General Physics (PHY 2130)

Lecture 8

- Forces
- Newton's Laws of Motion

http://www.physics.wayne.edu/~apetrov/PHY2130/

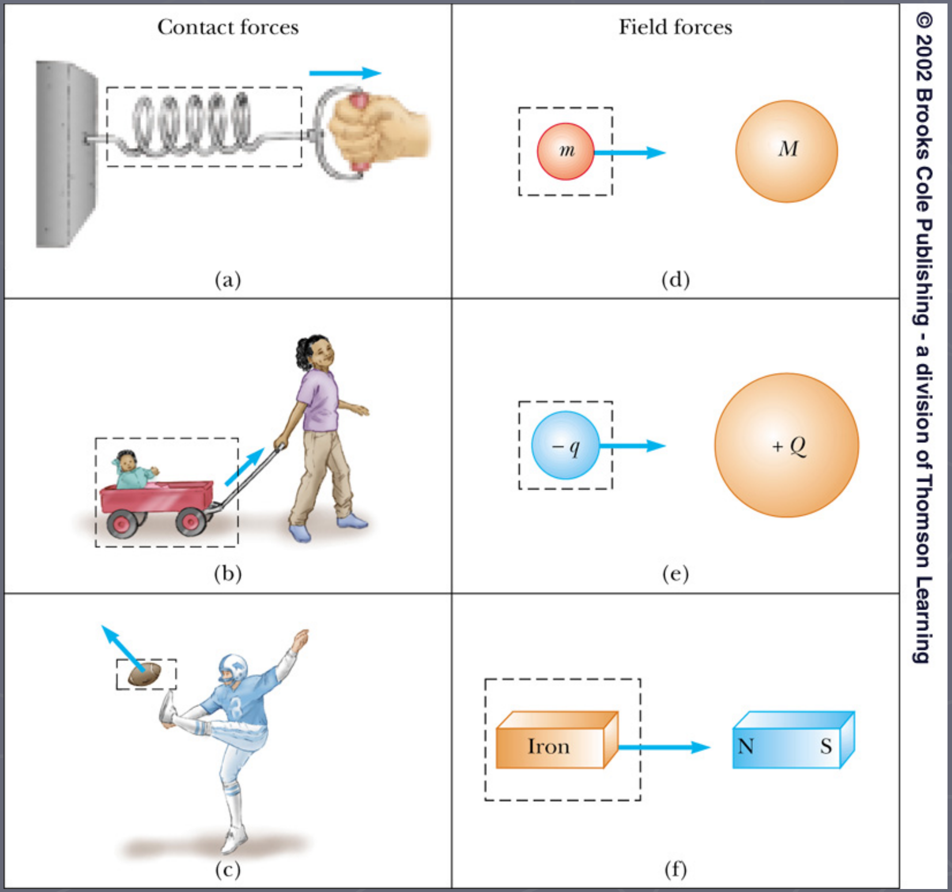
WAYNE STATE UNIVERSITY

Classical Mechanics

- Describes the relationship between the motion of objects in our everyday world and the forces acting on them
- Conditions when Classical Mechanics does not apply
  - very tiny objects (< atomic sizes)
  - objects moving near the speed of light

Forces

- Usually think of a force as a push or pull
- Vector quantity
- May be contact
  or
  long range (field) force



