Lecture 9
(Equilibrium, Dynamics, and Friction)

Physics 160-02 Spring 2017

Douglas Fields

Sun's Pull on the Earth

- Rotation of earth around the sun takes 365 days = 3.15×10^7s.
- Distance between the center of the sun and center of earth is 1.50×10^{11}m.
- Mass of Earth is 5.97×10^{24}kg.
- With what force does the sun pull on the earth?
- 3.56×10^{22}N.

CPS Question 10-2

- **With what force does the earth pull on the sun?**

A) More than $3.56x10^{22}$N

B) Less than $3.56x10^{22}$N

C) Equal to $3.56x10^{22}$N

D) Cannot determine, insufficient information.

A chair of weight 70.0 N lies atop a horizontal floor; the floor is not frictionless. You push on the chair with a force of F = 38.0 N directed at an angle of 36.0° below the horizontal and the chair slides along the floor.

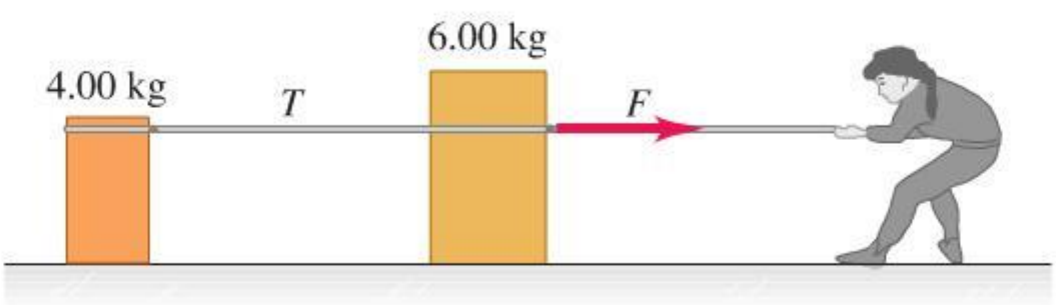
Part A

Using Newton's laws, calculate n, the magnitude of the normal force that the floor exerts on the chair. Express your answer in newtons.

Problem 4.43

4.43. Two crates, one with mass 4.00 kg and the other with mass 6.00 kg, sit on the frictionless surface of a frozen pond, connected by a light rope (Fig. 4.38). A woman wearing golf shoes (so she can get traction on the ice) pulls horizontally on the 6.00-kg crate with a force F that gives the crate an acceleration of $2.50\ \text{m/s}^2$. (a) What is the acceleration of the 4.00-kg crate? (b) Draw a free-body diagram for the 4.00-kg crate. Use that diagram and Newton's second law to find the tension T in the rope that connects the two crates. (c) Draw a free-body diagram for the 6.00-kg crate. What is the direction of the net force on the 6.00-kg crate? Which is larger in magnitude, force T or force F? (d) Use part (c) and Newton's second law to calculate the magnitude of the force F.

Figure **4.38** Problem 4.43.



Problem 4.24

4.24. The upward normal force exerted by the floor is 620 N on an elevator passenger who weighs 650 N. What are the reaction forces to these two forces? Is the passenger accelerating? If so, what are the magnitude and direction of the acceleration?

Problem 4.39

4.39. A Standing Vertical Jump. Basketball player Darrell Griffith is on record as attaining a standing vertical jump of 1.2 m (4 ft). (This means that he moved upward by 1.2 m after his feet left the floor.) Griffith weighed 890 N (200 lb). (a) What is his speed as he leaves the floor? (b) If the time of the part of the jump before his feet left the floor was 0.300 s, what was his average acceleration (magnitude and direction) while he was pushing against the floor? (c) Draw his free-body diagram (see Section 4.6). In terms of the forces on the diagram, what is the net force on him? Use Newton's laws and the results of part (b) to calculate the average force he applied to the ground.

Problem 4.49

4.49. A gymnast of mass m climbs a vertical rope attached to the ceiling. You can ignore the weight of the rope. Draw a free-body diagram for the gymnast. Calculate the tension in the rope if the gymnast (a) climbs at a constant rate; (b) hangs motionless on the rope; (c) accelerates up the rope with an acceleration of magnitude $|\vec{a}|$; (d) slides down the rope with a downward acceleration of magnitude $|\vec{a}|$.

