General Physics (PHY 2130)

Lecture 9

- Solving problems with Newton's laws
- Gravity
- Contact forces

http://www.physics.wayne.edu/~apetrov/PHY2130/

WAYNE STATE UNIVERSITY

Lightning Review

Last lecture:

Laws of motion: forces, three Newton's laws:

- ✓ If no forces act on an object, it continues in its original state of motion
- ✓ The acceleration of an object is directly proportional to the net force acting on it and inversely proportional to its mass.
- ✓ If two objects interact, the force F_{12} exerted by object 1 on object 2 is equal in magnitude but opposite in direction to the force F_{21} exerted by object 2 on object 1.

Review Problem: A football player kicks a football. After one second in flight, what external forces are acting on the ball (neglect air resistance)?

(1) force of the kick and force of gravity
(2) force of gravity only
(3) 9.8 m/s^2

Applying Newton’s Laws

- Assumptions
  - Objects behave as particles
    - can ignore rotational motion (for now)
  - Masses of strings or ropes are negligible
  - Interested only in the forces acting on the object

Equilibrium

- An object either at rest or moving with a constant velocity is said to be in *equilibrium*
- The net force acting on the object is zero

$$\sum \vec{F} = 0 \quad \rightarrow \quad \sum F_x = 0, \quad \sum F_y = 0$$

- Easier to work with the equation in terms of its components

Solving Equilibrium Problems

- Make a sketch of the situation described in the problem
- Draw a free body diagram for the isolated object under consideration and label all the forces acting on it
- Resolve the forces into x- and y-components, using a convenient coordinate system
- Apply equations, keeping track of signs
- Solve the resulting equations

Newton's Second Law Problems

- Similar to equilibrium except

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

- Use components

$$\sum F_x = ma_x \qquad \sum F_y = ma_y$$

- a_x or a_y may be zero

Solving Newton's Second Law Problems

- Make a sketch of the situation described in the problem
- Draw a free body diagram for the isolated object under consideration and label all the forces acting on it
  - If more than one object is present, draw free body diagram for each object
- Resolve the forces into x- and y-components, using a convenient coordinate system
- Apply equations, keeping track of signs
- Solve the resulting equations

Applying Newton's Laws

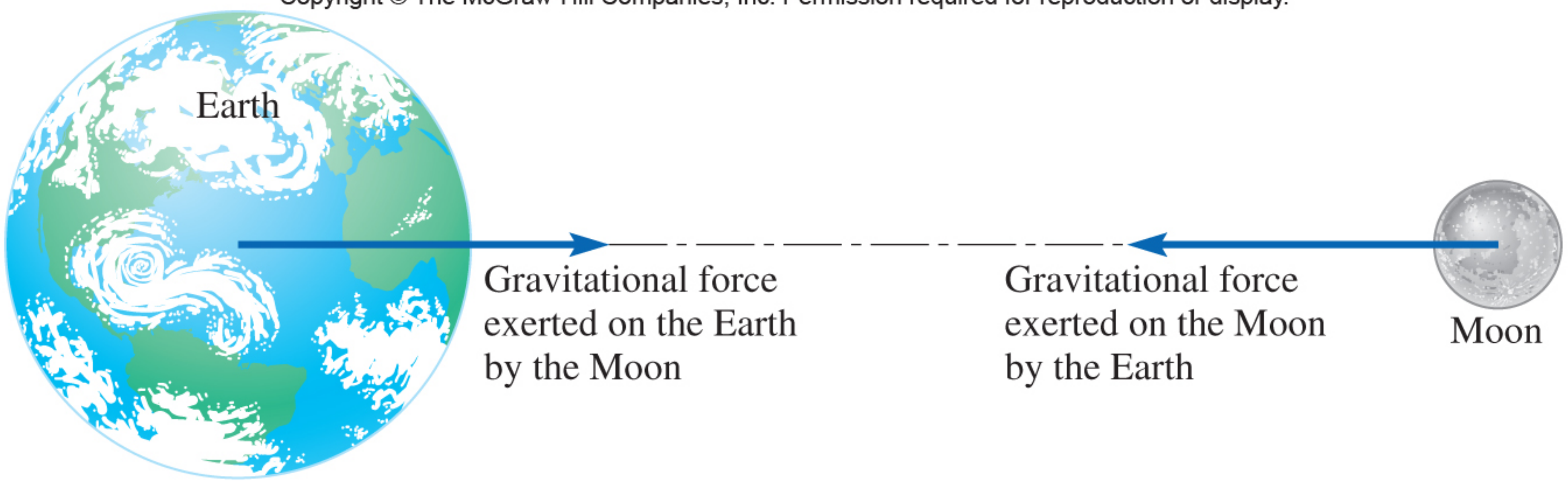
- Make a sketch of the situation described in the problem, introduce a coordinate frame
- Draw a free body diagram for the isolated object under consideration and label all the forces acting on it
- Resolve the forces into x- and y-components, using a convenient coordinate system
- Apply equations, keeping track of signs
- Solve the resulting equations

