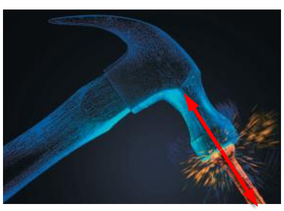
PHY131H1F
University of Toronto

Class 12 Preclass Video
by Jason Harlow

Based on Knight 3rd edition
Ch. 7, pgs. 167-184

Section 7.1

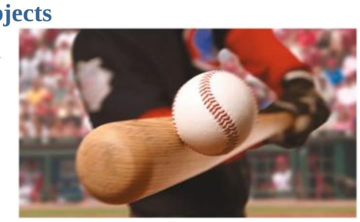
Interacting Objects



- When a hammer hits a nail, it exerts a forward force on the nail
- At the same time, the nail exerts a backward force on the hammer
- If you don't believe it, imagine hitting the nail with a glass hammer
- It's the force of the nail on the hammer that would cause the glass to shatter!

Interacting Objects

- When a bat hits a ball, the ball exerts a force on the bat
- When you pull someone with a rope in a tug-of-war, that person pulls back on you

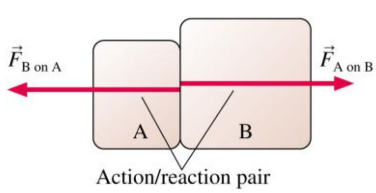


The bat and the ball are interacting with each other.

- When your chair pushes up on you (the normal force), you push down on the chair
- All forces come in pairs, called **action/reaction pairs**
- These forces occur simultaneously, and we cannot say which is the "action" and which is the "reaction"

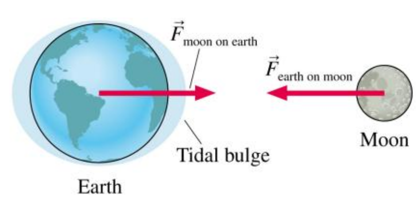
Interacting Objects

- If object A exerts a force on object B, then object B exerts a force on object A.
- The pair of forces, as shown, is called an **action/reaction pair**.



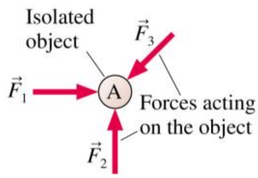
Interacting Objects

- Long-range forces, such as gravity, also come in pairs
- If you release a ball, it falls because the earth's gravity exerts a downward force $\vec{F}_{\text{earth on ball}}$
- At the same time, the ball pulls upward on the earth with a force $\vec{F}_{\text{ball on earth}}$
- The ocean tides are an indication of the long-range gravitational interaction of the earth and moon



Objects, Systems and the Environment

- Chapters 5 and 6 considered forces acting on a single object, modeled as a particle
- The figure shows a diagram representing single-particle dynamics

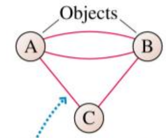


This is a force diagram.

- We can use Newton's second law, $\vec{a} = \vec{F}_{net}/m$, to determine the particle's acceleration

Objects, Systems and the Environment

- In this chapter we extend the particle model to include two or more objects that interact
- The figure shows three objects interacting via action/reaction pairs of forces

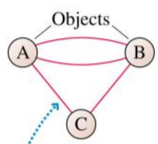


Each line represents an interaction and an action/reaction pair of forces. Some pairs of objects, such as A and B, can have more than one interaction.

- The forces can be given labels, such as $\vec{F}_{\text{A on B}}$ and $\vec{F}_{\text{B on A}}$

Objects, Systems and the Environment

- For example, set:
  - Object A = the hammer
  - Object B = the nail
  - Object C = the earth
- The earth interacts with both the hammer and the nail via gravity

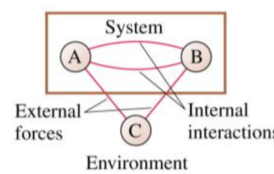


Each line represents an interaction and an action/reaction pair of forces. Some pairs of objects, such as A and B, can have more than one interaction.

