First Common Quiz
8:30 to 9:45 am
Friday, Oct. 2, 2009
211 KUPF
Cover Weeks 1-4's material

Chapter 5

The Laws of Motion

- An object moving at a constant speed requires 6.0 s to go once around a circle with a diameter of 4.0 m. What is the magnitude of the instantaneous acceleration of the particle during this time?

a. 2.2 m/s2
b. 2.7 m/s2
c. 3.3 m/s2
d. 3.8 m/s2
e. 4.4 m/s2

Sir Isaac Newton

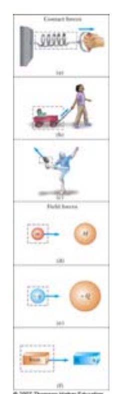
- 1642 – 1727
- Formulated basic laws of mechanics
- Discovered Law of Universal Gravitation
- Invented form of calculus
- Many observations dealing with light and optics

Force

- Forces are what cause any change in the velocity of an object
  - Newton's definition
  - A force is that which causes an acceleration

Classes of Forces

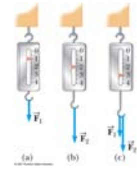
- Contact forces involve physical contact between two objects
  - Examples a, b, c
- Field forces act through empty space
  - No physical contact is required
  - Examples d, e, f



Fundamental Forces

- Gravitational force
  - Between objects
- Electromagnetic forces
  - Between electric charges
- Nuclear force
  - Between subatomic particles
- Weak forces
  - Arise in certain radioactive decay processes
- Note: These are all field forces

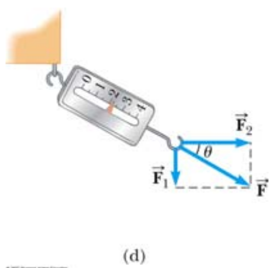
More About Forces



- A spring can be used to calibrate the magnitude of a force
- Doubling the force causes double the reading on the spring
- When both forces are applied, the reading is three times the initial reading

Vector Nature of Forces

- The forces are applied perpendicularly to each other
- The resultant (or net) force is the hypotenuse
- Forces are vectors, so you must use the rules for vector addition to find the net force acting on an object



Newton's First Law

- If an object does not interact with other objects, it is possible to identify a reference frame in which the object has zero acceleration
  - This is also called the *law of inertia*
  - It defines a special set of reference frames called *inertial frames*
    - We call this an ***inertial frame of reference***

Inertial Frames

- Any reference frame that moves with constant velocity relative to an inertial frame is itself an inertial frame
- A reference frame that moves with constant velocity relative to the distant stars is the best approximation of an inertial frame
  - We can consider the Earth to be such an inertial frame, although it has a small centripetal acceleration associated with its motion

Newton's First Law – Alternative Statement

- In the absence of external forces, when viewed from an inertial reference frame, an object at rest remains at rest and an object in motion continues in motion with a constant velocity
  - Newton's First Law describes what happens in the absence of a force
    - Does not describe zero net force
  - Also tells us that when no force acts on an object, the acceleration of the object is zero

Inertia and Mass

- The tendency of an object to resist any attempt to change its velocity is called ***inertia***
- ***Mass*** is that property of an object that specifies how much resistance an object exhibits to changes in its velocity
- Masses can be defined in terms of the accelerations produced by a given force acting on them:

$$\frac{m_1}{m_2} \equiv \frac{a_2}{a_1}$$

  - The magnitude of the acceleration acting on an object is inversely proportional to its mass

Mass vs. Weight

- Mass and weight are two different quantities
- Weight is equal to the magnitude of the gravitational force exerted on the object
  - Weight will vary with location
- Example:
  - w_{earth} = 180 lb; w_{moon} ~ 30 lb
  - m_{earth} = 2 kg; m_{moon} = 2 kg

Clicker Question

What is the gravitational acceleration at the surface of the Moon?

A. 9.8 m/s^2
B. 1.63 m/s^2
C. 58.8 m/s^2
D. 0 m/s^2
E. 4.9 m/s^2

Newton's Second Law

- When viewed from an inertial reference frame, the acceleration of an object is directly proportional to the net force acting on it and inversely proportional to its mass
  - Force is the cause of change in motion, as measured by the acceleration
- Algebraically,

$$\vec{\mathbf{a}} \propto \frac{\sum \vec{\mathbf{F}}}{m} \rightarrow \sum \vec{\mathbf{F}} = m\vec{\mathbf{a}}$$

  - With a proportionality constant of 1 and speeds much lower than the speed of light

More About Newton's Second Law

- $\sum \vec{\mathbf{F}}$ is the net force
  - This is the vector sum of all the forces acting on the object
- Newton's Second Law can be expressed in terms of components:
  - $\Sigma F_x = m\, a_x$
  - $\Sigma F_y = m\, a_y$
  - $\Sigma F_z = m\, a_z$

Units of Force

- The SI unit of force is the **newton** (N)
  - 1 N = 1 kg·m / s^2
- The US Customary unit of force is a **pound** (lb)
  - 1 lb = 1 slug·ft / s^2
- 1 N ~ ¼ lb

Gravitational Force

- The gravitational force, $\vec{\mathbf{F}}_g$, is the force that the earth exerts on an object
- This force is directed toward the center of the earth
- From Newton's Second Law
  - $\vec{\mathbf{F}}_g = m\vec{\mathbf{g}}$
- Its magnitude is called the weight of the object
  - Weight = F_g = mg

Lecture Quiz

- A ball is thrown horizontally from the top of a building 0.10 km high. The ball strikes the ground at a point 65 m horizontally away from and below the point of release. What is the speed of the ball just before it strikes the ground?