Let’s apply those ideas!

Gravitational Force

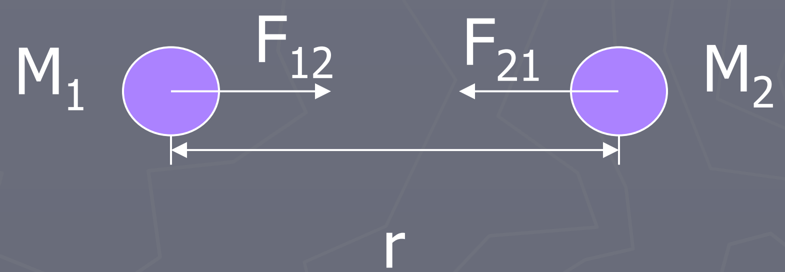
- Mutual force of attraction between any two objects
- Expressed by Newton's Law of Universal Gravitation:

$$F_g = G\frac{m_1 m_2}{r^2}$$



Properties of Gravitational Force

- Gravity is the force between two masses.
- Gravity is a long-range or field force.
- No contact is needed between the bodies.
- The force of gravity is always attractive



$$F = \frac{Gm_1 m_2}{r^2}$$

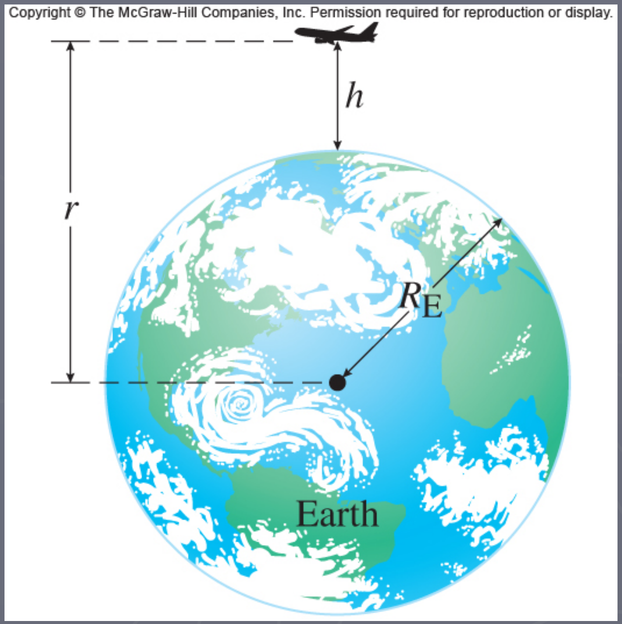
Universal Gravitational Constant
G = 6.674 x 10^{-11} Nm^2/kg^2

Gravitational force by Earth

The force the Earth exerts on mass m.

$$F = \left(\frac{GM_E}{r^2}\right)m$$

This is the force known as weight, w.



$$M_E = 5.98 \times 10^{24}\ \text{kg}$$

$$R_E = 6400\ \text{km}$$

If mass m falls toward Earth:

From Newton's 2nd law

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

$$\left(\frac{GM_E}{r^2}\right)m = ma$$

$$a = \frac{GM_E}{r^2}$$

Thus, near the surface of the Earth

$$a = g = \frac{GM_E}{R_E^2} = 9.8\ \text{N/kg} = 9.8\ \text{m/s}^2$$

Note that $\mathbf{g} = \frac{\mathbf{F}}{m}$ is the gravitational force per unit mass. This is called the gravitational field strength. It is also referred to as the acceleration due to gravity.

What is the direction of **g**?