- Practically, the earth remains at rest while the hammer and the nail move
- Define the **system** as those objects whose motion we want to analyze
- Define the **environment** as objects external to the system

Objects, Systems and the Environment

- The figure shows a new kind of diagram, an **interaction diagram**
- The objects of the system are in a box
- Interactions are represented by lines connecting the objects



This is an *interaction diagram.*

- Interactions with objects in the environment are called **external forces**

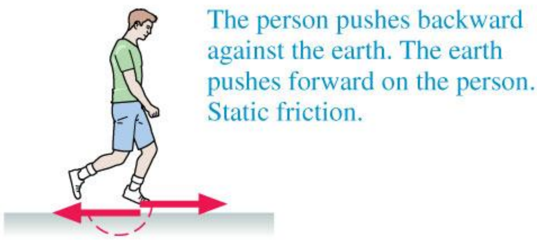
Section 7.2

Propulsion

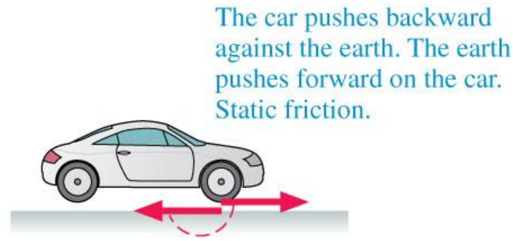
- If you try to walk across a frictionless floor, your foot slips and slides *backward*
- In order to walk, your foot must *stick* to the floor as you straighten your leg, moving your body forward
- The force that prevents slipping is *static friction*
- The static friction force points in the *forward* direction
- It is static friction that propels you forward!

What force causes this sprinter to accelerate?

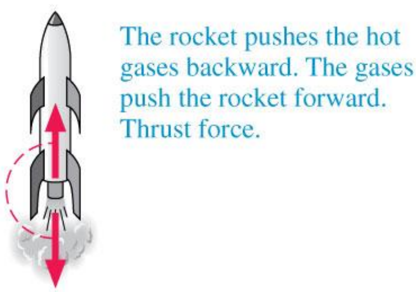
Examples of Propulsion



Examples of Propulsion



Examples of Propulsion



Section 7.3

Newton's Third Law

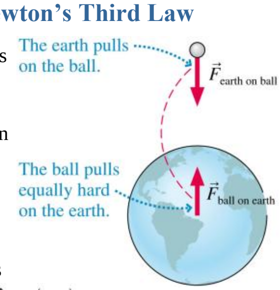
- Every force occurs as one member of an action/reaction pair of forces
- The two members of an action/reaction pair act on two *different* objects
- The two members of an action/reaction pair are equal in magnitude, but opposite in direction:

$$\vec{F}_{\text{A on B}} = -\vec{F}_{\text{B on A}}$$

- A catchy phrase, which is less precise, is:

"For every action there is an equal but opposite reaction."

Reasoning with Newton's Third Law



- When you release a ball, it falls down
- The action/reaction *forces* of the ball and the earth are *equal* in magnitude
- The acceleration of the ball is

$$\vec{a}_{\text{B}} = \frac{(\vec{F}_{\text{G}})_{\text{B}}}{m_{\text{B}}} = -g\hat{j}$$

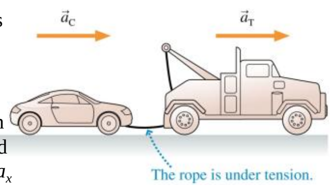
- The acceleration of the earth is

$$\vec{a}_{\text{E}} = \frac{\vec{F}_{\text{ball on earth}}}{m_{\text{E}}} = \frac{m_{\text{B}}\,g\hat{j}}{m_{\text{E}}} = \left(\frac{m_{\text{B}}}{m_{\text{E}}}\right)g\hat{j}$$

