Physics 111: Mechanics
Lecture 4

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Chapter 5 Applying Newton's Laws

- ✓ 5.1 Using Newton's 1st Law: Particles in Equilibrium
- ✓ 5.2 Using Newton's 2nd Law: Dynamics of Particles
- ❑ 5.3 Frictional Forces (next week)
- ❑ 5.4 Dynamics of Circular Motion (later)
- ❑ 5.5* The Fundamental Forces of Nature Summary (self-study)

Isaac Newton's work represents one of the greatest contributions to science ever made by an individual.

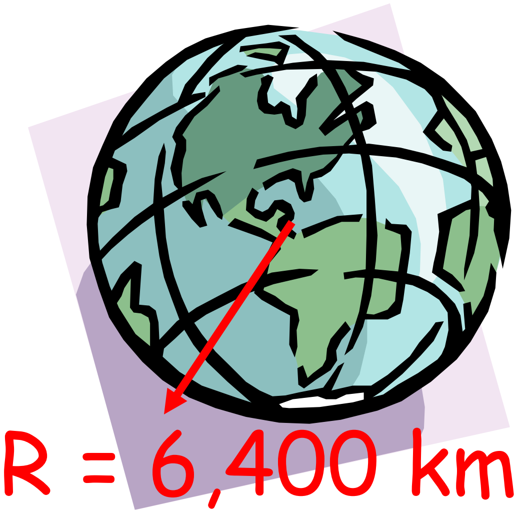
Weight

- 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: $\boldsymbol{w = mg}$
- $\boldsymbol{g}$ can also be found from the Law of Universal Gravitation
- Weight has a unit of N

$$F_g = G\frac{mM}{R^2} \qquad w = F_g = mg$$

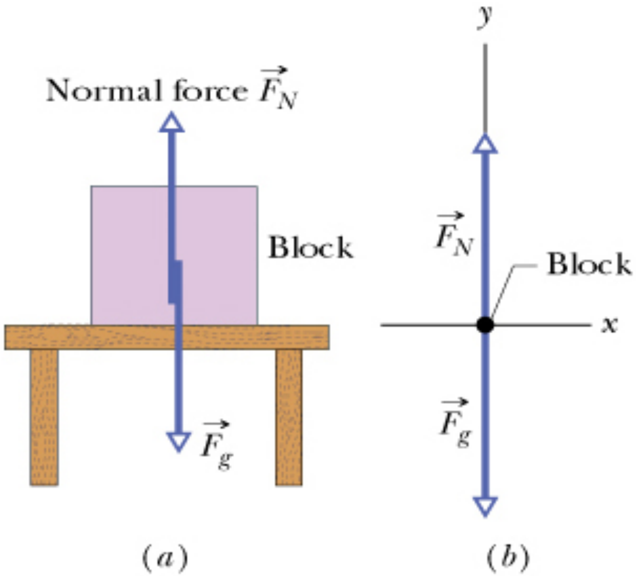
$$g = G\frac{M}{R^2} = 9.8\,\mathrm{m/s^2}$$

- Weight depends upon location



Normal Force

- Force from a solid surface which keeps object from falling through
- Direction: always perpendicular to the surface
- Magnitude: depend on situation



$$\vec{F}_N + \vec{F}_g = m\vec{a}$$

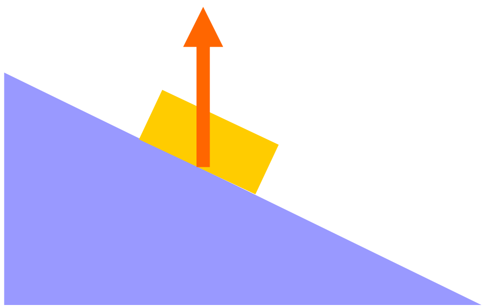
$$F_N - mg = ma_y$$

$F_N = mg$ **only** if $a_y = 0$ **and** no other forces are present

Normal Force

- Which diagram can represent the normal force acting on the block on a ramp?

A)



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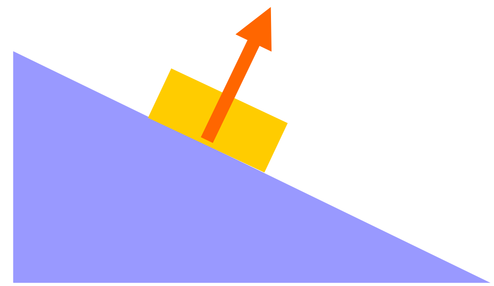

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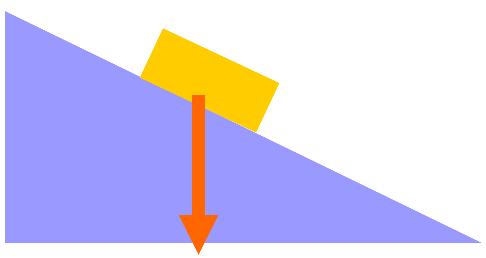