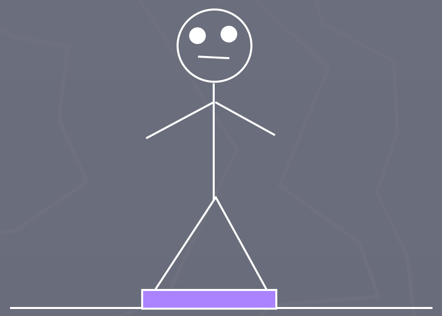
What is the direction of **w**?

Let's talk more about the Weight

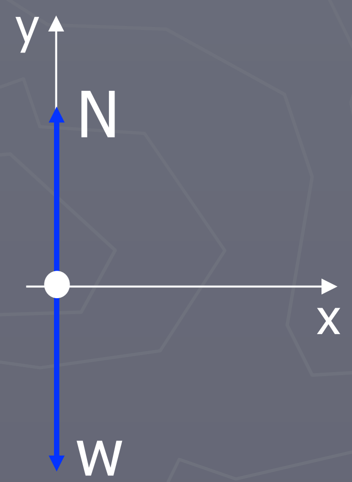
- As defined previously, the magnitude of the gravitational force acting on an object of mass m near the Earth's surface is called the weight w of the object
  - $w = m g$ is a special case of Newton's Second Law

Real-life example: measuring weight

How does the bathroom scale work?



FBD:



Apply Newton's 2nd Law:

$$\sum F_y = N - w = ma_y$$

$$N - mg = ma_y$$

Note that a_y could be non-zero if the scale is located, say in an elevator!

The normal force is the force the scale exerts on you. By Newton's 3^{rd} Law this is also the force (magnitude only) you exert on the scale. A scale will read the normal force, i.e.

$$N = m\left(g + a_y\right)$$ is what the scale reads.

When $a_y = 0$, $N = mg$. The scale reads your true weight.

When $a_y \neq 0$, $N > mg$ or $N < mg$.

Example: A woman of mass 51 kg is standing in an elevator. If the elevator pushes up on her feet with 408 Newtons of force, what is the acceleration of the elevator?

Given:

N = 408 N

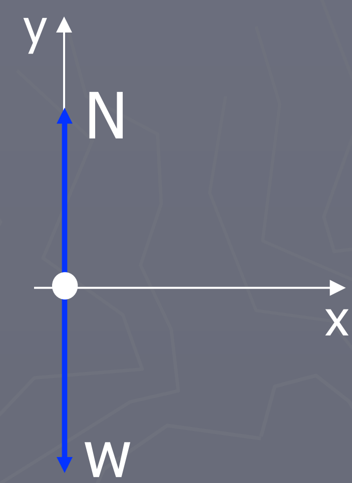
m = 51 kg

g = 9.8 m/s^2

Find:

a_y = ?

1. Draw a free body diagram:



2. Apply Newton's 2nd Law:

$$\sum F_y = N - w = ma_y$$

$$N - mg = ma_y$$

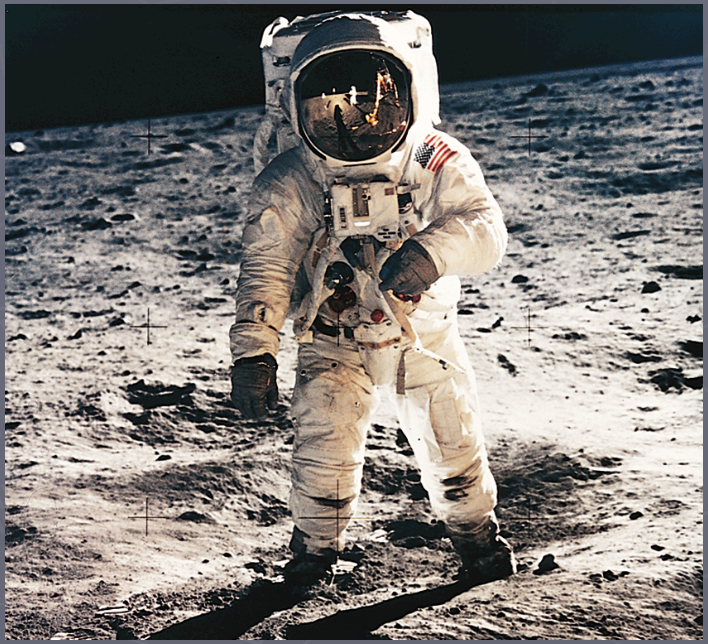
3. Solve for a_y:

$$a_y = \frac{N - mg}{m} = -1.8\ \mathrm{m/s^2}$$

The elevator could be (1) traveling upward with decreasing speed, or (2) traveling downward with increasing speed.