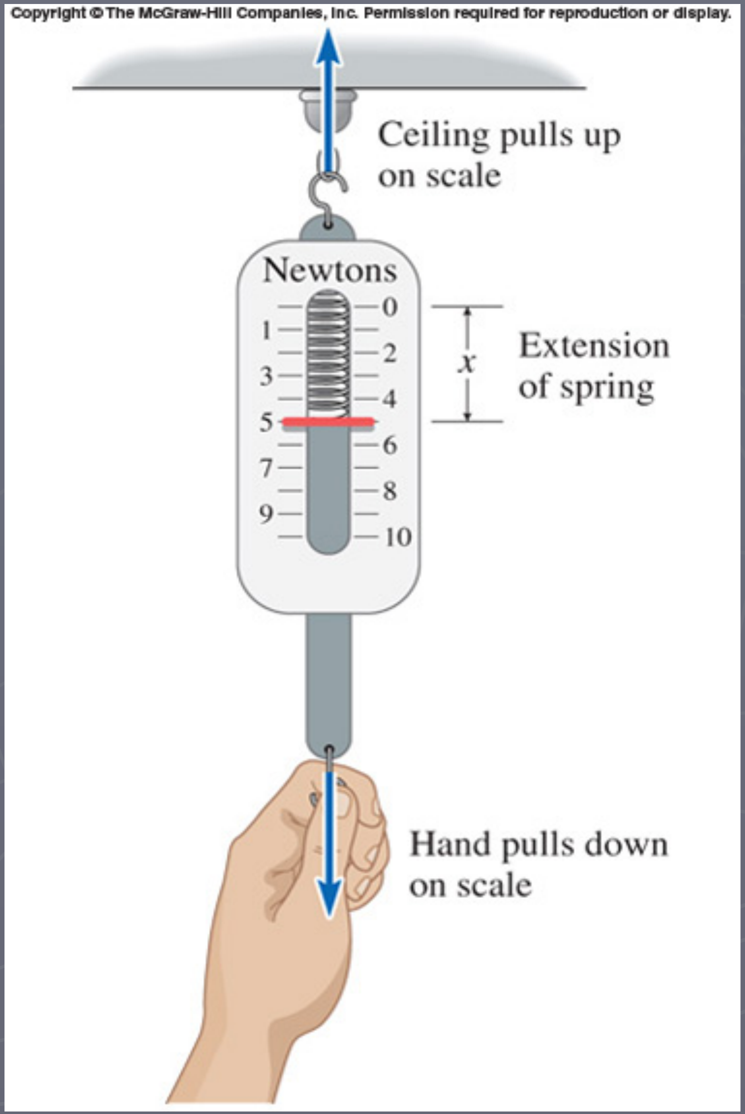
Fundamental Forces

- Types
  - Strong nuclear force
  - Electromagnetic force
  - Weak nuclear force
  - Gravity
- Characteristics
  - All field forces
  - Listed in order of decreasing strength
  - Only gravity and electromagnetic in mechanics

Measuring the force

How can a force be measured?

One way is with a spring scale.



Units of Force

- SI unit of force is a Newton (N)

$$1\,\mathrm{N} \equiv 1\,\frac{\mathrm{kg\,m}}{\mathrm{s}^2}$$

Units of force	
SI	Newton (N=kg m/ s^2)
CGS	Dyne (dyne=g cm/s^2)
US Customary	Pound (lb=slug ft/s^2)

