**Correct**

## Part B

A physicist attempts to push the crate up the incline. The physicist senses that if he applies slightly more force the crate will move up the incline but cannot muster enough strength to get the motion started. What can you say now about the force of friction acting on the crate?

ANSWER:

- ○ The frictional force points up the incline.
- ◉ The frictional force points down the incline.
- ○ The frictional force is zero.

**Correct**

## Part C

The first physicist gets a second physicist to help. They both push on the crate, parallel to the surface of the incline, and it moves at constant speed up the incline. How does the force exerted by the two physicists on the crate compare with the force of friction on the crate?

**Hint 1.** Comparing forces

When answering any question regarding forces, your first step should be to draw a free-body diagram. Once you know the forces involved in the situation, your next step should be to determine the acceleration of the object. By Newton's 2nd law, the net force must be proportional to the object's acceleration.

**Hint 2.** Apply Newton's 2nd law

Construct a free-body diagram for the crate, with all forces beginning at the origin. Notice that three forces act in the direction parallel to the incline: the push, friction, and a component of the force of gravity. According to Newton's 2nd law,

$$(\sum \vec{F})_{||} = ma_{||}.$$

Considering the acceleration of the crate and the directions of the three forces, which force must have the largest magnitude?

ANSWER:

- the push
- friction
- the component of gravity

ANSWER:

$F_{\text{two physicists}}$ [ is less than / equals / is greater than ] $F_{\text{friction}}$.

- is less than
- equals
- is greater than

**Correct**

## Contact Forces Introduced

**Learning Goal:**

To introduce contact forces (normal and friction forces) and to understand that, except for friction forces under certain circumstances, these forces must be determined from: net Force = ma.

Two solid objects cannot occupy the same space at the same time. Indeed, when the objects touch, they exert repulsive *normal* forces on each other, as well as *frictional* forces that resist their slipping relative to each other. These *contact forces* arise from a complex interplay between the electrostatic forces between the electrons and ions in the objects and the laws of quantum mechanics. As two surfaces are pushed together these forces increase exponentially over an atomic distance scale, easily becoming strong enough to distort the bulk material in the objects if they approach too close. In everyday experience, contact forces are limited by the deformation or acceleration of the objects, rather than by the fundamental interatomic forces. Hence, we can conclude the following:

The magnitude of contact forces is determined by $\sum \vec{F} = m\vec{a}$, that is, by the other forces on, and acceleration of, the contacting bodies. The only exception is that the frictional forces cannot exceed $\mu n$ (although they can be smaller than this or even zero).

## Normal and friction forces

Two types of contact forces operate in typical mechanics problems, the *normal* and *frictional* forces, usually designated by $n$ and $f$ (or $F_{\rm fric}$, or something similar) respectively. These are the components of the overall contact force: $n$ perpendicular to and $f$ parallel to the plane of contact.

## Kinetic friction when surfaces slide

When one surface is sliding past the other, experiments show three things about the friction force (denoted $f_{\rm k}$):

1. The frictional force opposes the relative motion at the point of contact,
2. $f_{\rm k}$ is proportional to the normal force, and
3. the ratio of the magnitude of the frictional force to that of the normal force is fairly constant over a wide range of speeds.

The constant of proportionality is called the *coefficient of kinetic friction*, often designated $\mu_{\rm k}$. As long as the sliding continues, the frictional force is then

$f_{\rm k} = \mu_{\rm k} n$ (valid when the surfaces slide by each other).

## Static friction when surfaces don't slide

When there is no relative motion of the surfaces, the frictional force can assume *any* value from zero up to a maximum $\mu_{\rm s} n$, where $\mu_{\rm s}$ is the *coefficient of static friction*. Invariably, $\mu_{\rm s}$ is larger than $\mu_{\rm k}$, in agreement with the observation that when a force is large enough that something breaks loose and starts to slide, it often accelerates.

The frictional force for surfaces with no relative motion is therefore

$f_{\rm s} \le \mu_{\rm s} n$ (valid when the contacting surfaces have no relative motion).