Equilibrium and Dynamics

- Equilibrium = no acceleration = sum of forces = 0

$$\sum F_x = 0 \qquad \sum F_y = 0 \qquad \sum F_z = 0$$

- Dynamics = acceleration = sum of forces = ma

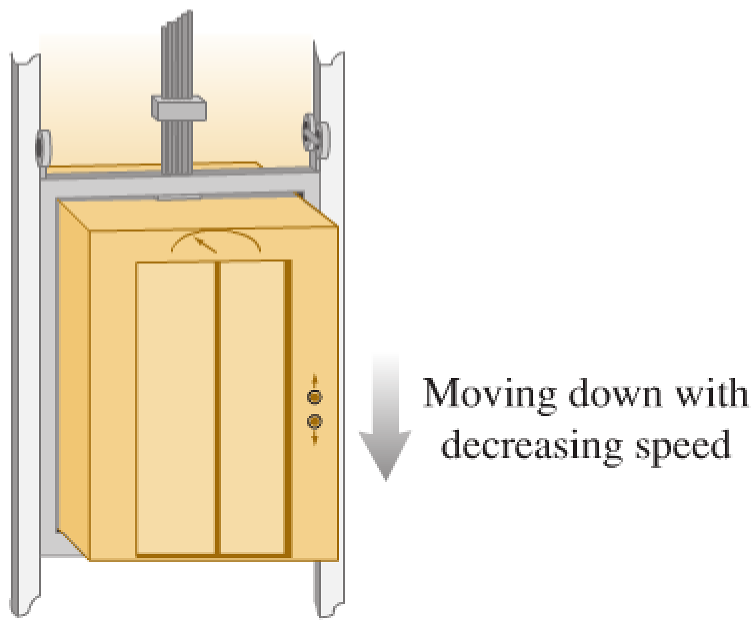
$$\sum F_x = ma_x \qquad \sum F_y = ma_y \qquad \sum F_z = ma_z$$

- Both of these cases are covered with Newton's second law: $\sum \vec{F} = m\vec{a}$
  so, I won't treat them differently.

Elevators…

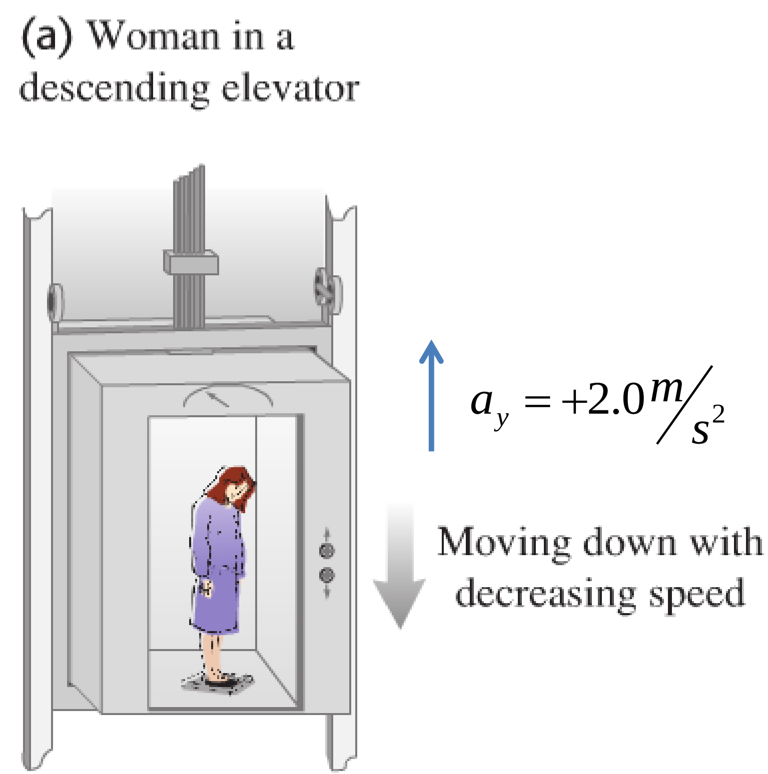
An elevator and its load have a combined mass of 800 kg (Fig. 5.9a). The elevator is initially moving downward at 10.0 m/s; it slows to a stop with constant acceleration in a distance of 25.0 m. What is the tension T in the supporting cable while the elevator is being brought to rest?