- 1 N = 10^5 dyne = 0.225 lb

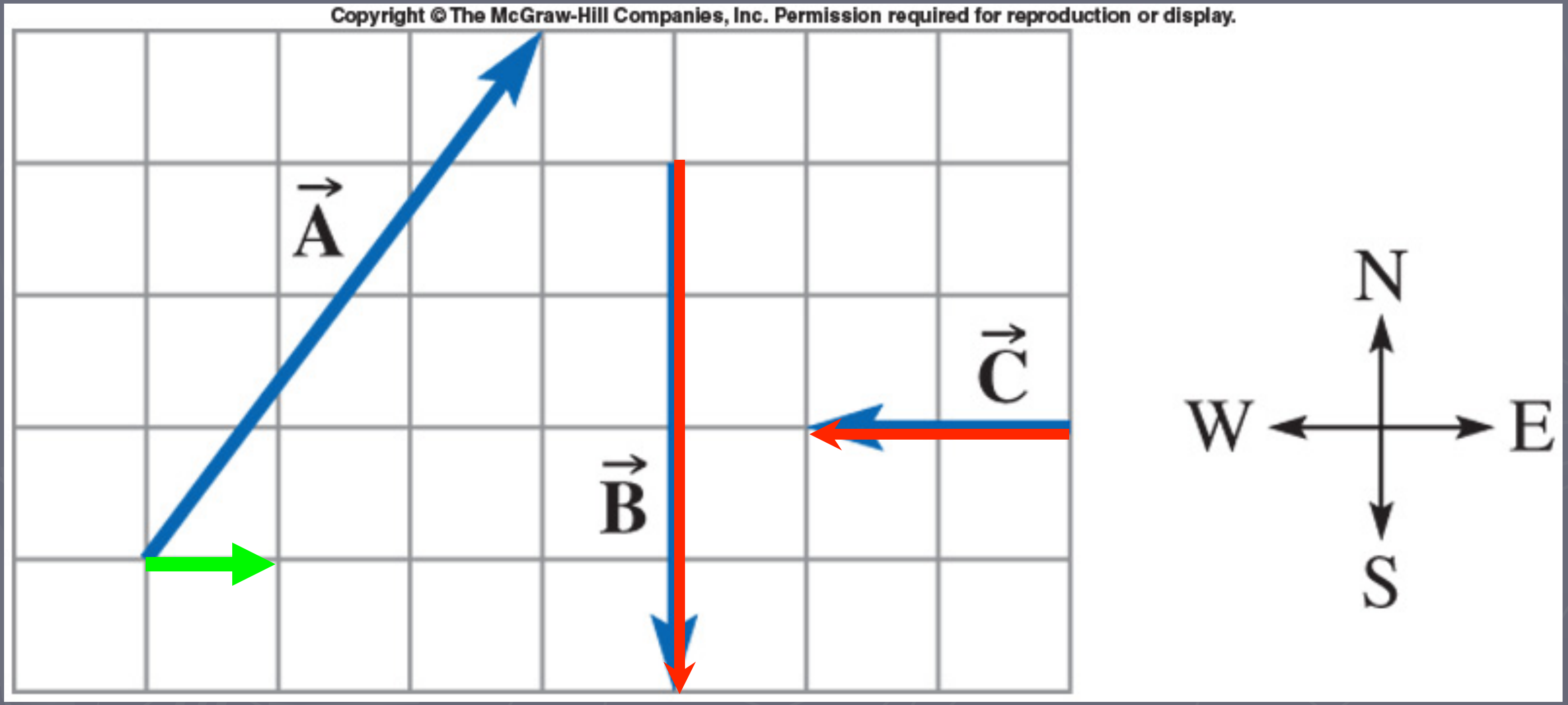
More about forces

- What if there is more than one force acting on a body?
  - Different forces can be added vectorially

- The **net force** is the vector sum of all the forces acting on a body:

$$\vec{\mathbf{F}}_{net} = \sum_{all} \vec{\mathbf{F}} = \vec{\mathbf{F}}_1 + \vec{\mathbf{F}}_2 + \vec{\mathbf{F}}_3 + \ldots$$

In the drawing, what is the vector sum of forces A + B+ C if each grid square is 2 N on a side?



(Answer 2N to East)

Free Body Diagram

- Must identify all the forces acting on the object of interest
- Choose an appropriate coordinate system
- If the free body diagram is incorrect, the solution will likely be incorrect

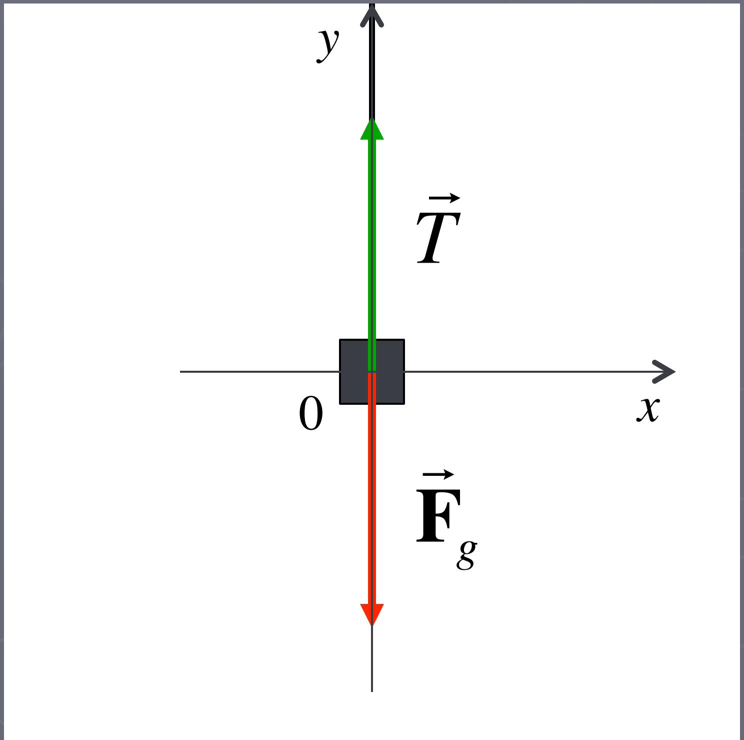
Free Body Diagram

- ✓ Draw an idealization of the body in question (a dot, a box,…). You will need one free body diagram for each body in the problem that will provide useful information for you to solve the given problem.
- ✓ Choose an appropriate coordinate system!!!
- ✓ Indicate only the forces acting on the body. Label the forces appropriately. Do not include the forces that this body exerts on any other body.
- ✓ You may indicate the direction of the body's acceleration or direction of motion if you wish, but it must be done well off to the side of the free body diagram.