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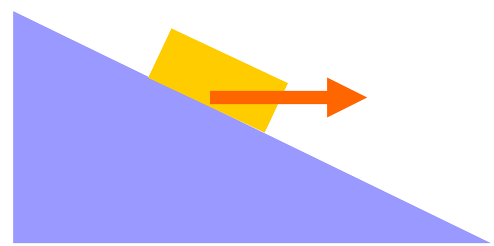
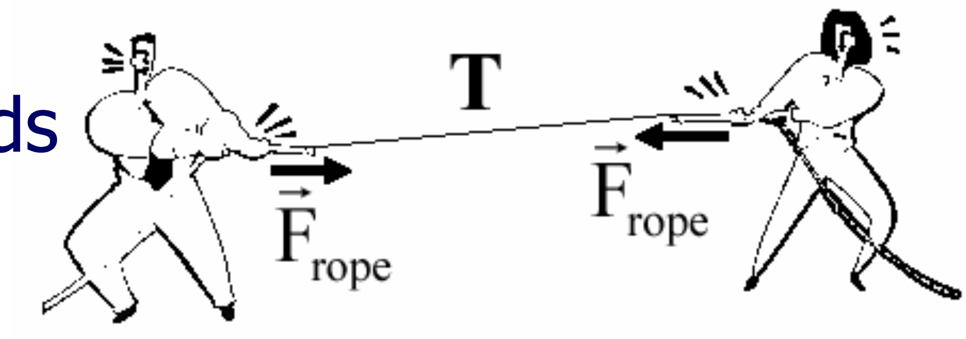
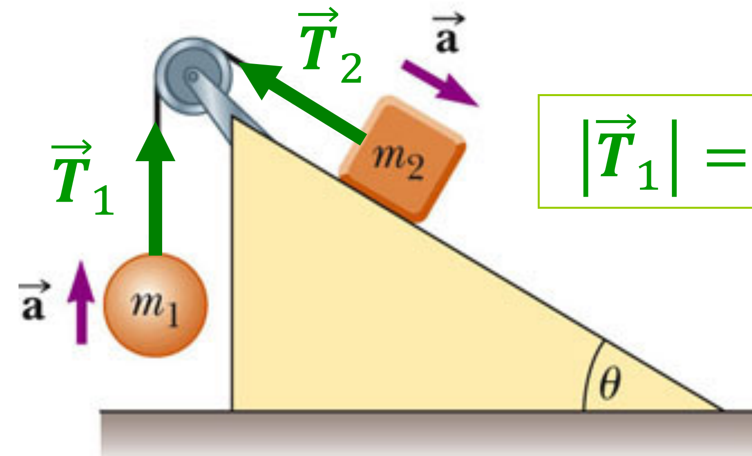


Tension Force: T

- A taut rope exerts forces on whatever holds its ends
- Direction: always along the cord (rope, cable, string ……) and away from the object
- Sometimes simplified as massless and unstretchable cord
- Magnitude: depend on situation



$$\left|\vec{F}_{on\ A}\right| = T = \left|\vec{F}_{on\ B}\right|$$



$$|\vec{T}_1| = |\vec{T}_2|$$

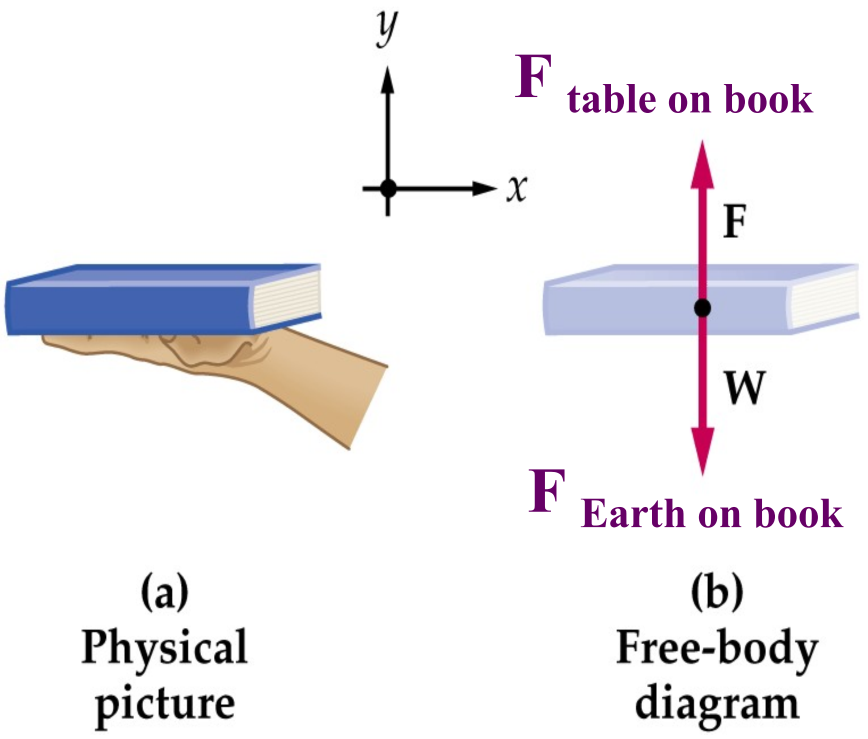
Gravity and Normal Force

- What is <u>the net force</u> on a 1 N apple when you hold it at rest above your head and what is <u>the net force</u> on it after you release it?

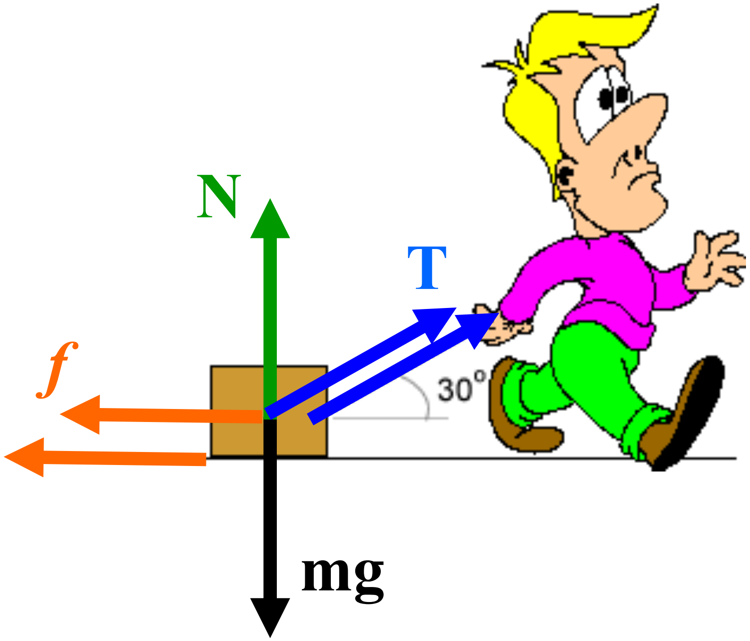
A) 1N, 0N
B) 0N, 1N
C) 0N, 0N
D) 1N, 1N
E) All are wrong

