

Chapter 7 Newton's Third Law

You may be wondering why we've talked only about Newton's first two laws so far:

Newton's first law An object that is at rest will remain at rest, or an object that is moving will continue to move in a straight line with constant velocity, if and only if the net force acting on the object is zero.

Newton's second law An object of mass m subjected to forces $\vec{F}_1, \vec{F}_2, \vec{F}_3, \dots$ will undergo an acceleration \vec{a} given by

$$\vec{a} = \frac{\vec{F}_{\text{net}}}{m} \quad (5.4)$$

where the net force $\vec{F}_{\text{net}} = \vec{F}_1 + \vec{F}_2 + \vec{F}_3 + \dots$ is the vector sum of all forces acting on the object. The acceleration vector \vec{a} points in the same direction as the net force vector \vec{F}_{net} .

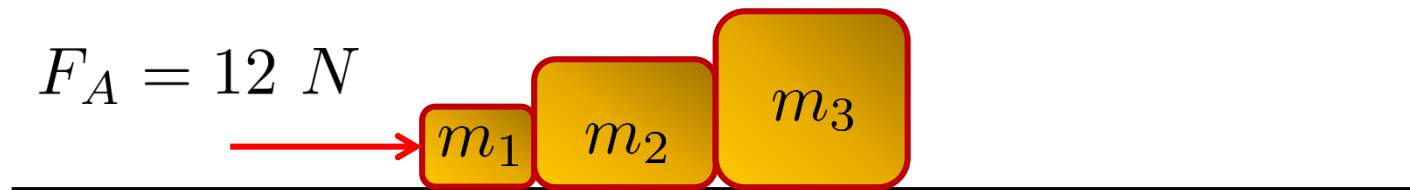
Newton's first two laws define Force and tell us precisely what a force does.

The third law describes how objects interact with each other (i.e. exert forces on each other); until now we haven't needed it. [Here's a problem where it's needed.](#)

A Problem where Newton's 3rd Law is needed

Blocks with masses of 1 kg, 2 kg, and 3 kg are lined up in a row on a frictionless table. All three are pushed forward by a 12 N force applied to the 1 kg block.

- How much force does the 2 kg block exert on the 3kg block?
- How much force does the 2 kg block exert on the 1 kg block?



One thing that is fairly obvious that we can do is to determine the acceleration which will be the same for all of the blocks. **What is this acceleration? (LC)**

$$a = \frac{F_A}{(m_1 + m_2 + m_3)} = 2\text{ m/s}^2$$

But how do we find the forces between the blocks? Neither of Newton's first two laws tell us what to do – we need Newton's third law.

Newton's 3rd Law

In Newton's own words*:

*“To every action there is always opposed an equal reaction:
OR the mutual actions of two bodies upon each other are
always equal, and directed to contrary parts.”*

From your text:

Newton's third law Every force occurs as one member of an action/reaction pair of forces.

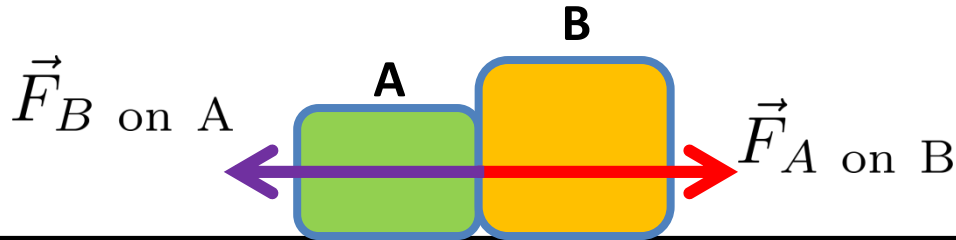
- The two members of an action/reaction pair act on two different objects.
- The two members of an action/reaction pair are equal in magnitude but opposite in direction: $\vec{F}_{A \text{ on } B} = -\vec{F}_{B \text{ on } A}$.