More about weight

- Weight is **not** an inherent property of an object
  - mass **is** an inherent property
- Weight depends upon location



Example: What is the weight of a 100 kg astronaut on the surface of the Earth (force of the Earth on the astronaut)? How about in low Earth orbit? This is an orbit about 300 km above the surface of the Earth.

On Earth: $w = mg = 980\ \mathrm{N}$

In low Earth orbit: $w = mg(r_o) = m\left(\dfrac{GM_E}{(R_E + h)^2}\right) = 890\ \mathrm{N}$

Their weight is reduced by about 10%.
The astronaut is NOT weightless!

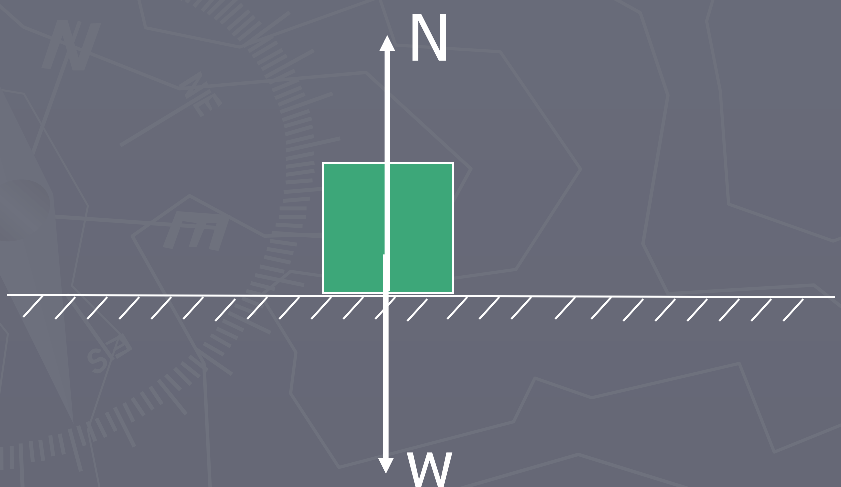
Contact forces

Note: arise because of an interaction between the atoms in the surfaces in contact.

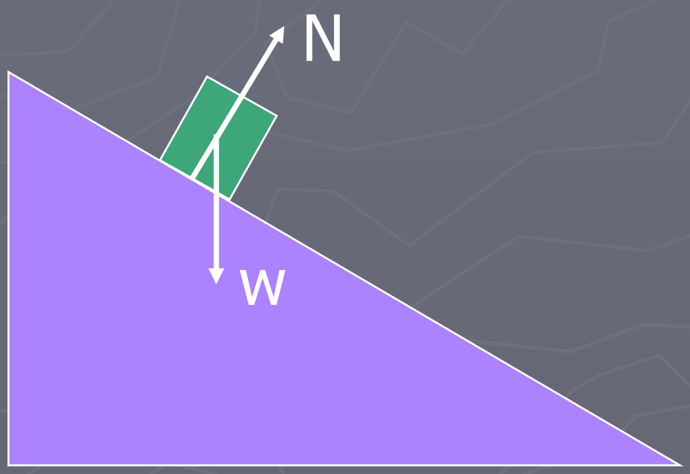
Example: Normal force

- Normal force: contact force exerted on an object by, for example, the surface of a floor or wall, preventing the object from penetrating the surface.
  - acts in the direction perpendicular to the contact surface.