The actual magnitude and direction of the static friction force are such that it (together with other forces on the object) causes the object to remain motionless with respect to the contacting surface as long as the static friction force required does not exceed $\mu_{\rm s} n$. The equation $f_{\rm s} = \mu_{\rm s} n$ is valid *only* when the surfaces are on the verge of sliding.

### Part A

When two objects slide by one another, which of the following statements about the force of friction between them, is true?

ANSWER:

- The frictional force is always equal to \mu_{\rm k}n.
- The frictional force is always less than \mu_{\rm k}n.
- The frictional force is determined by other forces on the objects so it can be either equal to or less than \mu_{\rm k}n.

**Correct**

---

## Part B

When two objects are in contact with no relative motion, which of the following statements about the frictional force between them, is true?

ANSWER:

- The frictional force is always equal to $\mu_s n$.
- The frictional force is always less than $\mu_s n$.
- The frictional force is determined by other forces on the objects so it can be either equal to or less than $\mu_s n$.

**Correct**

For static friction, the actual magnitude and direction of the friction force are such that it, together with any other forces present, will cause the object to have the observed acceleration. The magnitude of the force cannot exceed $\mu_s n$. If the magnitude of static friction needed to keep acceleration equal to zero exceeds $\mu_s n$, then the object will slide subject to the resistance of kinetic friction. Do *not* automatically assume that $f_s = \mu_s n$ unless you are considering a situation in which the magnitude of the static friction force is as large as possible (i.e., when determining at what point an object will just begin to slip). Whether the actual magnitude of the friction force is 0, less than $\mu_s n$, or equal to $\mu_s n$ depends on the magnitude of the other forces (if any) as well as the acceleration of the object through $\sum \vec{F} = m\vec{a}$.

### Part C

When a board with a box on it is slowly tilted to larger and larger angle, common experience shows that the box will at some point "break loose" and start to accelerate down the board.

The box begins to slide once the component of gravity acting parallel to the board $F_g$ equals the force of static friction. Which of the following is the most general explanation for why the box accelerates down the board?

ANSWER:

- ◉ The force of kinetic friction is smaller than that of static friction, but $F_g$ remains the same.
- ○ Once the box is moving, $F_g$ is smaller than the force of static friction but larger than the force of kinetic friction.
- ○ Once the box is moving, $F_g$ is larger than the force of static friction.
- ○ When the box is stationary, $F_g$ equals the force of static friction, but once the box starts moving, the sliding reduces the normal force, which in turn reduces the friction.

**Correct**

At the point when the box finally does "break loose," you know that the component of the box's weight that is parallel to the board is equal to $\mu_s n$ (i.e., this component of gravitational force on the box has just reached a magnitude such that the force of static friction, which has a maximum value of $\mu_s n$ , can no longer oppose it.) For the box to then accelerate, there must be a net force on the box along the board. Thus, the component of the box's weight parallel to the board must be greater than the force of kinetic friction. Therefore the force of kinetic friction $\mu_k n$ must be less than the force of static friction $\mu_s n$ which implies $\mu_k < \mu_s$, as expected.

### Part D

Consider a problem in which a car of mass $M$ is on a road tilted at an angle $\theta$. The normal force

**Select the best answer.**

ANSWER:

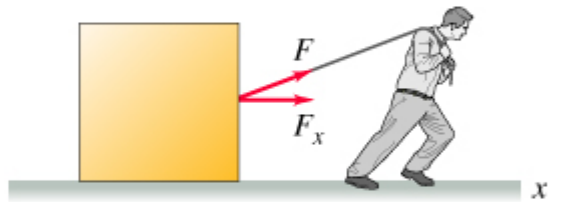
- $n = Mg$
- $n = Mg\cos(\theta)$
- $n = \frac{Mg}{\cos(\theta)}$
- is found using $\sum \vec{F} = M\vec{a}$

**Correct**

The key point is that contact forces must be determined from Newton's equation. In the problem described above, there is not enough information given to determine the normal force (e.g., the acceleration is unknown). Each of the answer options is valid under some conditions ($\theta = 0$, the car is sliding down an icy incline, or the car is going around a banked turn), but in fact none is likely to be correct if there are other forces on the car or if the car is accelerating. Do not memorize values for the normal force valid in different problems--you must determine $\vec{n}$ from $\sum \vec{F} = m\vec{a}$.