A. 43 m/s
B. 47 m/s
C. 39 m/s
D. 36 m/s
E. 14 m/s

Newton's Third Law

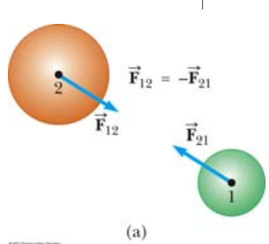
- If two objects interact, the force $\vec{\mathbf{F}}_{12}$ exerted by object 1 on object 2 is equal in magnitude and opposite in direction to the force $\vec{\mathbf{F}}_{21}$ exerted by object 2 on object 1
- $\vec{\mathbf{F}}_{12} = -\vec{\mathbf{F}}_{21}$
  - Note on notation: $\vec{\mathbf{F}}_{AB}$ is the force exerted *by* A *on* B

Newton's Third Law, Alternative Statements

- Forces always occur in pairs
- A single isolated force cannot exist
- The action force is equal in magnitude to the reaction force and opposite in direction
  - One of the forces is the action force, the other is the reaction force
  - It doesn't matter which is considered the action and which the reaction
  - The action and reaction forces must act on different objects and be of the same type

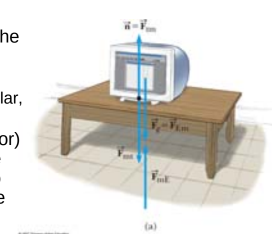
Action-Reaction Examples, 1

- The force $\vec{\mathbf{F}}_{12}$ exerted by object 1 on object 2 is equal in magnitude and opposite in direction to $\vec{\mathbf{F}}_{21}$ exerted by object 2 on object 1
- $\vec{\mathbf{F}}_{12} = -\vec{\mathbf{F}}_{21}$



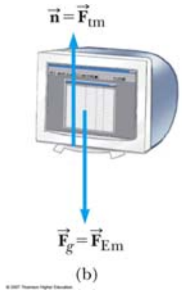
Action-Reaction Examples, 2

- The normal force (table on monitor) is the reaction of the force the monitor exerts on the table
  - Normal means perpendicular, in this case
- The action (Earth on monitor) force is equal in magnitude and opposite in direction to the reaction force, the force the monitor exerts on the Earth



Free Body Diagram

- In a free body diagram, you want the forces acting on a particular object
  - Model the object as a particle
- The normal force and the force of gravity are the forces that act on the monitor



Free Body Diagram, cont.

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

Particles in Equilibrium

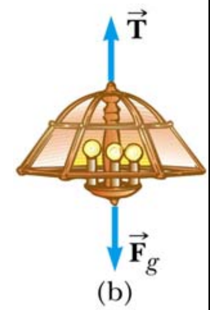
- If the acceleration of an object that can be modeled as a particle is zero, the object is said to be in **equilibrium**
  - The model is the *particle in equilibrium model*
- Mathematically, the net force acting on the object is zero

$$\sum \vec{\mathbf{F}} = 0$$
$$\sum F_x = 0 \text{ and } \sum F_y = 0$$

Equilibrium, Example 1a

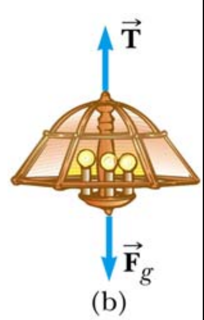
- A lamp is suspended from a chain of negligible mass
- The forces acting on the lamp are
  - the downward force of gravity
  - the upward tension in the chain
- Applying equilibrium gives

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



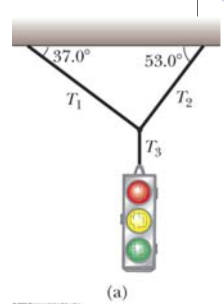
Equilibrium, Example 1b

- $\vec{T}$ *and* $\vec{F}_g$
  - **Not** an action-reaction pair
  - Both act on the lamp
- $\vec{T}$ *and* $\vec{T}'$
  - Action-reaction forces
  - Lamp on chain and chain on lamp
- $\vec{T}'$ *and* $\vec{T}''$
  - Action-reaction forces
  - Chain on ceiling and ceiling on chain
- Only the forces acting on the lamp are included in the free body diagram



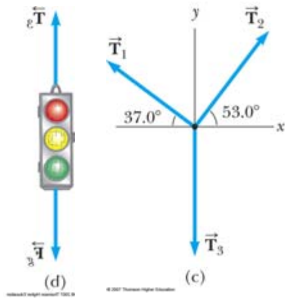
Equilibrium, Example 2a

- Example 5.4
- 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 a particle in equilibrium