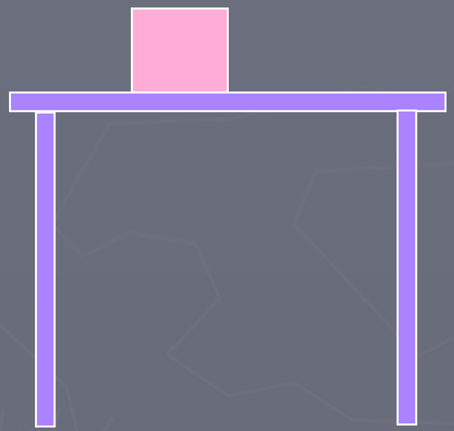
Force of the ground on the box



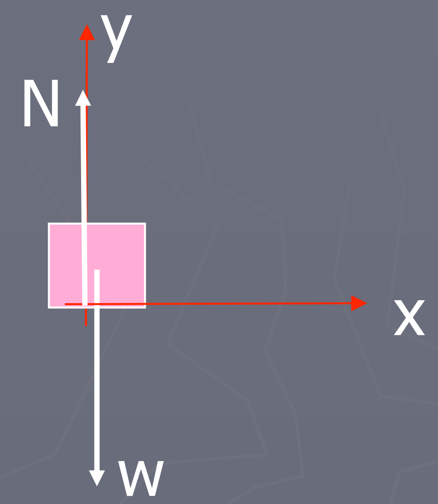
Force of the ramp on the box



Example: Consider a box on a table.



FBD for box



Apply Newton's 2nd law

$$\sum F_y = N - w = 0$$

So that N = w = mg

In this example: the magnitude of the normal force equals the magnitude of the weight; they are not Newton's third law interaction partners.

Forces of Friction

- When an object is in motion on a surface or through a viscous medium, there will be a resistance to the motion
  - This is due to the interactions between the object and its environment
- This is resistance is called the *force of friction*

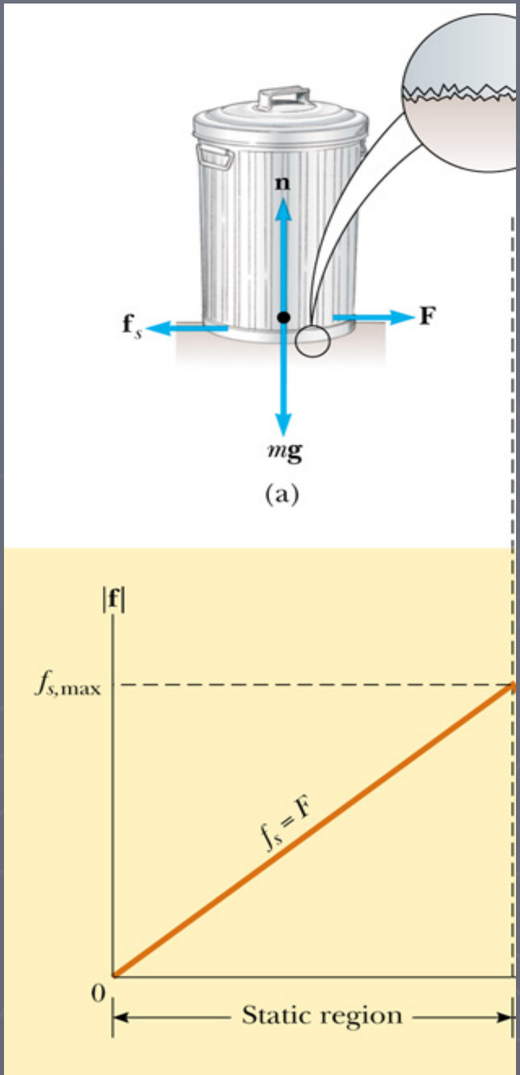
More About Friction

- Friction is proportional to the normal force
- The force of static friction is generally greater than the force of kinetic friction
- The coefficient of friction (μ) depends on the surfaces in contact
- The direction of the frictional force is opposite the direction of motion
- The coefficients of friction are nearly independent of the area of contact

Static Friction, f_s

- Static friction acts to keep the object from moving
- If F increases, so does f_s
- If F decreases, so does f_s