In a few weeks, we'll also see that another way to say this is, “for an isolated system of bodies, momentum is conserved.”

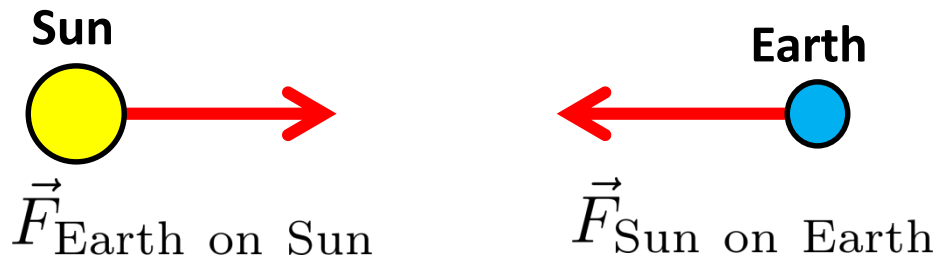
*We heard lots of stuff in Newton's own words in the video last week.

Action/Reaction Force Pairs

For contact forces (usually normal, friction, or tension):



Long range forces (e.g. gravity)



Notice: Action/Reaction pair forces act on different bodies, and are always equal in magnitude, but in opposite directions.

That's the essence of Newton's 3rd Law.

Chair demo 

Identifying Action/Reaction Pairs

This is a bit much,
but there is some
good stuff on it:



TACTICS BOX 7.1



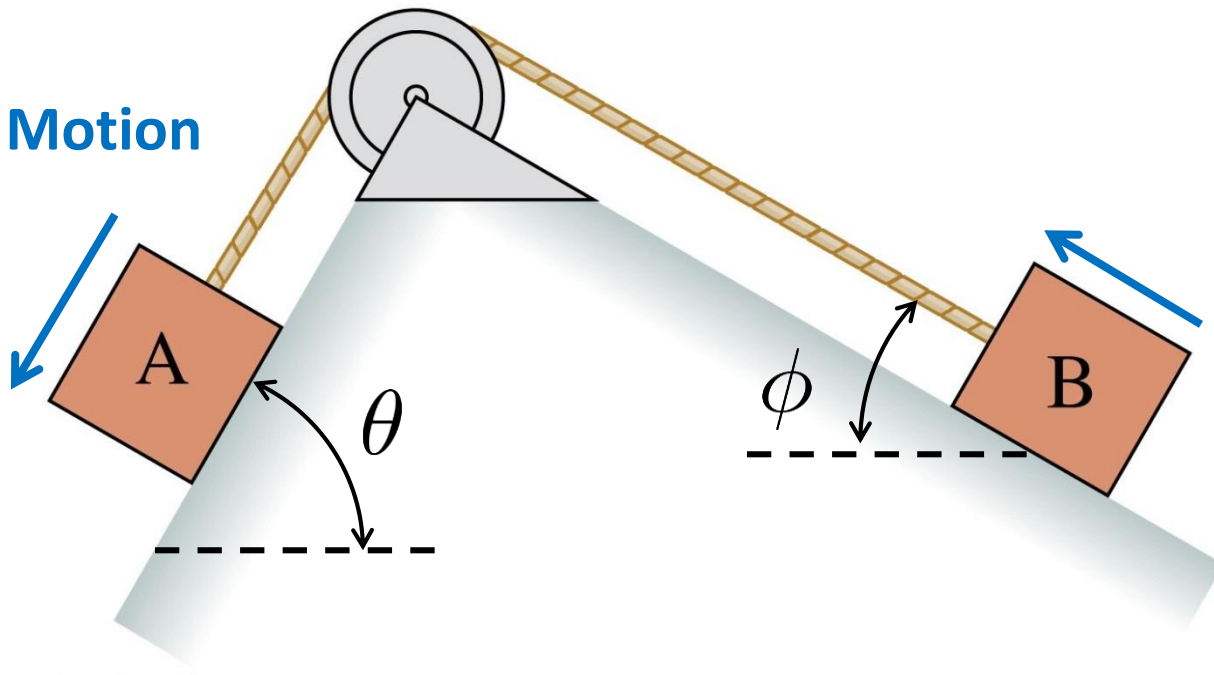
Analyzing interacting objects

- 1 **Represent each object as a circle** with a name and label. Place each in the correct position relative to other objects. The surface of the earth (label S; contact forces) and the entire earth (label EE; long-range forces) should be considered separate objects.
- 2 **Identify interactions.** Draw *one* connecting line between relevant circles to represent each interaction.
 - Every interaction line connects two and only two objects.
 - A surface can have two interactions: friction (parallel to the surface) and a normal force (perpendicular to the surface).
 - The entire earth interacts only by the long-range gravitational force.
- 3 **Identify the system.** Identify the objects of interest; draw and label a box enclosing them. This completes the interaction diagram.
- 4 **Draw a free-body diagram for each object in the system.** Include only the forces acting *on* each object, not forces exerted by the object.
 - Every interaction line crossing the system boundary is one external force acting on an object. The usual symbols, such as \vec{n} and \vec{T} can be used.
 - Every interaction line within the system represents an action/reaction pair of forces. There is one force vector on *each* of the objects, and these forces point in opposite directions. Use labels like $\vec{F}_{A \text{ on } B}$ and $\vec{F}_{B \text{ on } A}$.
 - Connect the two action/reaction forces—which must be on *different* free-body diagrams—with a dashed line.



Whiteboard Exercise 7-1

Block A in the figure is heavier than block B and is sliding down the incline. The rope is massless and the massless pulley turns on frictionless bearings, but the surface is not frictionless.



Draw free body diagrams for blocks A and B. Connect action/reaction pairs with dotted lines. 6

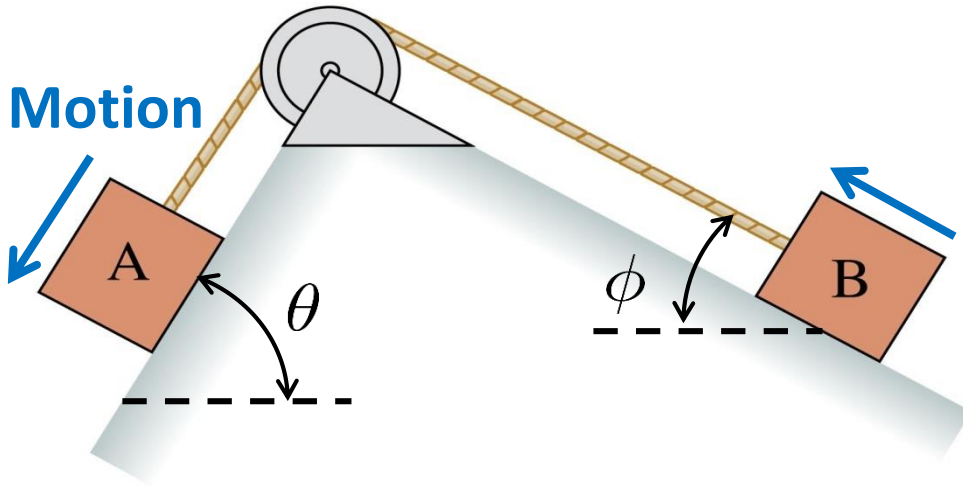
Solution Whiteboard Exercise 7-1

Notice:

Each FBD can have its own coordinate system.