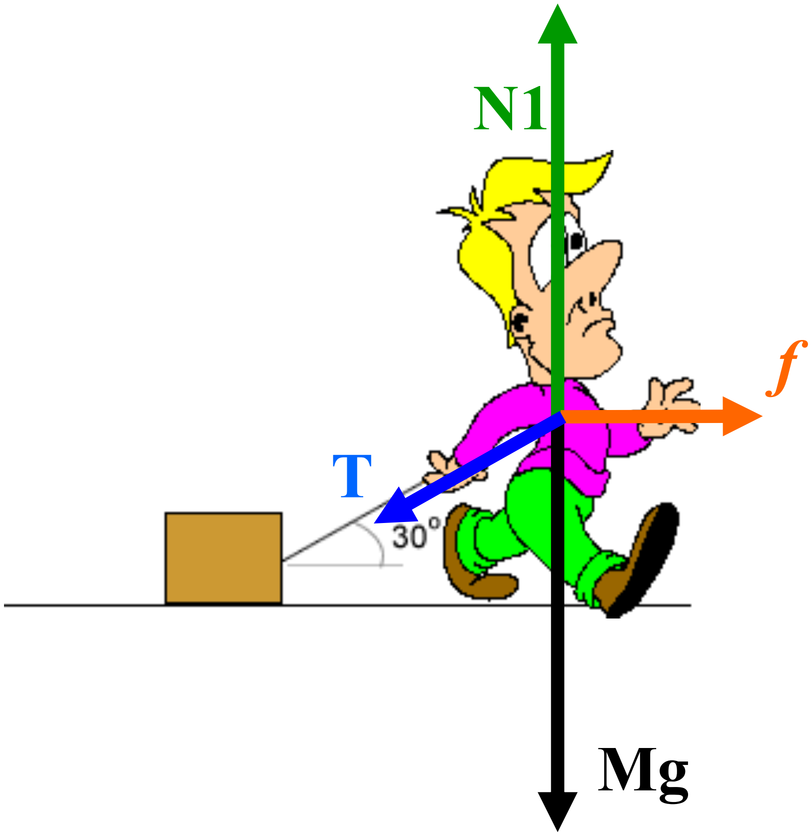
Free Body Diagram

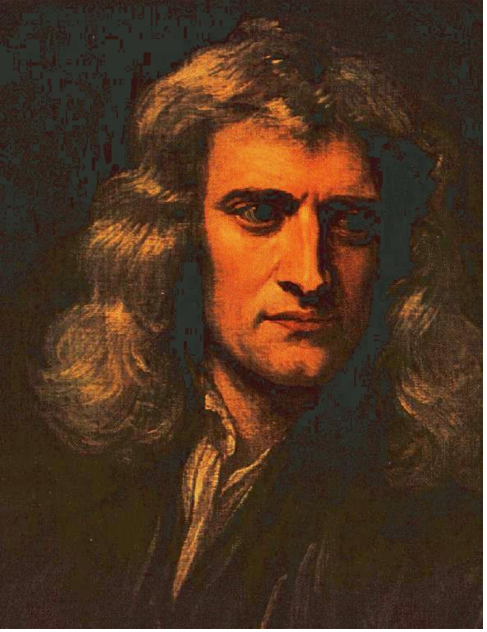
- The most important step in solving problems involving Newton's Laws is to draw the free body diagram
- **<u>Be sure to include only the forces acting on the object of interest</u>**
- Include any field forces acting on the object
- Do not assume the normal force equals the weight



Free Body Diagram







Force is a vector
Unit of force in S.I.:

$$1N = 1\frac{kg \bullet m}{s^2}$$

Newton's Laws

I. If no net force acts on a body, then the body's velocity cannot change.

II. The net force on a body is equal to the product of the body's mass and acceleration.

III. When two bodies interact, the force on the bodies from each other are always equal in magnitude and opposite in direction.

Objects in Equilibrium

- Objects that are either <u>at rest</u> or <u>moving with constant velocity</u> are said to be in **equilibrium**
- Acceleration of an object in equilibrium : $\vec{a} = 0$
- Mathematically, the net force acting on the object is zero

$$\vec{\boldsymbol{F}}_{\text{net}} = \sum \vec{\boldsymbol{F}} = 0$$

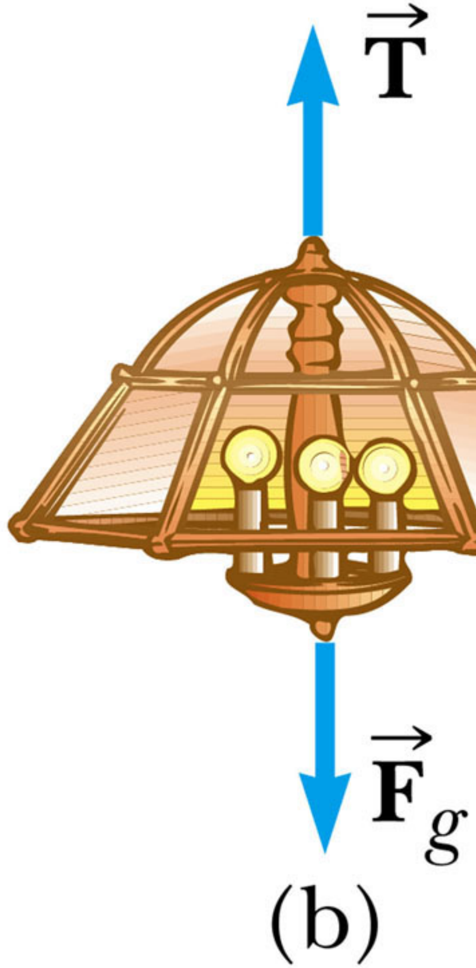
- Equivalent to the set of component equations given by

$$F_{\text{net},x} = \sum F_x = 0 \qquad F_{\text{net},y} = \sum F_y = 0$$

Equilibrium, Example 1

- A lamp is suspended from a chain of negligible mass
- The forces acting on the lamp are
  - the downward force of gravity
  - the upward tension in the chain
- Applying equilibrium gives

