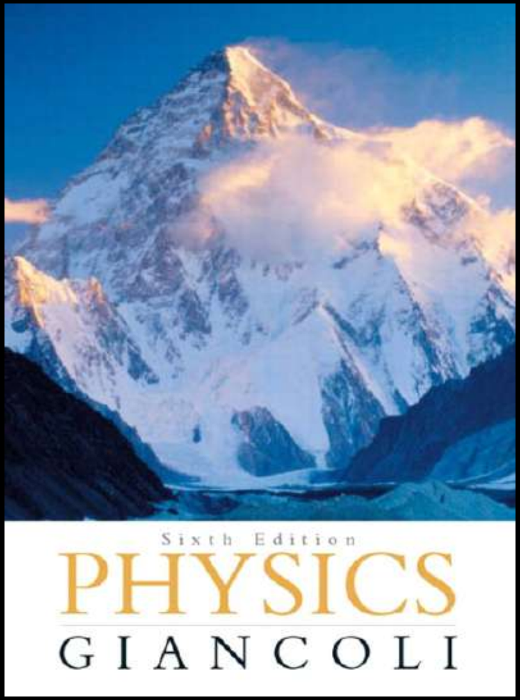


Lecture PowerPoints

Chapter 5

Physics: Principles with Applications, 6th edition

Giancoli

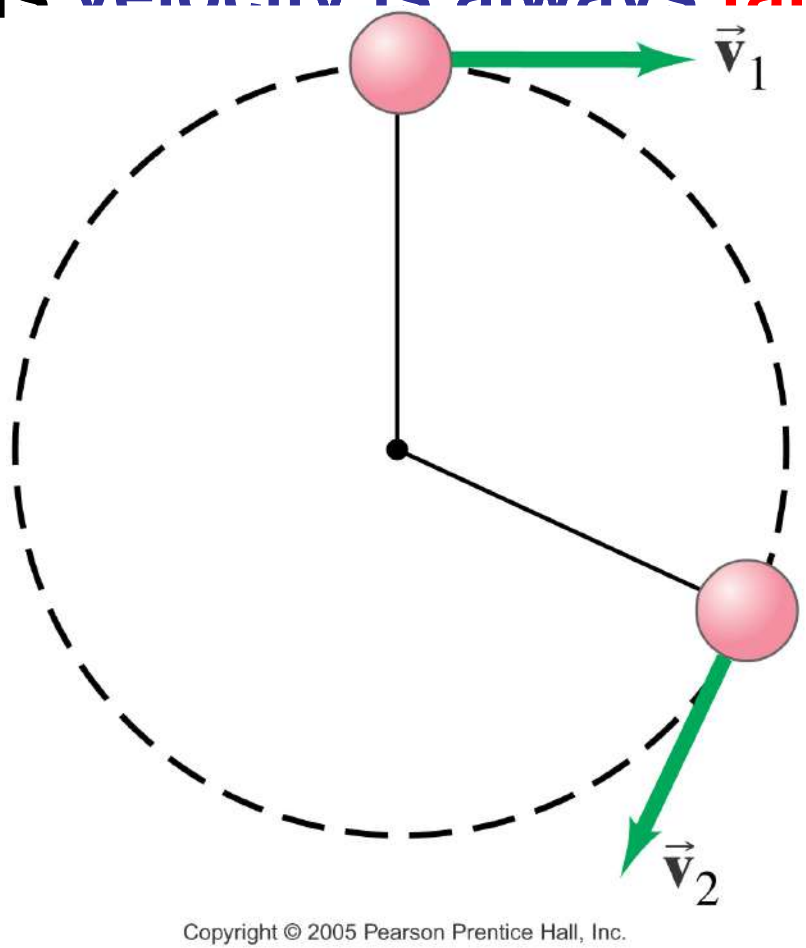
Chapter 5

Circular Motion; Gravitation

5-1 Kinematics of Uniform Circular Motion

Uniform circular motion: motion in a circle of constant radius at constant speed

Instantaneous velocity is always tangent to circle.