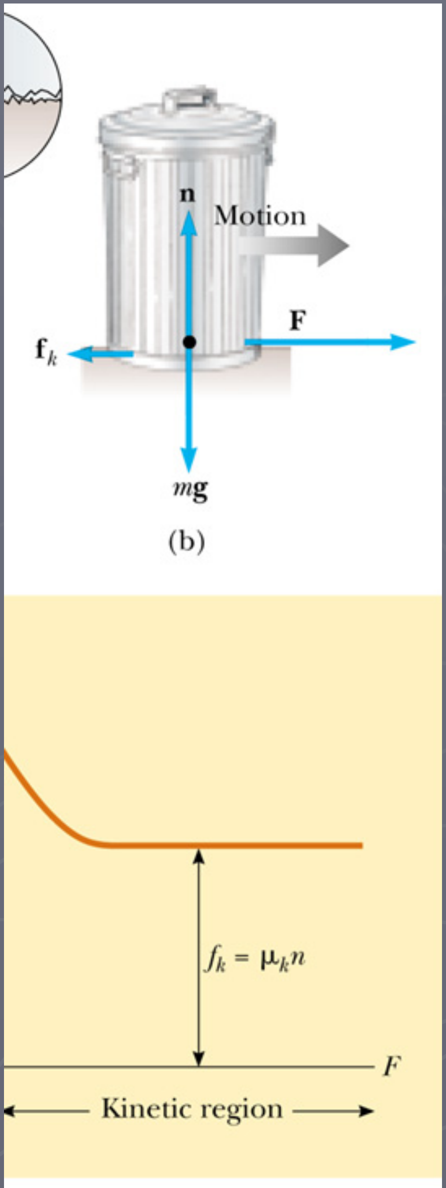
$$f_s \leq \mu N$$



Kinetic Friction

- The force of kinetic friction acts when the object is in motion

$$f_k = \mu N$$



ConcepTest

You are pushing a wooden crate across the floor at constant speed.You decide to turn the crate on end, reducing by half the surface area in contact with the floor. In the new orientation, to push the same crate across the same floor with the same speed, the force that you apply must be about

1. four times as great
2. twice as great
3. equally great
4. half as great
5. one-fourth as great

as the force required before you changed the crate's orientation.

ConcepTest

You are pushing a wooden crate across the floor at constant speed.You decide to turn the crate on end, reducing by half the surface area in contact with the floor. In the new orientation, to push the same crate across the same floor with the same speed, the force that you apply must be about

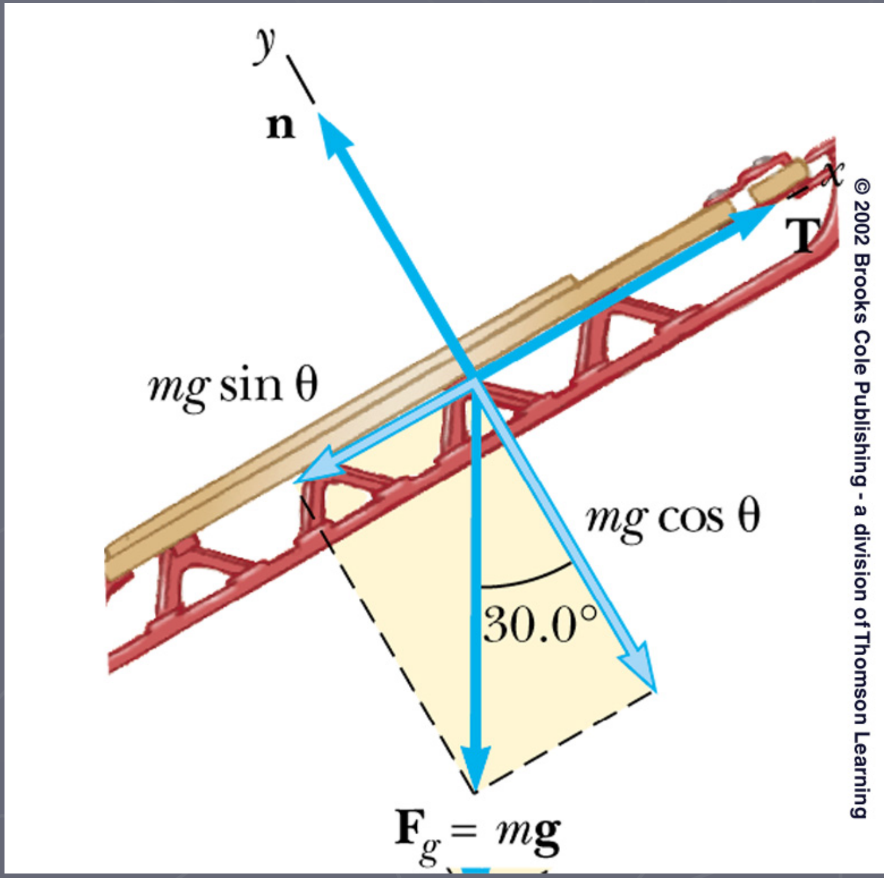
1. four times as great
2. twice as great
3. equally great ✓
4. half as great
5. one-fourth as great

as the force required before you changed the crate’s orientation.