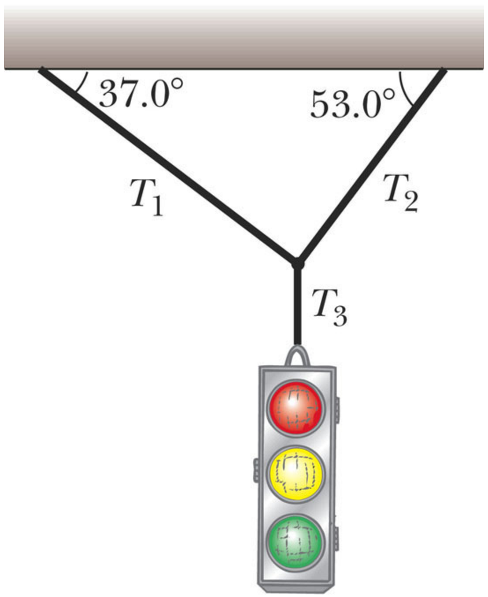
$$\sum F_y = 0 \rightarrow T - F_g = 0 \rightarrow T = F_g$$



Equilibrium, Example 2

- A traffic light weighing 100 N hangs from a vertical cable tied to two other cables that are fastened to a support. The upper cables make angles of 37° and 53° with the horizontal beam. Find the tension in each of the three cables.
- Conceptualize the traffic light
  - Assume cables don't break
  - Nothing is moving
- Categorize as an equilibrium problem
  - No movement, so acceleration is zero
  - Model as an object in equilibrium

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



(a)

Equilibrium, Example 2

- Need 2 free-body diagrams
  - Apply equilibrium equation to light

$$\sum F_y = 0 \qquad \vec{T}_3 + \vec{F}_g = 0 \quad T_3 = F_g = 100\ N$$

  - Apply equilibrium equations to knot

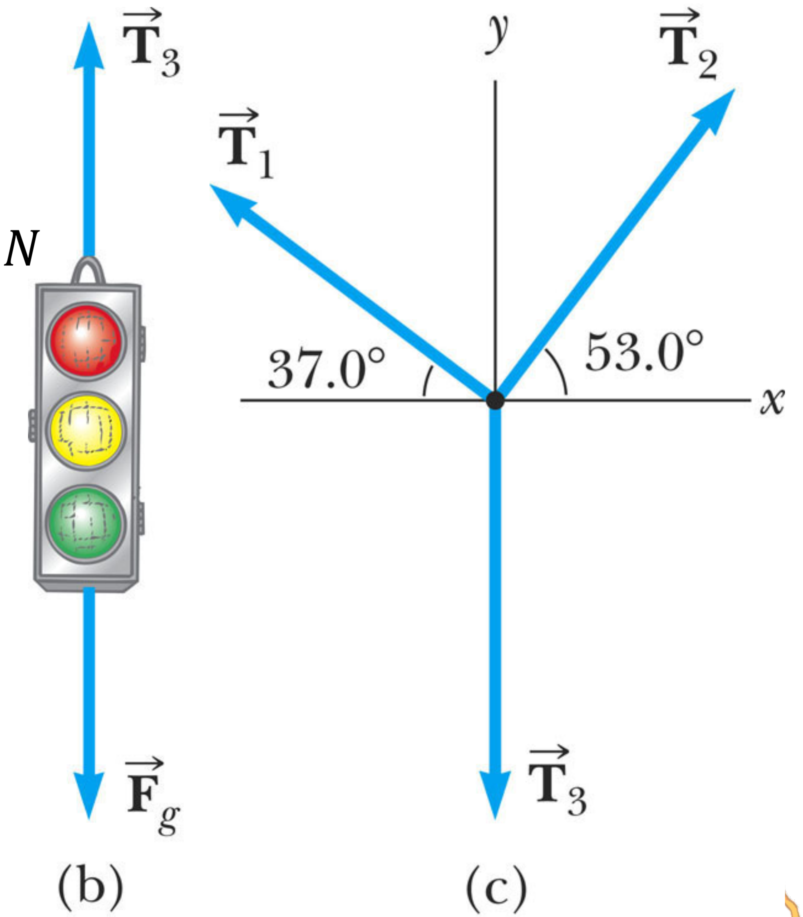
$$\sum F_x = T_{1x} + T_{2x} = -T_1 \cos 37^\circ + T_2 \cos 53^\circ = 0$$

$$\sum F_y = T_{1y} + T_{2y} + T_{3y}$$

$$= T_1 \sin 37^\circ + T_2 \sin 53^\circ - 100N = 0$$

$$T_2 = T_1\left(\frac{\cos 37^\circ}{\cos 53^\circ}\right) = 1.33T_1$$

$$T_1 = 60N \qquad T_2 = 1.33T_1 = 80N$$



Accelerating Objects

- If an object that can be modeled as a particle experiences an acceleration, there must be a nonzero net force acting on it
- Draw a free-body diagram
- Apply Newton's Second Law in component form