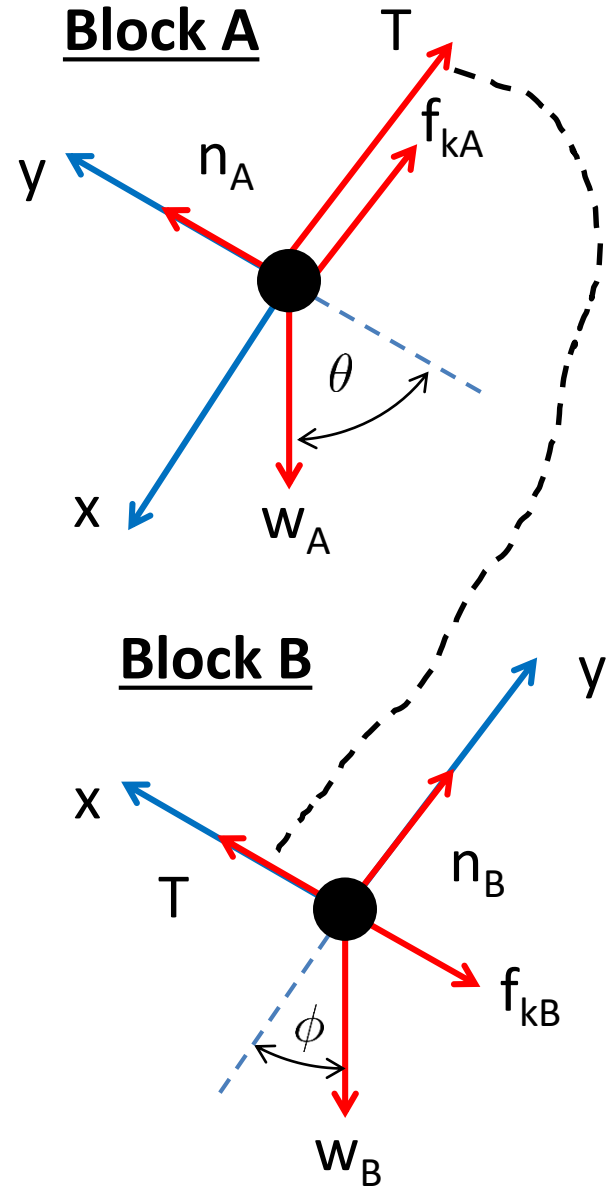
Action/reaction pairs go in opposite directions in the different FBD's.

Where are the action/reaction pairs for the friction forces, normal forces and the weights?



Constraint: $|\vec{a}_A| = |\vec{a}_B|$

So: $a_{A_x} = a_{B_x} = a$



So, how do we solve problems?

PROBLEM-SOLVING STRATEGY 7.1

MP

Interacting-objects problems

MODEL Identify which objects are part of the system and which are part of the environment. Make simplifying assumptions.

VISUALIZE Draw a pictorial representation.

- Show important points in the motion with a sketch. You may want to give each object a separate coordinate system. Define symbols, list acceleration constraints, and identify what the problem is trying to find.
- Draw an interaction diagram to identify the forces on each object and all action/reaction pairs.
- Draw a separate free-body diagram for each object showing only the forces acting on that object, not forces exerted by the object. Connect the force vectors of action/reaction pairs with dashed lines.

SOLVE Use Newton's second and third laws.

- Write the equations of Newton's second law for each object, using the force information from the free-body diagrams.
- Equate the magnitudes of action/reaction pairs.
- Include the acceleration constraints, the friction model, and other quantitative information relevant to the problem.
- Solve for the acceleration, then use kinematics to find velocities and positions.

ASSESS Check that your result has the correct units and significant figures, is reasonable, and answers the question.

Some familiar stuff here,
and some new stuff.