Example: Free Body Diagram

Real life

Free body diagram



Newton's First Law

- If no forces act on an object, it continues in its original state of motion; that is, unless something exerts an external force on it, an object at rest remains at rest and an object moving with some velocity continues with that same velocity.

Newton's First Law, cont.

- External force
  - any force that results from the interaction between the object and its environment
- Alternative statement of Newton's 1st Law
  - When there are no external forces acting on an object, the acceleration of the object is zero.

Inertia and Mass

- Inertia is the tendency of an object to continue in its original motion
- Mass is a measure of the inertia, i.e resistance of an object to changes in its motion due to a force
- Recall: mass is a scalar quantity

Units of mass	
SI	kilograms (kg)
CGS	grams (g)
US Customary	slug (slug)

Inertia and Mass: Two Examples

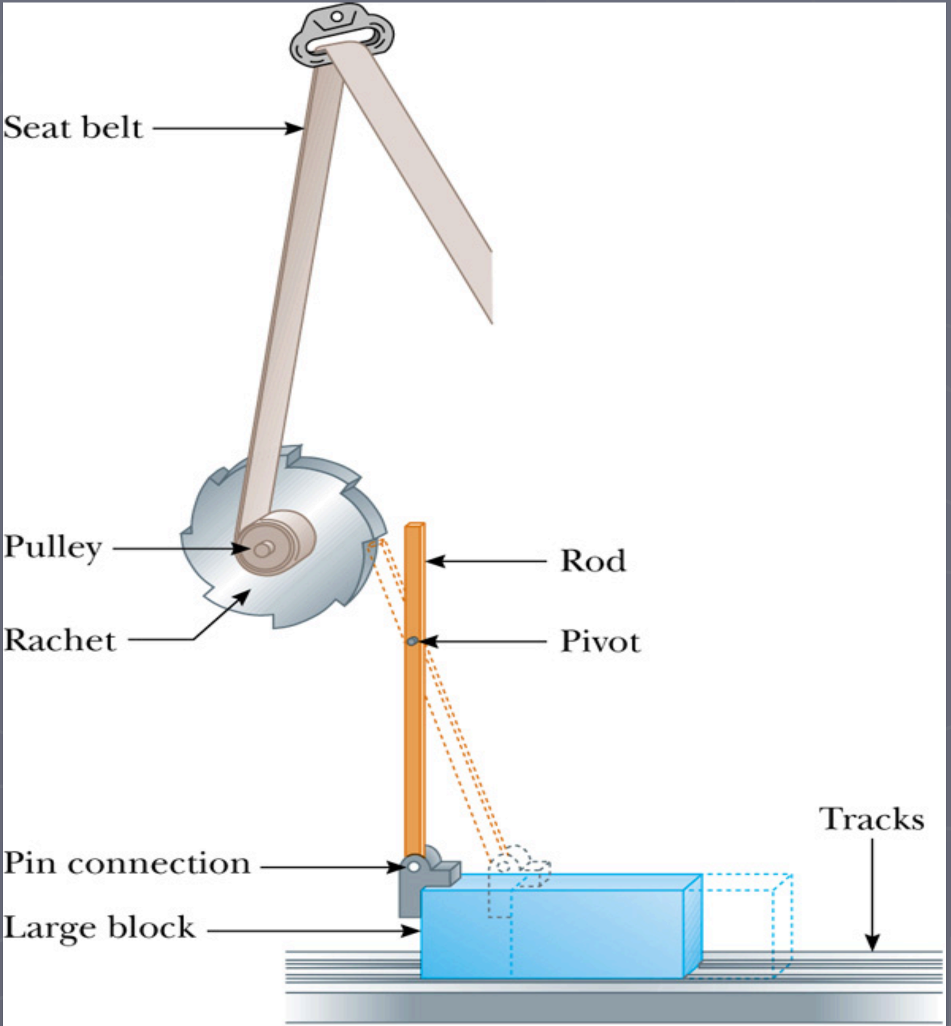
Runaway train

- Inertia is the tendency of an object to continue in its original motion
- Mass is a measure of the inertia, i.e resistance of an object to changes in its motion due to a force