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

$$F_{net,x} = \sum F_x = ma_x \qquad F_{net,y} = \sum F_y = ma_y$$

Accelerating Objects, Example 1

- A man is standing in an elevator. While the elevator is at rest, he measures a weight of 800 N.
  - What is the force exerted on him by the elevator if the elevator accelerates upward at 2.0 m/s^2? a = 2.0 m/s^2
  - What is the force exerted on him by the elevator if the elevator accelerates downward at 2.0 m/s^2? a = - 2.0
- Upward: $\sum F_y = N - Fg = N - mg = ma$

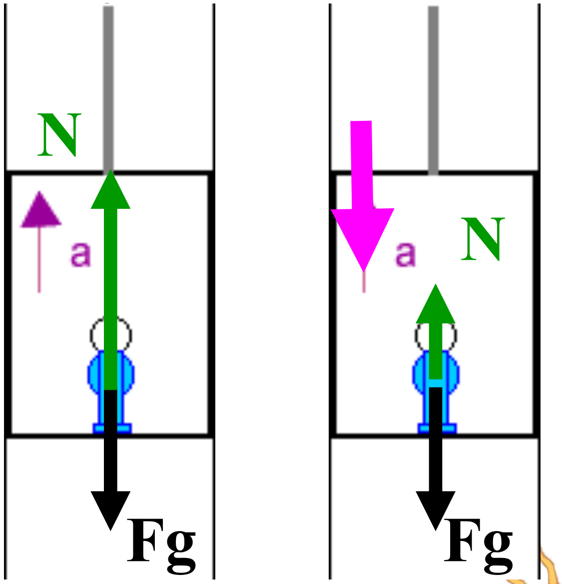
$$N = mg + ma = m(g + a) \qquad N = 80(2.0 + 9.8) = 1560N$$

$$m = \frac{w}{g} = \frac{800N}{9.8m/s^2} = 80kg$$

$$N > mg$$

- Downward: $N = 80(-2.0 + 9.8) = 624N$

$$N < mg$$



Newton's 2nd Laws

- A mass with a weight of 98 N is suspended with a cable. When it moves downward with an acceleration magnitude of 5 m/s². The tension force of the cable should be about

A) 98 N
B) 10 N
C) 148 N
D) 48 N
E) 0 N

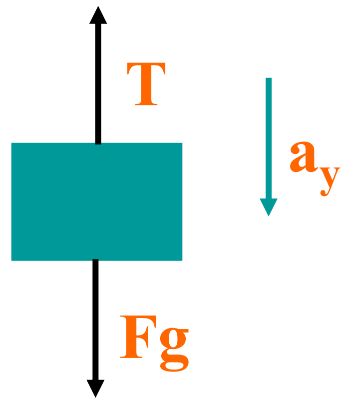
$$F_{net,y} = \sum F_y = ma_y$$

$$T - F_g = ma_y$$

$$T = mg + ma_y = w + ma_y$$

$$w = mg = 98N$$

$$T = 98 - (\frac{98}{9.8}) \times 5 = 48 \text{ N}$$



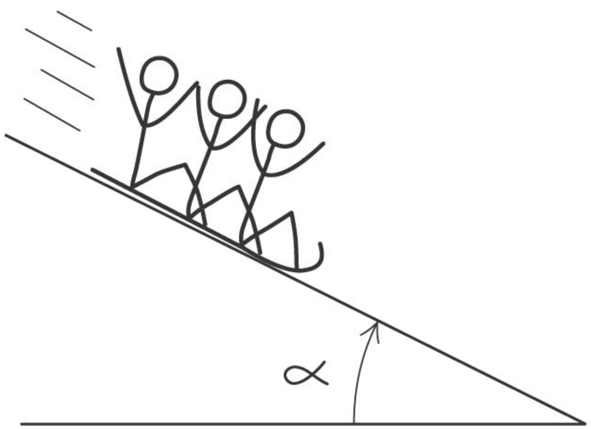
Hints for Problem-Solving

- **Read** the problem carefully at least once
- **Draw** a picture of the system, identify the object of primary interest, and indicate forces with arrows
- **Label** each force in the picture in a way that will bring to mind what physical quantity the label stands for (e.g., T for tension)
- **Draw** a free-body diagram of the object of interest, based on the labeled picture. If additional objects are involved, draw separate free-body diagram for them
- **Choose a convenient coordinate system** for each object
- **Apply Newton's second law.** The x- and y-components of Newton second law should be taken from the vector equation and written individually. This often results in two equations and two unknowns
- **Solve** for the desired unknown quantity, and substitute the numbers

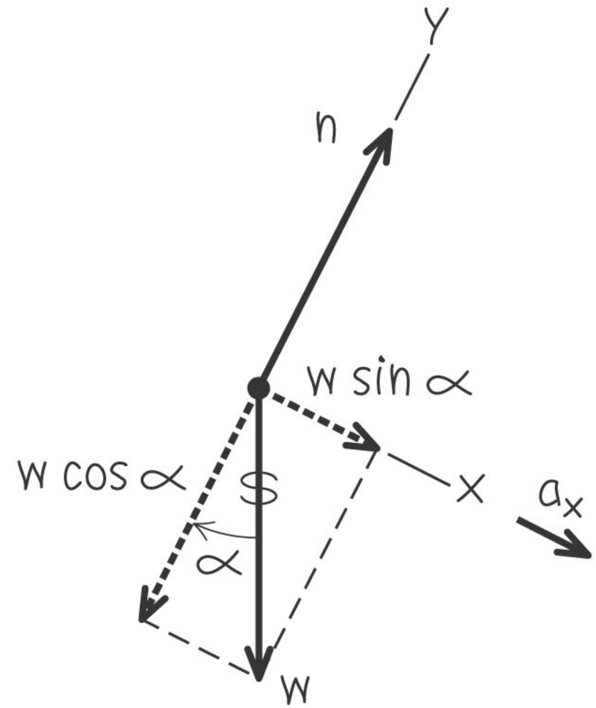
Acceleration down a hill

- What is the acceleration of a toboggan sliding down a friction-free slope (Textbook Example 5.10.)