Note: The force is proportional to the coefficient of kinetic friction and the weight of the crate. Neither depends on the size of the surface in contact with the floor.

Big Example: Inclined Planes

- Choose the coordinate system with x along the incline and y perpendicular to the incline
- Replace the force of gravity with its components



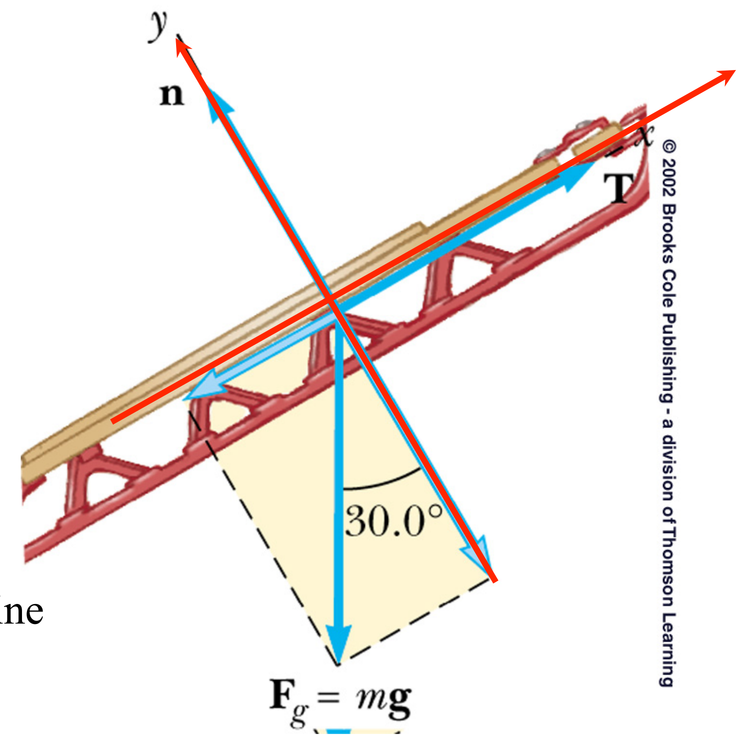
Example: Inclined Planes

Problem:

A child holds a sled at rest on frictionless, snow-covered hill, as shown in figure. If the sled weights 77.0 N, find the force **T** exerted by the rope on the sled and the force **n** exerted by the hill on the sled.

Example: Inclined Planes

- Choose the coordinate system with x along the incline and y perpendicular to the incline
- Replace the force of gravity with its components



<u>Given:</u>

angle: $\alpha=30°$
weight: $w=77.0$ N

<u>Find</u>:

Tension **T**=?
Normal **n**=?

1. Introduce <u>coordinate frame</u>:
   Oy: y is directed perp. to incline
   Ox: x is directed right, along incline

$$\underline{Note}: \quad \sum \vec{F} = 0$$

$$Ox: \sum F_x = T - mg\sin\alpha = 0,$$

$$T = mg(\sin 30^\circ) = 77.0N(\sin 30^\circ) = \underline{38.5N}$$ ✓

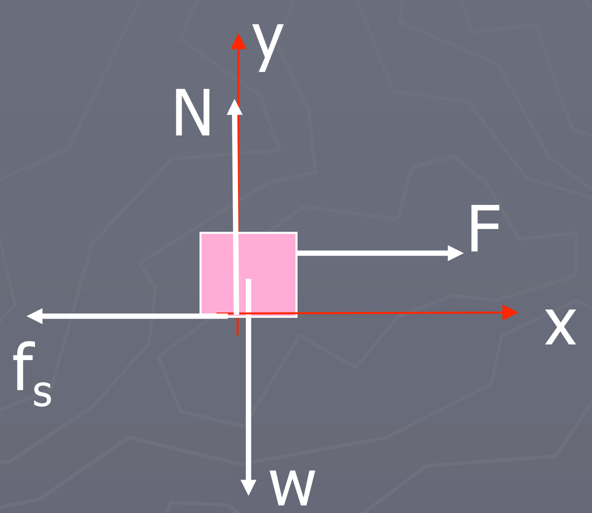
$$Oy: \sum F_y = n - mg\cos\alpha = 0,$$

$$n = mg(\cos 30^\circ) = 77.0N(\cos 30^\circ) = \underline{66.7N}$$ ✓

Example (text problem 4.77): A box full of books rests on a wooden floor. The normal force the floor exerts on the box is 250 N.