- If the ball has a mass of 1 kg, the earth accelerates upward at 2×10^{-24} m/s^2

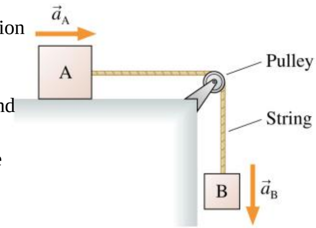
Acceleration Constraints

- If two objects A and B move together, their accelerations are *constrained* to be equal: $a_A = a_B$
- This equation is called an **acceleration constraint**
- Consider a car being towed by a truck
- In this case, the acceleration constraint is $a_{Cx} = a_{Tx} = a_x$
- Because the accelerations of both objects are equal, we can drop the subscripts C and T and call both of them a_x



Acceleration Constraints

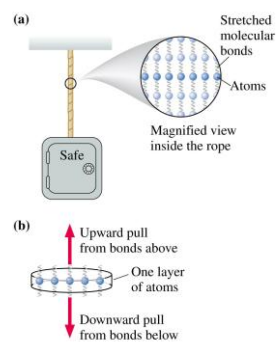
- Sometimes the acceleration of A and B may have different signs
- Consider the blocks A and B in the figure
- The string constrains the two objects to accelerate together



- But, as A moves to the right in the $+x$ direction, B moves down in the $-y$ direction
- In this case, the acceleration constraint is $a_{Ax} = -a_{By}$

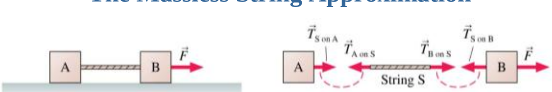
Section 7.4

Tension Revisited



- Figure (a) shows a heavy safe hanging from a rope
- The combined pulling force of billions of stretched molecular springs is called *tension*
- Tension pulls equally *in both directions*
- Figure (b) is a very thin cross section through the rope
- This small piece is in equilibrium, so it must be pulled equally from both sides

The Massless String Approximation



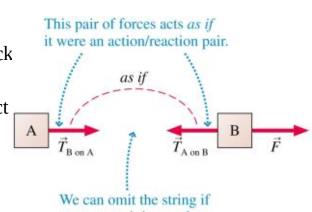
- Often in problems the mass of the string or rope is much less than the masses of the objects that it connects.
- In such cases, we can adopt the following **massless string approximation**:

$$T_{B\ on\ S} = T_{A\ on\ S} \quad \text{(massless string approximation)}$$

The Massless String Approximation

- Two blocks are connected by a massless string, as block B is pulled to the right
- Forces $\vec{T}_{S\ on\ A}$ and $\vec{T}_{S\ on\ B}$ act *as if* they are an action/reaction pair:

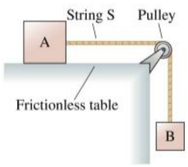
$$\vec{T}_{S\ on\ A} = -\vec{T}_{S\ on\ B}$$

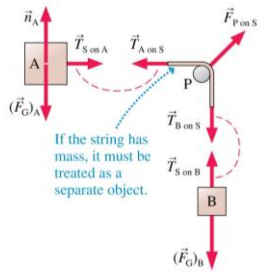


- All a massless string does is transmit a force from A to B without changing the magnitude of that force
- **For problems in this book, you can assume that any strings or ropes are massless unless it explicitly states otherwise**

Pulleys

- Block B drags block A across a frictionless table as it falls
- The string *and* the pulley are both massless
- There is no friction where the pulley turns on its axle
- Therefore, $T_{\text{A on S}} = T_{\text{B on S}}$





Pulleys

- Since $T_{\text{A on B}} = T_{\text{B on A}}$, we can draw the simplified free-body diagram on the right, below
- Forces $\vec{T}_{\text{A on B}}$ and $\vec{T}_{\text{B on A}}$ act *as if* they are in an action/reaction pair, even though they are not opposite in direction because the tension force gets "turned" by the pulley