Inertia and Mass: Two Examples

Seatbelt

- Inertia is the tendency of an object to continue in its original motion
- Mass is a measure of the inertia, i.e resistance of an object to changes in its motion due to a force



Newton's Second Law

- The acceleration of an object is directly proportional to the net force acting on it and inversely proportional to its mass.

$$\vec{a} \propto \frac{\sum \vec{F}}{m} \quad or \quad \sum \vec{F} = m\vec{a}$$

  - **F** and **a** are both vectors
- Can also be applied three-dimensionally
  - acceleration can also be caused by change of the direction of velocity

Newton's Second Law

- Note: $\sum \vec{F}$ represents the vector sum of all external forces acting on the object.
- Since N2[nd]L is a vector equation, we can always write it in terms of components:

$$\sum \vec{F} = m\vec{a}: \quad \begin{cases} F_x = ma_x \\ F_y = ma_y \\ F_z = ma_z \end{cases}$$

Example: force on the bullet

A 5.0-g bullet leaves the muzzle of a rifle with a speed of 320 m/s. What total force (assumed constant) is exerted on the bullet while it is traveling down the 1-m-long barrel of the rifle?

<u>Given:</u>

$m = 5$ g
$= 0.005$ kg
$v_f = 320$ m/s
$v_i = 0$ m/s
$\Delta x = 1$ m

<u>Find:</u>

$F = ?$

Solution:

Idea: let's use 2nd Newton's law F=ma. To do so, we would need to calculate bullet's acceleration.

$$v_f^2 = v_i^2 + 2a\Delta x \quad \text{or}$$

$$a = \frac{v_f^2}{2\Delta x} = \frac{(320\, m/s)^2}{2(1m)} = 51200\, m/s^2$$

Now, force:

$$F = ma = 0.005kg \times 51200\, m/s^2 = 256N$$

ConcepTest

A car rounds a curve while maintaining a constant speed. Is there a net force on the car as it rounds the curve?

1. No—its speed is constant.
2. Yes.
3. It depends on the sharpness of the curve and the speed of the car.
4. It depends on the driving experience of the driver.

ConcepTest

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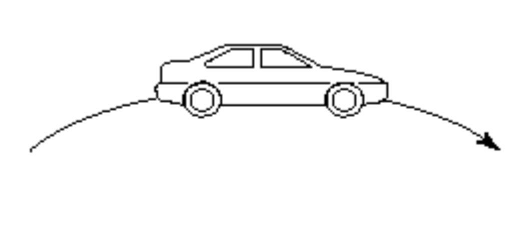


1. No—its speed is constant.
2. Yes. ✓
3. It depends on the sharpness of the curve and the speed of the car.
4. It depends on the driving experience of the driver.

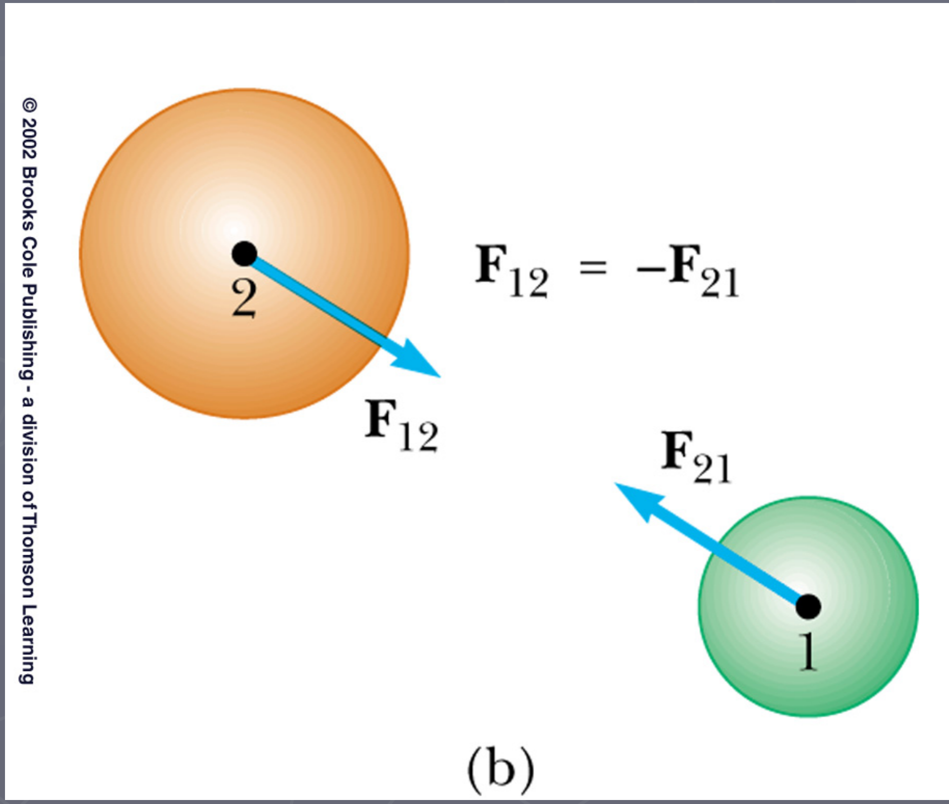
Note: Acceleration is a change in the speed and/or direction of an object. Thus, because its direction has changed, the car has accelerated and a force must have been exerted on it.