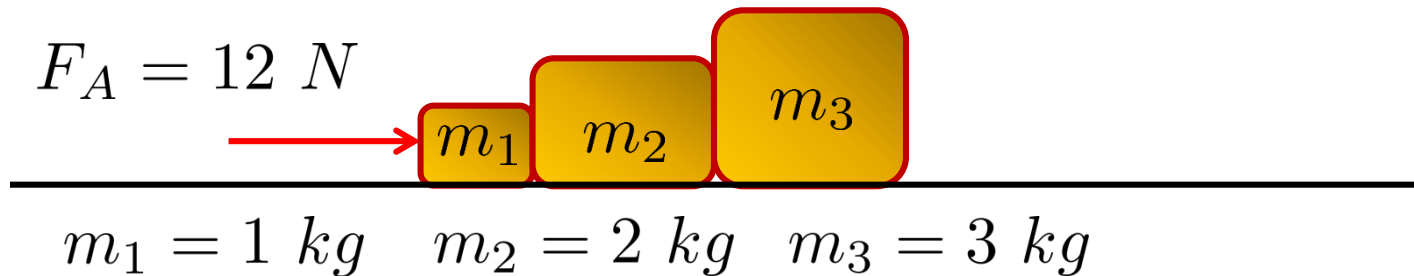
Constraints:
(objects that have the same
magnitude of acceleration)

These are some of longest
and most detailed
problems that we'll do in
PHY181. They will involve
lots of drawing and paper!

OK, Now Let's Solve This Problem

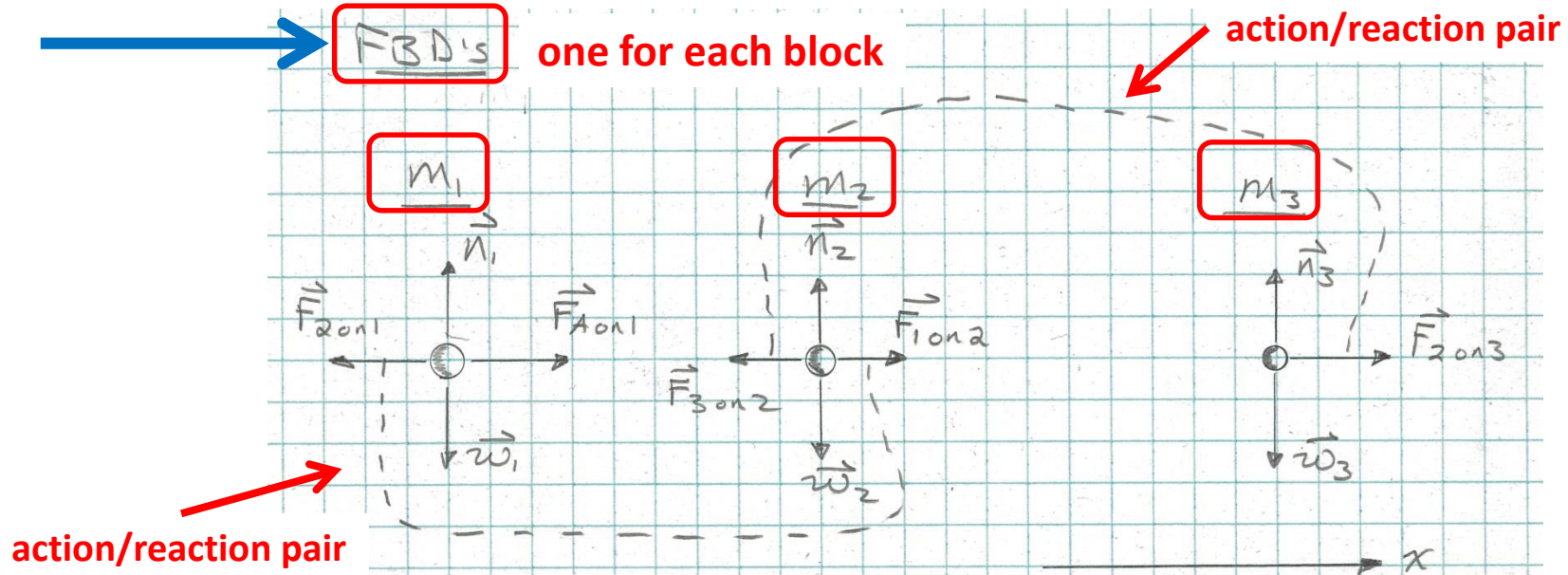
Blocks with masses of 1 kg, 2 kg, and 3 kg are lined up in a row on a frictionless table. All three are pushed forward by a 12 N force applied to the 1 kg block.