(a) The situation

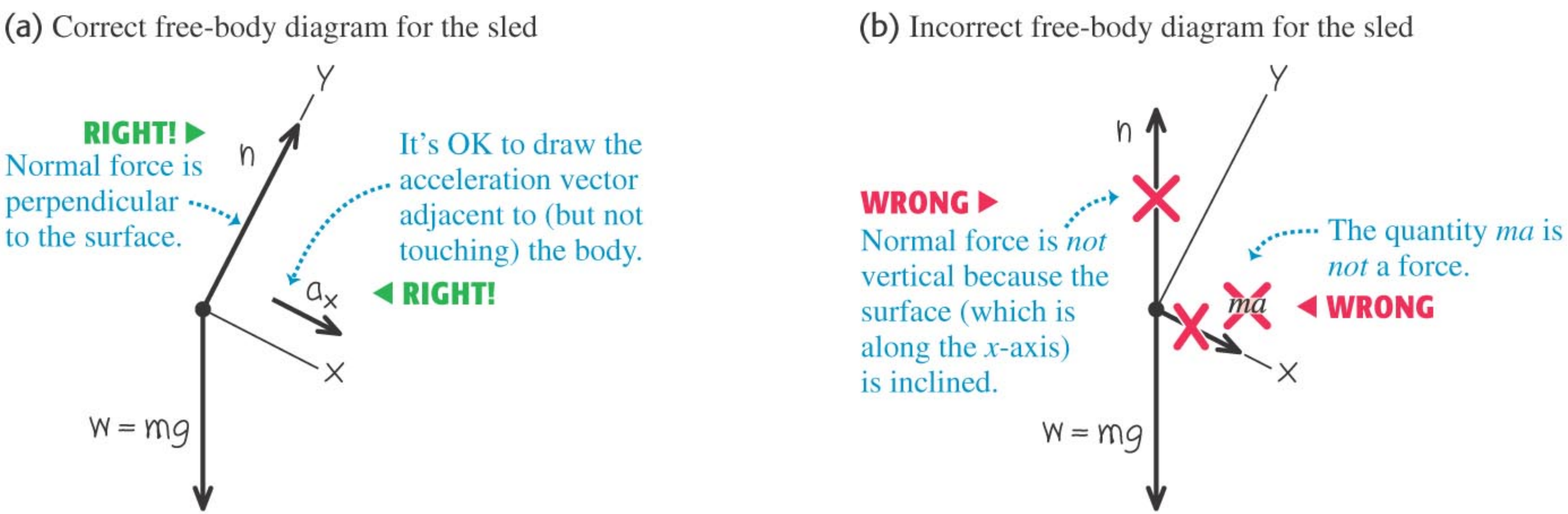


(b) Free-body diagram for toboggan



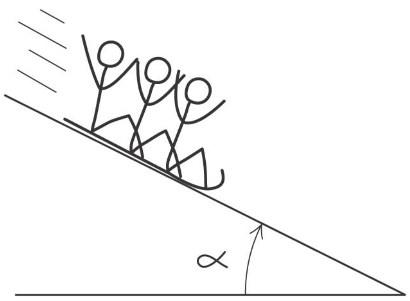
Two common free-body diagram errors

- The normal force must be perpendicular to the surface.
- There is no "*ma* force."

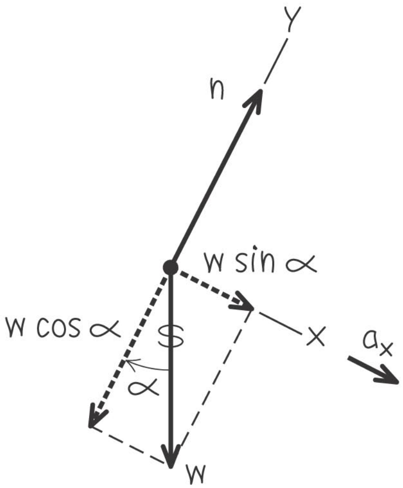


Acceleration down a hill

(a) The situation



(b) Free-body diagram for toboggan



$$\sum F_x = w \sin\alpha = ma_x$$

$$\sum F_y = n - w\cos\alpha = ma_y = 0$$

$$a_x = g\sin\alpha$$

$$n = w\cos\alpha = mg\cos\alpha$$

Acceleration down a hill

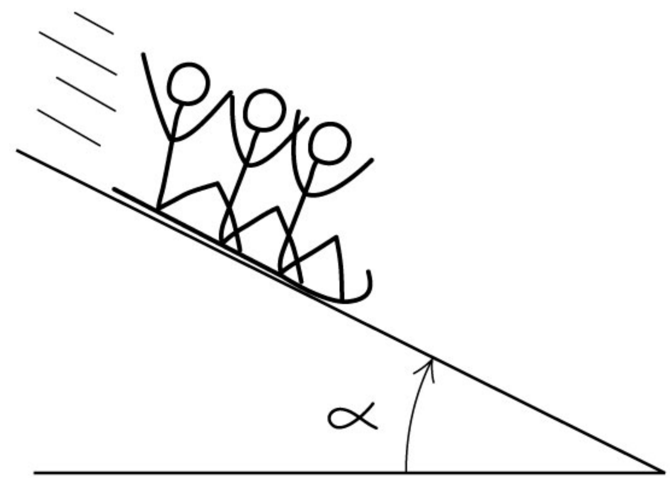
A toboggan with one passengers slides down a frictionless hill of angle α. Another one with two passengers slides down the same hill from the same height later. Which statement about the speed at the bottom of the hill is *correct* (v_1 and v_2 denote the 1st and 2nd case respectively)?