(a) You push horizontally on the box with a force of 120 N, but it refuses to budge. What can you say about the coefficient of friction between the box and the floor?

FBD for box



Apply Newton's 2nd Law

$$(1)\sum F_y = N - w = 0$$

$$(2)\sum F_x = F - f_s = 0$$

$$f_s \le \mu_s N \quad \Rightarrow \quad \frac{f_s}{N} \le \mu_s$$

The box refuses to budge, $\Rightarrow \dfrac{f_s}{N} < \mu_s$

From (2): $F = f_s \Rightarrow \dfrac{f_s}{N} = \dfrac{F}{N} = \dfrac{120N}{250N} = 0.48 < \mu_s$

$$\boxed{\mu_s > 0.48.}$$

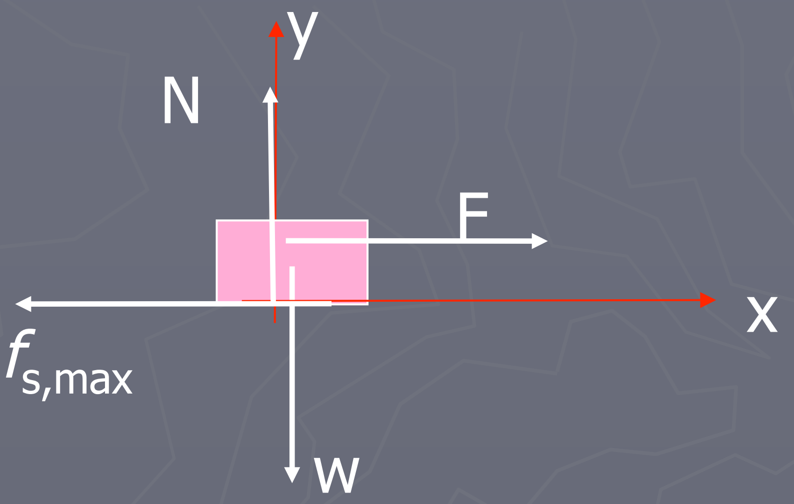
(b) If you must push horizontally on the box with 150 N force to start it sliding, what is the coefficient of static friction?

Apply Newton's 2nd Law

$$(1)\sum F_y = N - w = 0$$

$$(2)\sum F_x = F - f_{s,\max} = 0$$

$$f_s \le \mu_s N \quad \Rightarrow \quad \frac{f_s}{N} \le \mu_s$$



The box starts sliding, the friction force is $f_{s,max}$ here

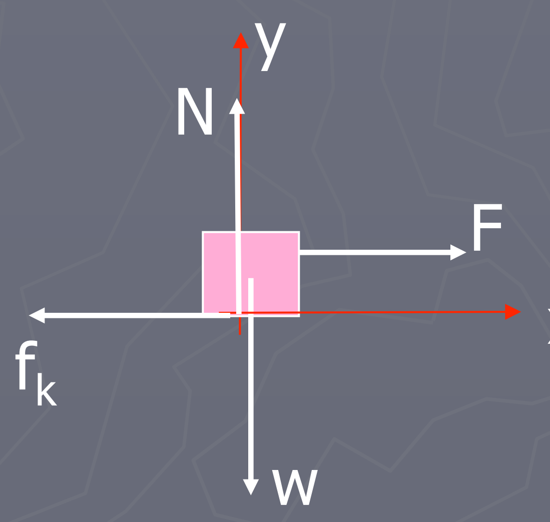
From (2): $F = f_{s,\max} \Rightarrow \mu_s = \frac{f_{s,\max}}{N} = \frac{F}{N} = \frac{150N}{250N} = 0.60$

$$\boxed{\mu_s = 0.60.}$$

Example continued:

(c) Once the box is sliding, you only have to push with a force of 120 N to keep it sliding. What is the coefficient of kinetic friction?

FBD for box



Apply Newton's 2nd Law

$$(1)\sum F_y = N - w = 0$$

$$(2)\sum F_x = F - f_k = 0$$

From 2: $F = f_k = \mu_k N$

$$\mu_k = \frac{F}{N} = \frac{120\text{ N}}{250\text{ N}} = 0.48$$

$$\mu_k = 0.48$$