(a) Descending elevator



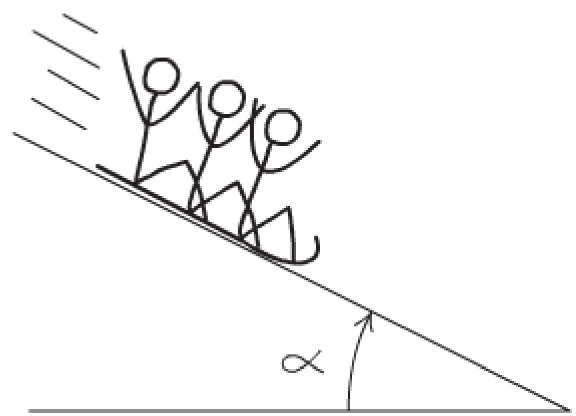
Elevators…

A 50.0-kg woman stands on a bathroom scale while riding in the elevator in Example 5.8. What is the reading on the scale?



Inclined Planes

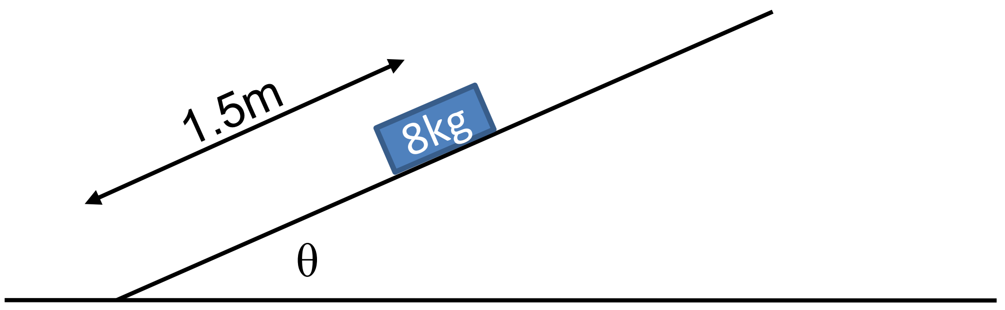
A toboggan loaded with students (total weight w) slides down a snow-covered slope. The hill slopes at a constant angle α, and the toboggan is so well waxed that there is virtually no friction. What is its acceleration?



Problem

5.20. A 8.00-kg block of ice, released from rest at the top of a 1.50-m-long frictionless ramp, slides downhill, reaching a speed of 2.50 m/s at the bottom. (a) What is the angle between the ramp and the horizontal? (b) What would be the speed of the ice at the bottom if the motion were opposed by a constant friction force of 10.0 N parallel to the surface of the ramp?

Two Problems:
1) 1D motion with acceleration
2) Newton's Second Law



Problem

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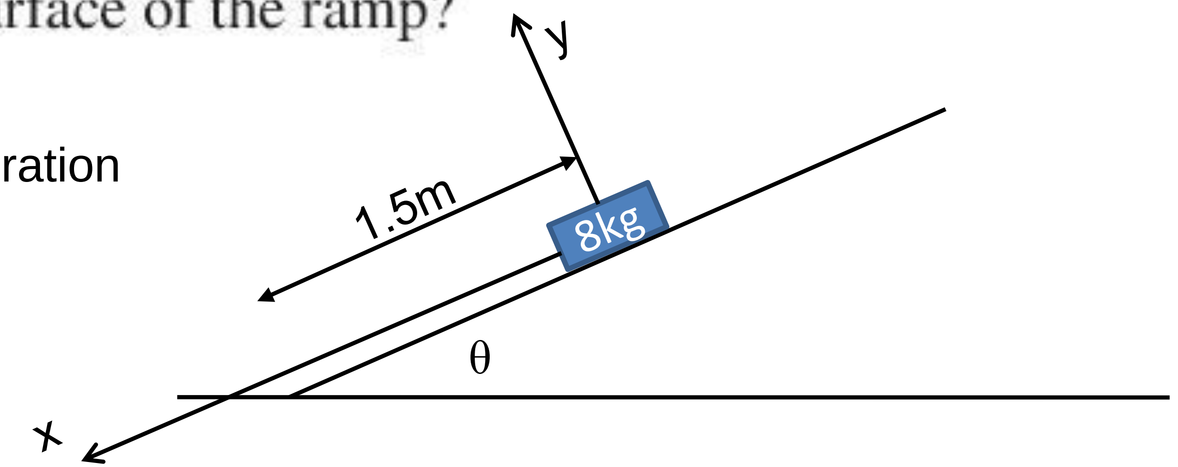