- How much force does the 2 kg block exert on the 3kg block?
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The system is the three blocks. The surface and the Earth are the environment.

Solution



$\Sigma F_x = \text{max}$ for each FBD.

Acceleration Constraint: **Constraint**
 $a_{x_1} = a_{x_2} = a_{x_3} = a$

block 1 $(\Sigma F_x)_1 = m_1 a_{x_1}$

$$-F_{2on1} + F_{Aon1} = m_1 a \quad (1)$$

block 2 $(\Sigma F_x)_2 = m_2 a_{x_2}$

$$-F_{3on2} + F_{1on2} = m_2 a \quad (2)$$

block 3 $(\Sigma F_x)_3 = m_3 a_{x_3}$

$$F_{2on3} = m_3 a \quad (3)$$

Solution

→ Add equation:

$$F_{Aon1} + \underbrace{(-F_{2on1} + F_{1on2})}_{=0} + \underbrace{(-F_{3on2} + F_{2on3})}_{=0} = (m_1 + m_2 + m_3)a$$

by Newton's 3rd:

So $F_{Aon1} = (m_1 + m_2 + m_3)a$

$$a = \frac{F_{Aon1}}{(m_1 + m_2 + m_3)} = \underline{2 \text{ m/s}^2}$$

Now: equ'n (3):

→ $F_{2on3} = m_3 a = \underline{6 \text{ N}}$

And, equ'n (2):

→ $F_{1on2} = m_2 a + F_{3on2}$
 $= \underline{10 \text{ N}}$

So, how do we solve problems with interacting bodies? **More Points**

Some familiar stuff here,
and some new stuff.

Constraints:
(objects that have the same
magnitude of acceleration)

Isolate each body and
identify all of the forces
acting ON each body.

Draw a FBD for each body.

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PROBLEM-SOLVING STRATEGY 7.1

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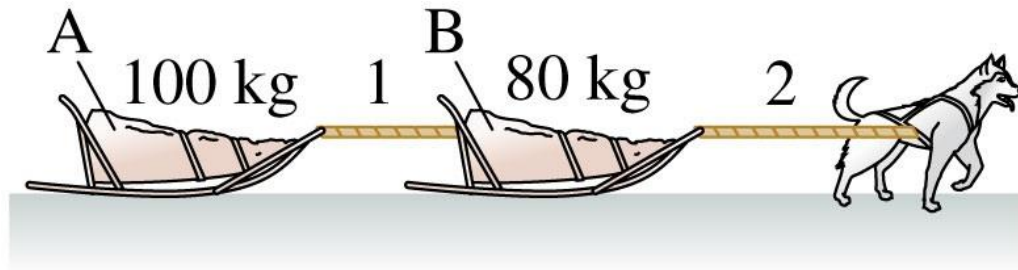
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Whiteboard Problem 7-2