Newton's Third Law

- If two objects interact, the force F_{12} exerted by object 1 on object 2 is equal in magnitude but opposite in direction to the force F_{21} exerted by object 2 on object 1.
  - Equivalent to saying a single isolated force cannot exist

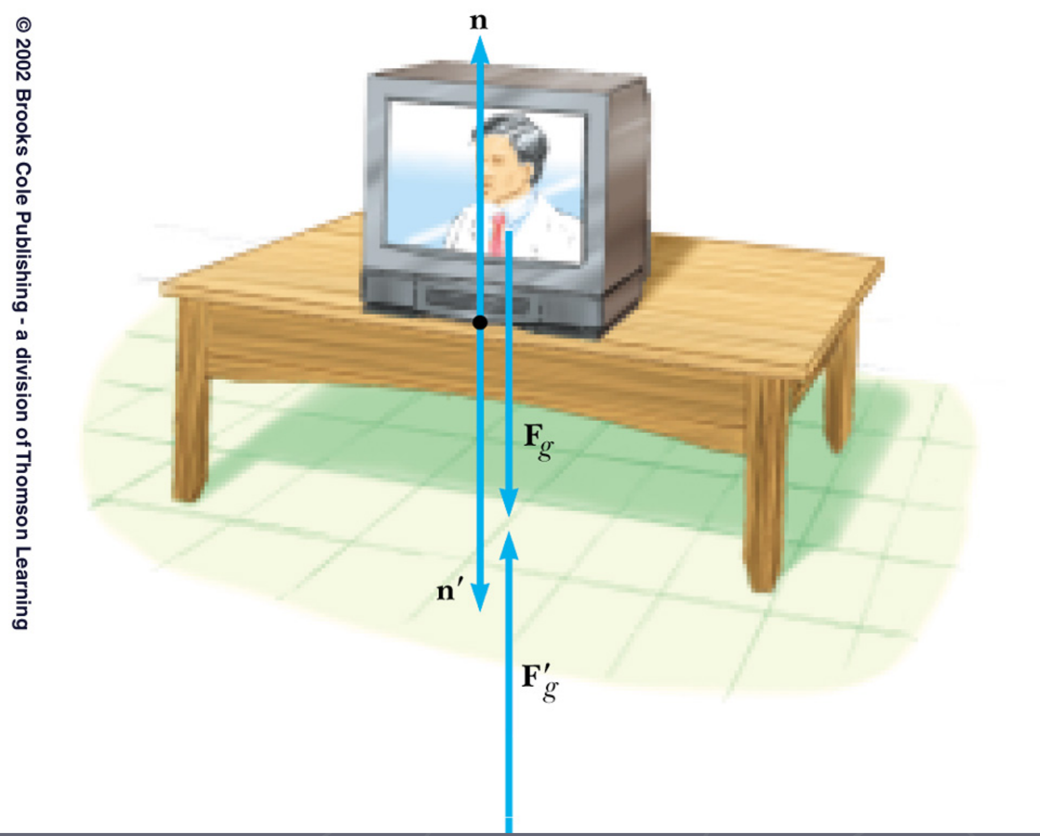
Example: Newton's Third Law

- Consider collision of two spheres
- F_{12} may be called the *action* force and F_{21} the *reaction* force
  - Actually, either force can be the action or the reaction force
- The action and reaction forces act on **different** objects