1) 1D motion with acceleration

x_0 = 0m
x_f = 1.5m
v_{x0} = 0m/s
v_{xf} = 2.5m/s
a_x = ?
t = ?

$$v_{xf}^2 = v_{x0}^2 + 2a_x(x_f - x_0)$$

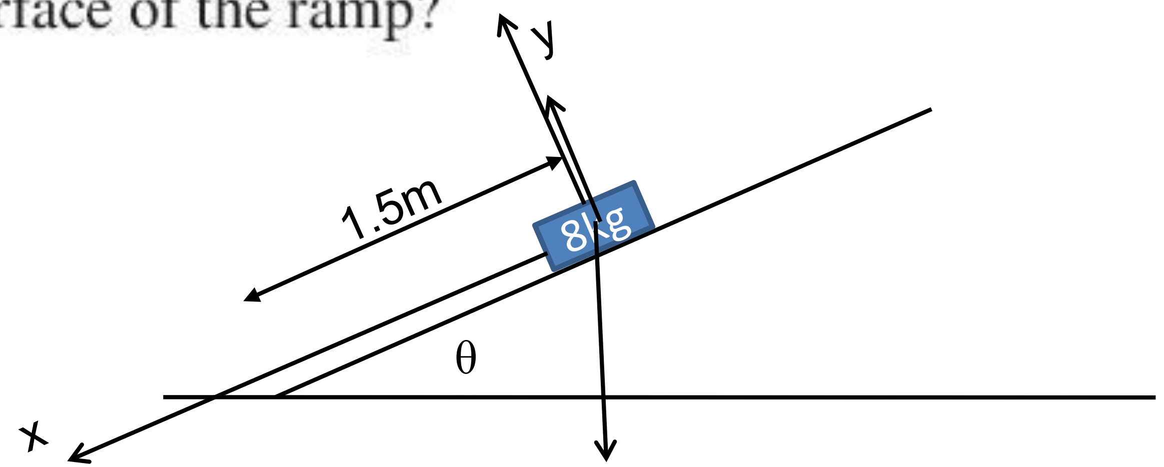
Problem

5.20. A 8.00-kg block of ice, released from rest at the top of a 1.50-m-long frictionless ramp, slides downhill, reaching a speed of 2.50 m/s at the bottom. (a) What is the angle between the ramp and the horizontal? (b) What would be the speed of the ice at the bottom if the motion were opposed by a constant friction force of 10.0 N parallel to the surface of the ramp?