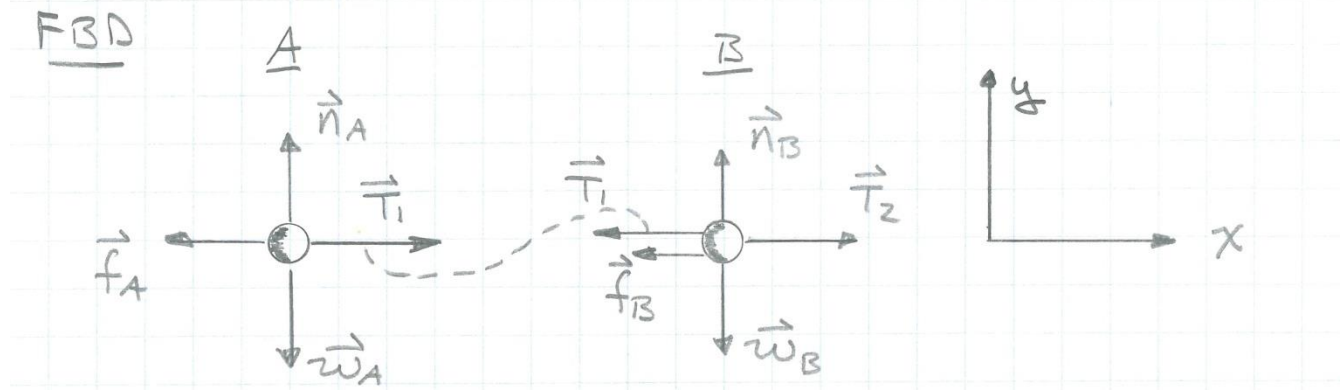
The sled dog in the figure drags sleds A and B across the snow. The coefficient of friction between the sleds and the snow is 0.10. **If the tension in rope 1 is 150 N, what is the tension in rope 2. (LC)**
(Show us your FBDs)



Hint: FBDs

$$T_1 = 150 \text{ N}$$

$$\mu_k = 0.1$$



Acceleration Constraint: $a_{x_A} = a_{x_B} = a$

Ideal Ropes and Pulleys

As shown in the previous problem, we can treat tension in ropes and strings as a contact force. In that problem, we assumed that the strings were massless. We do something similar for pulleys – assume massless and frictionless*.

TACTICS BOX 7.2



Working with ropes and pulleys

Ideal



For massless ropes or strings and massless, frictionless pulleys:

- If a force pulls on one end of a rope, the tension in the rope equals the magnitude of the pulling force.
- If two objects are connected by a rope, the tension is the same at both ends.
- If the rope passes over a pulley, the tension in the rope is unaffected.

(i.e. the pulley just turns the direction of the tension)

Exercises 17–22



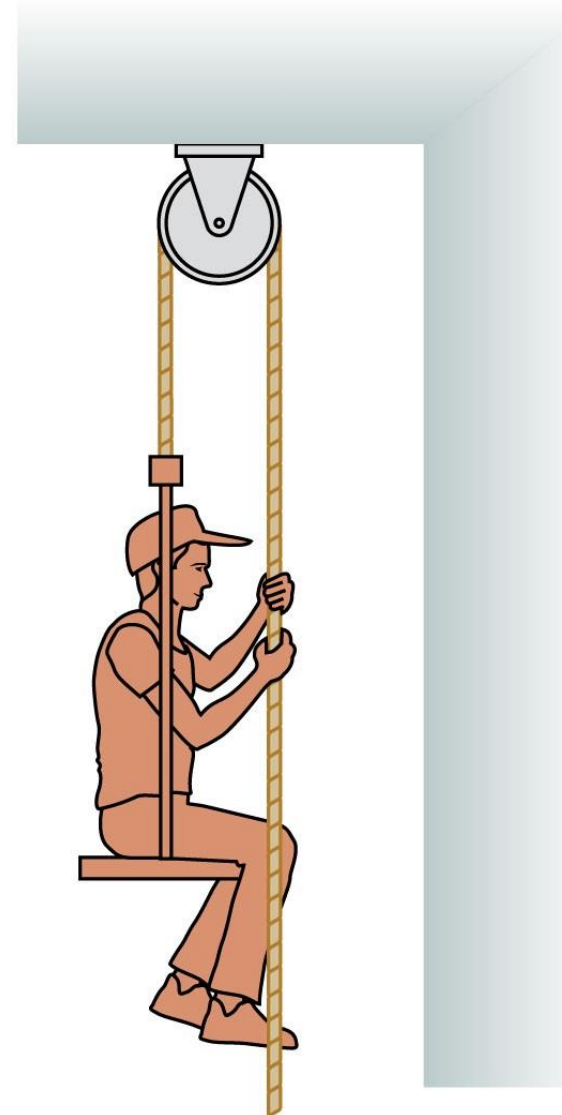
*In Chapter 12, we'll briefly look at real pulleys that have mass and friction

Whiteboard Problem: 7-3

A house painter uses a chair-and-pulley arrangement to lift himself up the side of a house. The painter's mass is 70 kg and chair's mass is 10 kg.