A. $v_1 = v_2$

B. $v_1 > v_2$

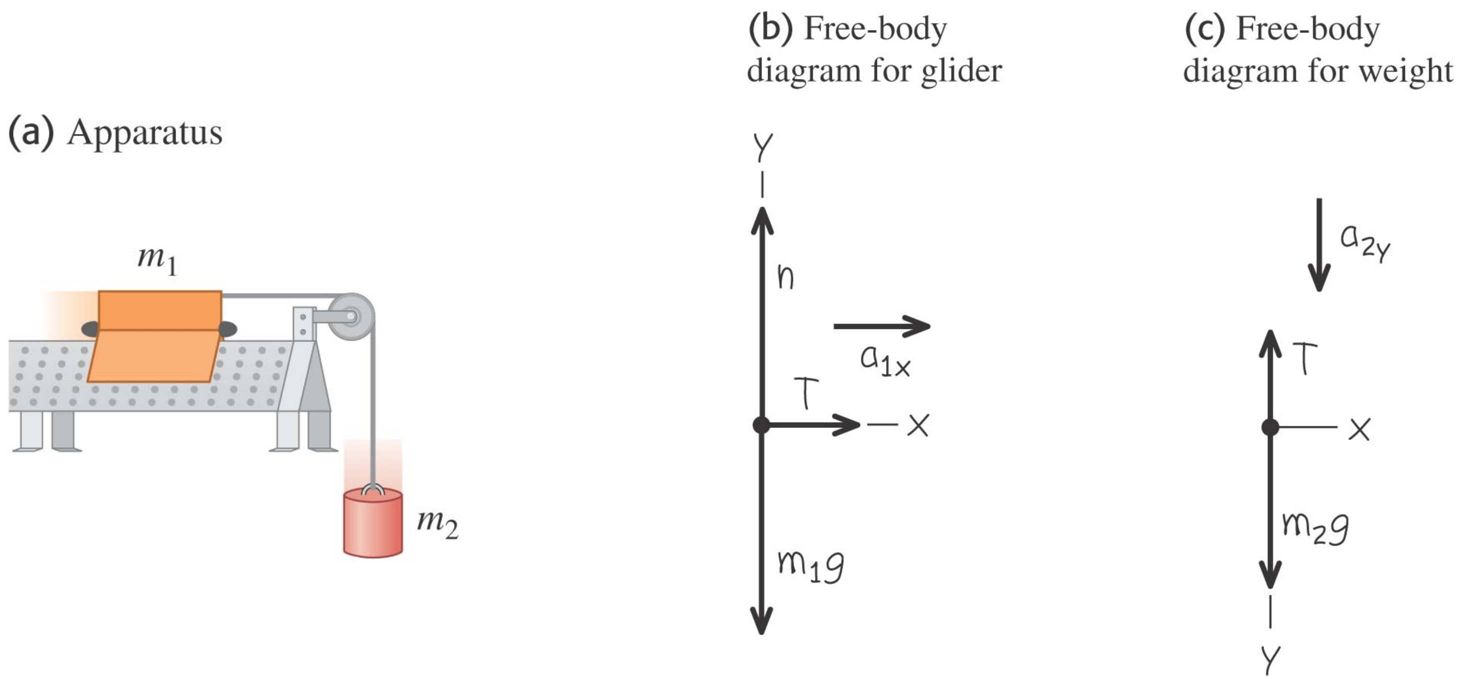
C. $v_1 < v_2$

D. not enough information given to decide

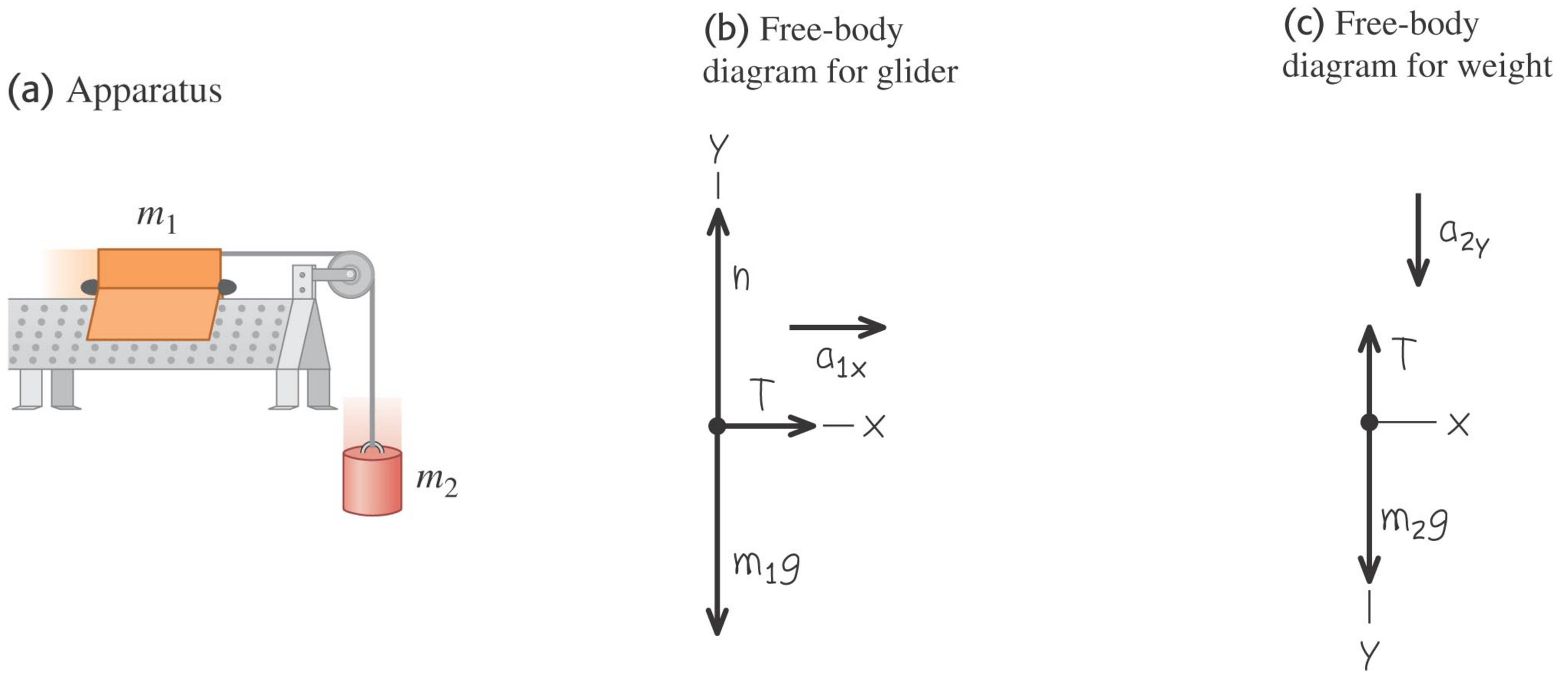


Two Connected Objects

- The glider on the air track and the falling weight move in different directions, but their accelerations have the same magnitude. Find the acceleration and tension in the string (Textbook Example 5.12).