2) Newton's Second Law

a_x = from last slide

$$\sum F_x = ma_x$$



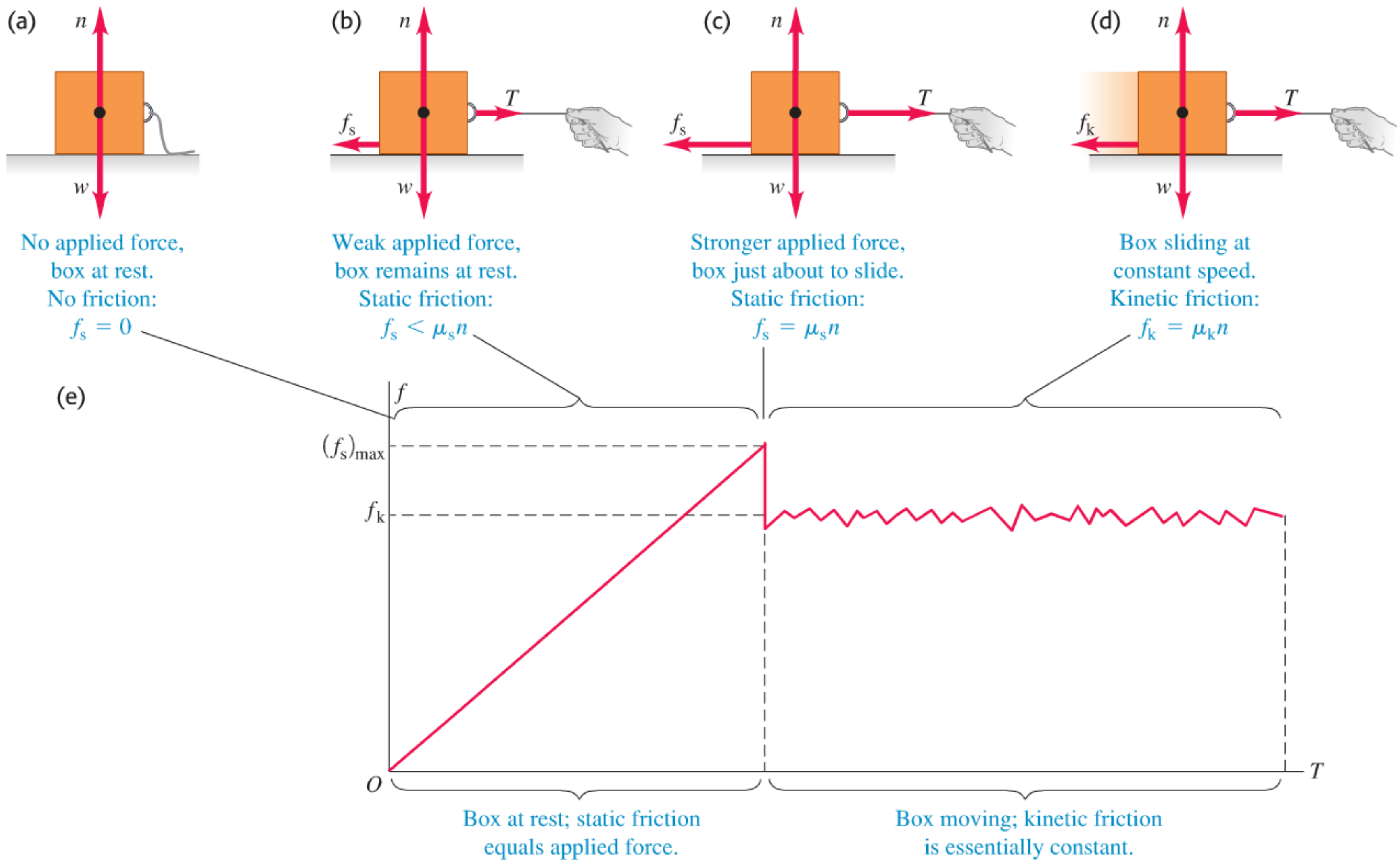
Friction

- Static Friction:
  - Magnitude depends on situation.
  - Has a maximum value = $\mu_s F_N$.
  - Opposes force to move something.
- Kinetic (motion) friction:
  - Always has the same magnitude = $\mu_k F_N$
  - $\mu_k < \mu_s$
- Neither depend upon surface area!

Other Friction Forces

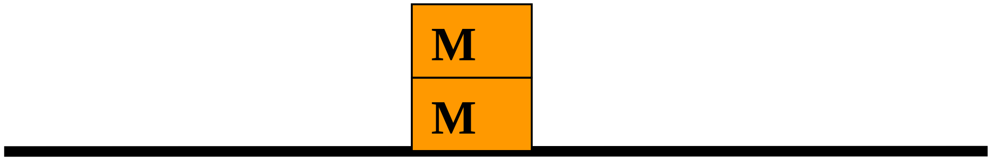
- Rolling Friction
  - $f = \mu_r F_N$
- Fluid Resistance
  - For low speeds: $f = kv$
  - For high speeds: $f = Dv^2$
- Terminal speed:
  - For low speeds: $v_t = mg/k$
  - For high speeds: $v_t = \sqrt{(mg/D)}$

Friction


(a)
n
w
No applied force,
box at rest.
No friction:
$f_s = 0$
(b)
n
T
f_s
w
Weak applied force,
box remains at rest.
Static friction:
$f_s < \mu_s n$
(c)
n
T
f_s
w
Stronger applied force,
box just about to slide.
Static friction:
$f_s = \mu_s n$
(d)
n
T
f_k
w
Box sliding at
constant speed.
Kinetic friction:
$f_k = \mu_k n$
(e)
f
$(f_s)_{max}$
f_k
O
T
Box at rest; static friction
equals applied force.
Box moving; kinetic friction
is essentially constant.

CPS Question 11-1

- **A block of mass M sits on a horizontal plane with a coefficient of static friction of μ_s. Another mass M is added on top of the block. What happens to the force of friction between the bottom block and the table?**



A) It doubles.

B) It's halved.