With what force must he pull down on the rope in order to accelerate upward at 0.2 m/s^2 ? (LC)

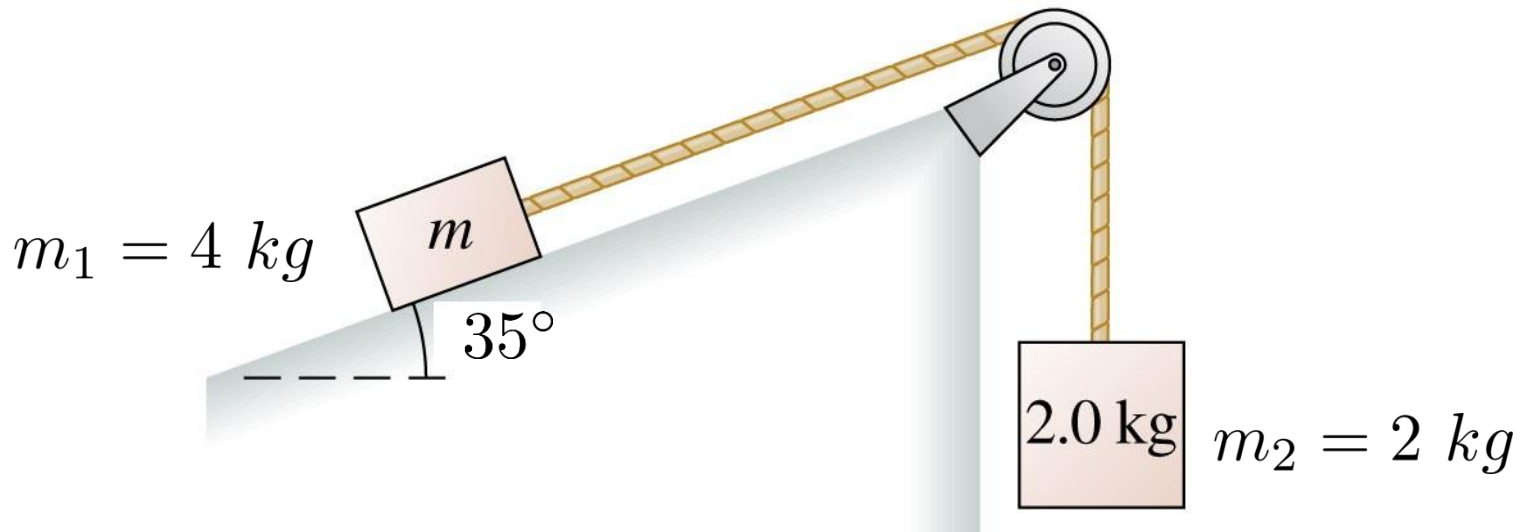
Hint: treat the painter and chair as one body. Isolate and draw a free body diagram.



Whiteboard Problem: 7-4

A 4.0 kg box is on a frictionless 35° slope and is connected via a massless string over a massless, frictionless pulley to a hanging 2.0 kg weight.

- Draw the Free Body Diagrams of m_1 and m_2 . What is the acceleration constraint?**
- If the box is released, find the acceleration and the tension (LC) in the string.**



Whiteboard Problem: 7-5

Consider the two blocks shown. All surfaces are frictionless, and a horizontal force F acts on the wedge.

Find an expression for the magnitude of the force F so that m_1 does not slip either up or down along the wedge. (LC)

Hint: this is one case where you do not want to choose axes parallel and perpendicular to the incline. It works best here if you choose x horizontal and y vertical for both bodies. Then for m_1 to not slip up or down the incline, you use the constraint $a_{1x} = a_{2x}$.