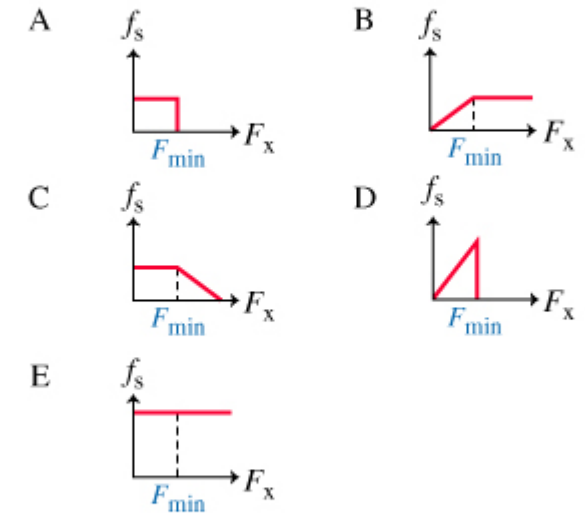
## A Friction Experiment

During an experiment, a crate is pulled along a rough horizontal surface by a force $\vec{F}$ and the magnitude of the acceleration along the *x* direction, $a_x$, is measured. The vector $\vec{F}$ has a component along the *x* direction of magnitude $F_x$. The experiment is repeated several times, with different values of $F_x$ each time, while maintaining a constant value for, F_y, the vertical component of $\vec{F}$.



## Part A

Create a plot of the force of static friction, $f_s$, versus the *x* component of the pulling force, $F_x$, for the experiment. Let the point $F_{min}$, along the horizontal axis, represent the minimum force required to accelerate the crate. Choose the graph that most accurately depicts the relationship among $f_s$, $F_x$, and $F_{min}$.




**Hint 1.** Characteristics of static friction

There are two important characteristics to keep in mind about the the force of static friction:

- Only a stationary object can be acted upon by the force of static friction.
- $f_{{\rm s}} \leq \mu_{\rm s} n$, where $\mu_s$ is the coefficient of static friction and $n$ is the magnitude of the normal force. This inequality means that the actual force of static friction can have any magnitude between zero and a maximum value of $\mu_s n$.

**Hint 2.** Find the force of static friction

A horizontal force of magnitude $F_{\rm H}$ is exerted on a stationary crate. The maximum force of static friction, $f_{\rm s,\;max}$, between the crate and the floor is 15 $\rm{N}$. Assume that $F_{\rm H}$ is the only force, besides that of static friction, $f_s$, acting horizontally on the crate.

What is $f_s$ when no horizontal force is applied to the crate, that is, when $F_{\rm H} = 0 \;\rm{N}$? What is $f_s$ when $F_{\rm H} = 10\;\rm N$? What is $f_s$ the instant the crate starts to move?

**Enter your answers numerically in newtons. Separate each answer with a comma. For example if the answers are 100, 200, and $-50$ $\mathrm{N}$ enter `100,200,-50`.**

**Hint 1.** Applying Newton's 2nd law

A horizontal force $F$ is applied to the crate. However, the force of static friction, $f_s$, opposes this force and causes the crate to remain stationary, meaning that $a_x = 0$. From Newton's 2nd law we know that

$$\sum F_x = ma_x.$$

This yields

$$\sum F_x = F_{\rm H} - f_{\rm s} = ma_x = 0$$

when applied to this specific problem.