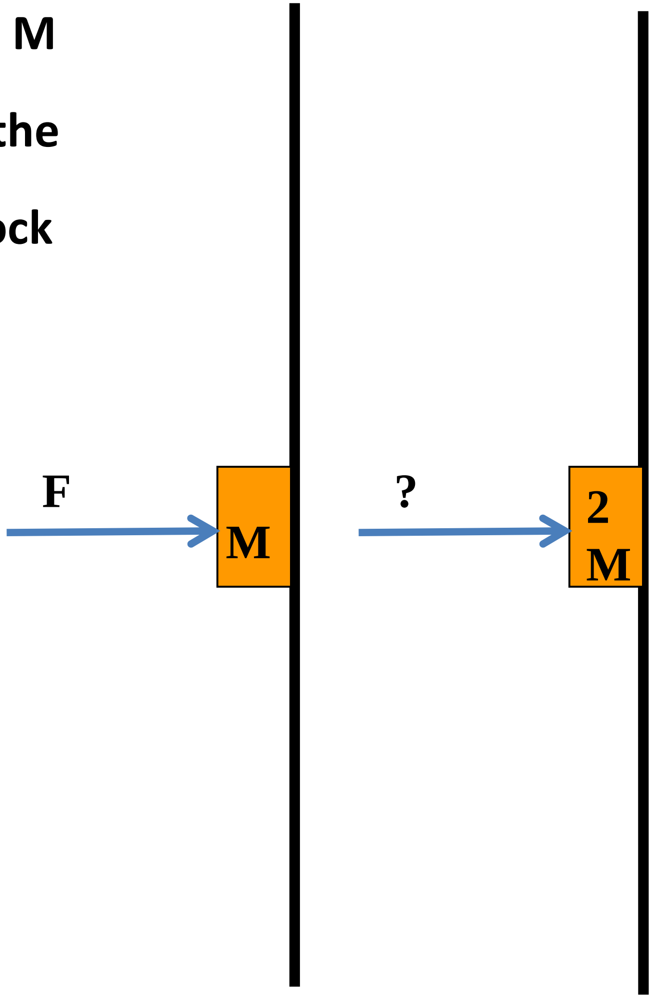
C) It stays the same.

D) It depends upon the surface of the table.

E) It cannot be determined.

CPS Question 11-2

- **A person pushes with force F on a block of mass M held against a wall with a coefficient of static friction of μ_s. If the mass is replaced with twice the mass but remains held against the wall, what happens to the force of friction between the block and the wall?**



A) It doubles.

B) It's halved.

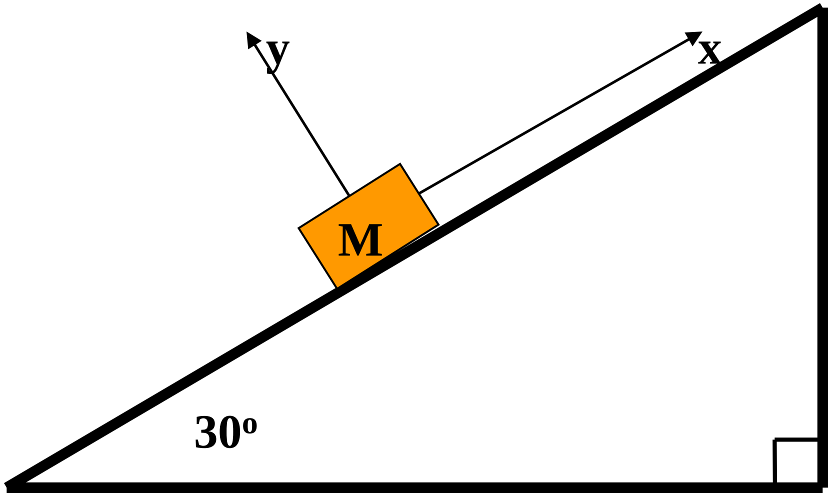
C) It stays the same.

D) It depends upon the surface of the wall.

E) It cannot be determined.

CPS Question 11-3

- **A block of mass M sits on an inclined plane with a coefficient of static friction of μ_s. Which best describes the force of friction on the block?**



A) μ_s*Mg in the positive x-direction

B) μ_s*Mg in the negative x-direction

C) Mg*sin(30) in the negative x-direction

D) Mg*sin(30) in the positive x-direction

E) μ_s*Mg*cos(30) in the negative x-direction