Two Connected Objects

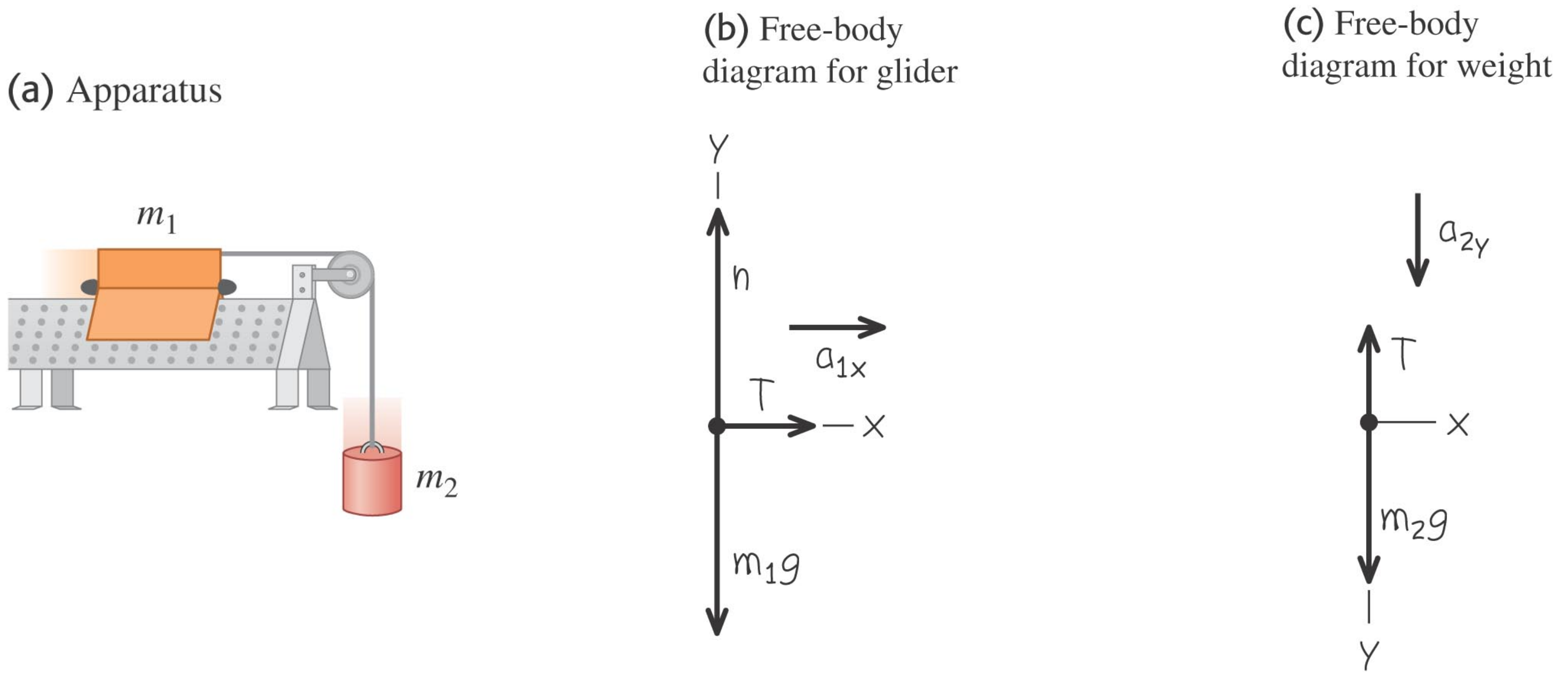


Glider: $\sum F_x = T = m_1 a_{1x} = m_1 a$

Glider: $\sum F_y = n + (-m_1 g) = m_1 a_{1y} = 0$

Lab weight: $\sum F_y = m_2 g + (-T) = m_2 a_{2y} = m_2 a$

Two Connected Objects



Glider: $T = m_1 a$

Lab weight: $m_2 g - T = m_2 a$

Acceleration

$$a = \frac{m_2}{m_1 + m_2} g$$

Tension

$$T = \frac{m_1 m_2}{m_1 + m_2} g$$