ANSWER:

$f_s =$ 0,10,15 $\mathrm{N}$

ANSWER:

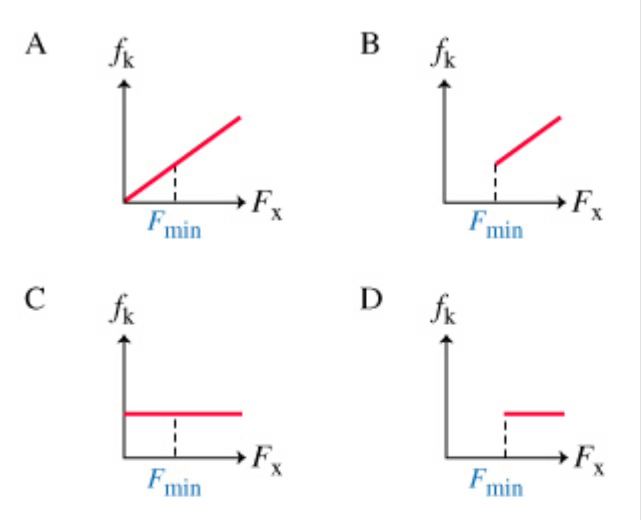
- A
- B
- C
- D
- E

**Correct**

Notice that until the pulling force $F_x$ exceeds f_{\rm s,\;max}, the force of static friction is exactly equal in magnitude to the pulling force.

## Part B

Create a plot of the force of kinetic friction, $f_k$, versus the *x* component of the pulling force, $F_x$, for the experiment. Let the point F_min, along the horizontal axis, represent the minimum force required to accelerate the crate. Choose the graph that most accurately depicts the relationship among $f_k$, $F_x$, and F_min.




**Hint 1.** Characteristics of kinetic friction

There are three important characteristics to keep in mind about the force of kinetic friction:

- Only an object that is sliding with respect to a surface can be acted upon by the force of kinetic friction.
- f_k_vec points in a direction that is parallel to the surface of contact and opposes the motion of the object.
- f_{\rm k} = \mu_{\rm k}n, where $\mu_k$ is the coefficient of kinetic friction and $N$ is the magnitude of the normal force.

ANSWER:

- A
- B
- C
- D

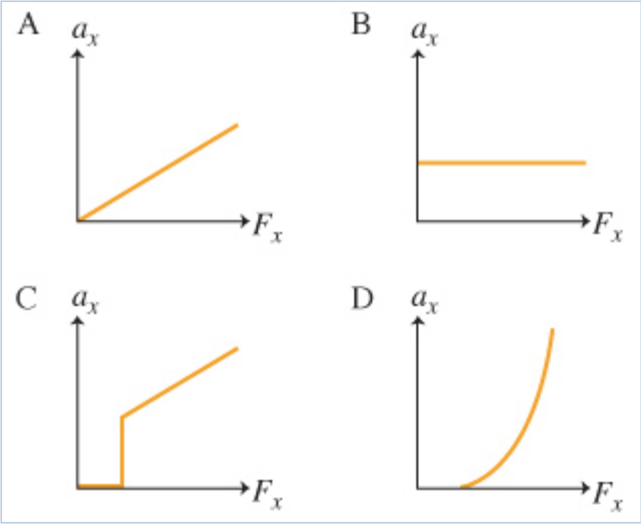
**Correct**

The most important things to keep in mind when dealing with kinetic friction are the following:

- Only an object that is sliding with respect to a surface can be acted upon by the force of kinetic friction.
- f_k_vec points in a direction that is parallel to the surface of contact and opposes the motion of the object.
- f_{\rm k} = \mu_{\rm k}n, where $\mu_k$ is the coefficient of kinetic friction and $N$ is the magnitude of the normal force.

## Part C

After all the trials are completed, a graph of acceleration $a_x$ as a function of force $F_x$ is plotted. Assuming the presence of both static and kinetic friction, which of the following graphs is most nearly correct?



ANSWER:

- A
- B
- C (selected)
- D

**Correct**

## Score Summary:

Your score on this assignment is 90.4%.
You received 18.07 out of a possible total of 20 points.