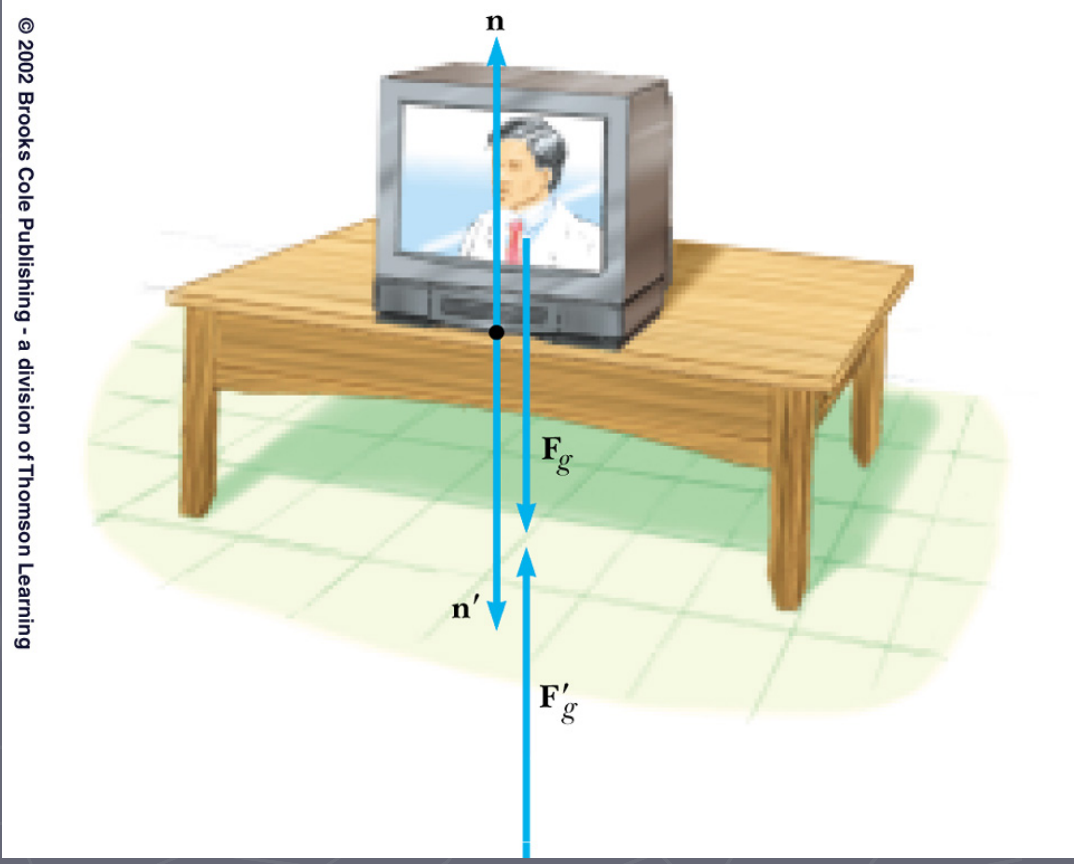
Example 1: Action-Reaction Pairs

- n and n'
  - n is the *normal* force, the force the table exerts on the TV
  - n is always perpendicular to the surface
  - n' is the reaction – the TV on the table
  - n = - n'



Example 2: Action-Reaction pairs

- F_g and F_g'
  - F_g is the force the Earth exerts on the object
  - F_g' is the force the object exerts on the earth
  - $F_g = -F_g'$



Forces Acting on an Object

- Newton's Law uses the forces acting *on* an object
- n and F_g are acting on the object
- n' and F_g' are acting on other objects

ConcepTest

Consider a person standing in an elevator that is accelerating upward. The upward normal force *N* exerted by the elevator floor on the person is

1. larger than
2. identical to
3. smaller than
4. equal to zero, i.e. irrelevant to

the downward weight *W* of the person.

ConcepTest

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the downward weight *W* of the person.

Note: In order for the person to be accelerated upward, the normal force exerted by the elevator floor on her must exceed her weight.

Three Newton's laws

1. If no forces act on an object, it continues in its original state of motion; that is, unless something exerts an external force on it, an object at rest remains at rest and an object moving with some velocity continues with that same velocity.

2. The acceleration of an object is directly proportional to the net force acting on it and inversely proportional to its mass.

3. If two objects interact, the force F_{12} exerted by object 1 on object 2 is equal in magnitude but opposite in direction to the force F_{21} exerted by object 2 on object 1.