Equilibrium, Example 2b

- Analyze
  - Need two free-body diagrams
  - Apply equilibrium equation to the light
  - Apply equilibrium equations to the knot



Equilibrium, Example 2 c

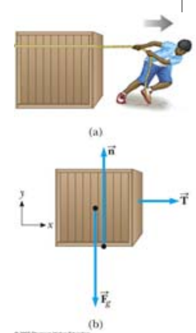
- Analyze, cont.
  - Find T_3 from applying equilibrium in the y-direction to the light
  - Find T_1 and T_2 from applying equilibrium in the x- and y-directions to the knot
- Finalize
  - Think about different situations and see if the results are reasonable

Particles Under a Net Force

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

Newton's Second Law, Example 1a

- Forces acting on the crate:
  - A tension, acting through the rope, is the magnitude of force $\vec{\mathbf{T}}$
  - The gravitational force, $\vec{\mathbf{F}}_g$
  - The normal force, $\vec{\mathbf{n}}$, exerted by the floor



Newton's Second Law, Example 1b

- Apply Newton's Second Law in component form:

$$\sum F_x = T = ma_x$$

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

- Solve for the unknown(s)
- If the tension is constant, then *a* is constant and the kinematic equations can be used to more fully describe the motion of the crate

Note About the Normal Force

- The normal force is **not** always equal to the gravitational force of the object
- For example, in this case

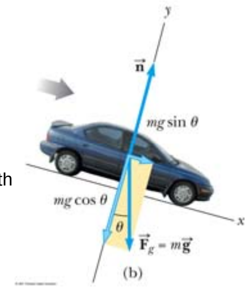
$$\sum F_y = n - F_g - F = 0$$

and $n = F_g + F$

- $\vec{\mathbf{n}}$ may also be less than $\vec{\mathbf{F}}_g$

Inclined Planes

- Forces acting on the object:
  - The normal force acts perpendicular to the plane
  - The gravitational force acts straight down
- Choose the coordinate system with *x* along the incline and *y* perpendicular to the incline
- Replace the force of gravity with its components

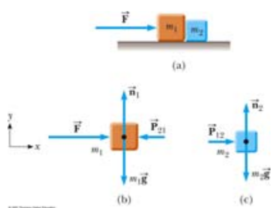


Multiple Objects

- When two or more objects are connected or in contact, Newton's laws may be applied to the system as a whole and/or to each individual object
- Whichever you use to solve the problem, the other approach can be used as a check

Multiple Objects, Conceptualize

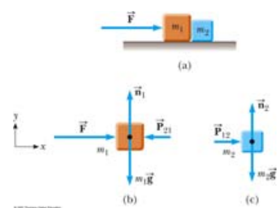
- Observe the two objects in contact
- Note the force
- Calculate the acceleration
- Reverse the direction of the applied force and repeat



Multiple Objects, Example 1

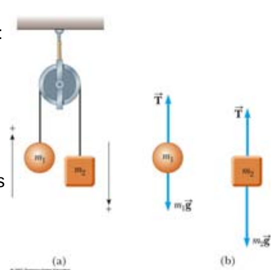
- First treat the system as a whole:

  $\sum F_x = m_{system} a_x$
- Apply Newton's Laws to the individual blocks
- Solve for unknown(s)
- Check: $|P_{12}| = |P_{21}|$



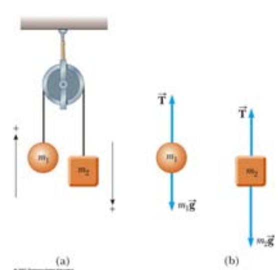
Multiple Objects, Example 2 – Atwood's Machine

- Forces acting on the objects:
  - Tension (same for both objects, one string)
  - Gravitational force
- Each object has the same acceleration since they are connected
- Draw the free-body diagrams
- Apply Newton's Laws
- Solve for the unknown(s)



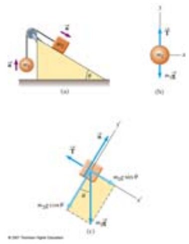
Exploring the Atwood's Machine

- Vary the masses and observe the values of the tension and acceleration
  - Note the acceleration is the same for both objects
  - The tension is the same on both sides of the pulley as long as you assume a massless, frictionless pulley



Multiple Objects, Example 3

- Draw the free-body diagram for each object
  - One cord, so tension is the same for both objects
  - Connected, so acceleration is the same for both objects
- Apply Newton's Laws
- Solve for the unknown(s)



Problem-Solving Hints Newton's Laws

- *Conceptualize*
  - Draw a diagram
  - Choose a convenient coordinate system for each object
- *Categorize*
  - Is the model a particle in equilibrium?
    - If so, $\Sigma F = 0$
  - Is the model a particle under a net force?
    - If so, $\Sigma F = m\,a$

Problem-Solving Hints Newton's Laws, cont

- Analyze
  - Draw free-body diagrams for each object
  - Include only forces acting on the object
  - Find components along the coordinate axes
  - Be sure units are consistent
  - Apply the appropriate equation(s) in component form
  - Solve for the unknown(s)
- Finalize
  - Check your results for consistency with your free-body diagram
  - Check extreme values