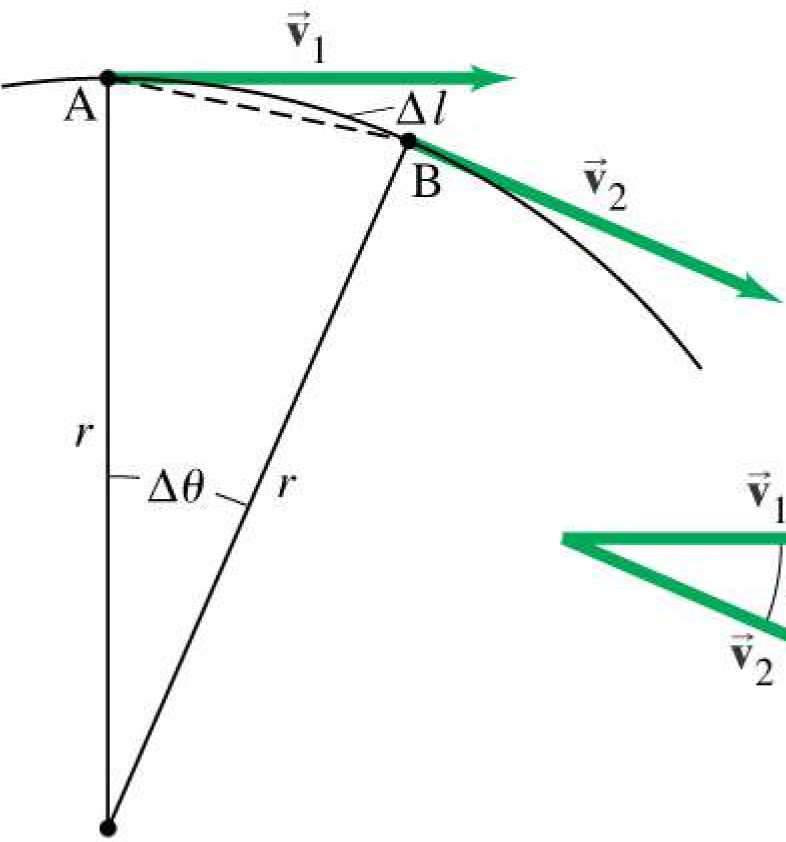
5-1 Kinematics of Uniform Circular Motion

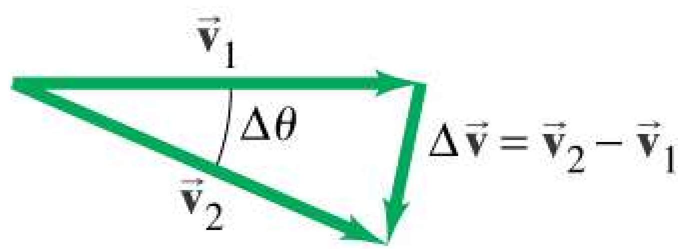
Looking at the change in velocity in the limit that the time interval becomes infinitesimally small, we see that

$$a_R = \frac{v^2}{r}$$

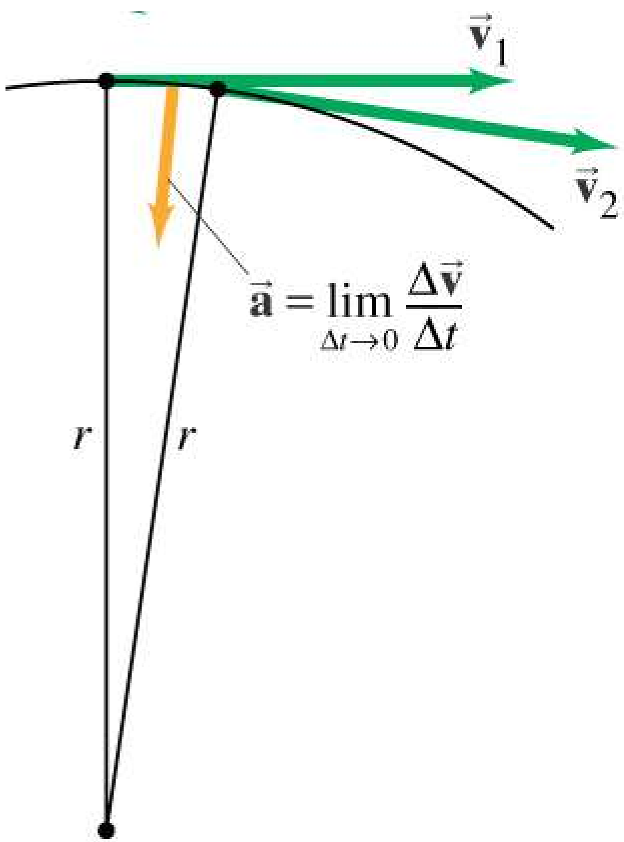
(on formula sheet)

(or a_C)





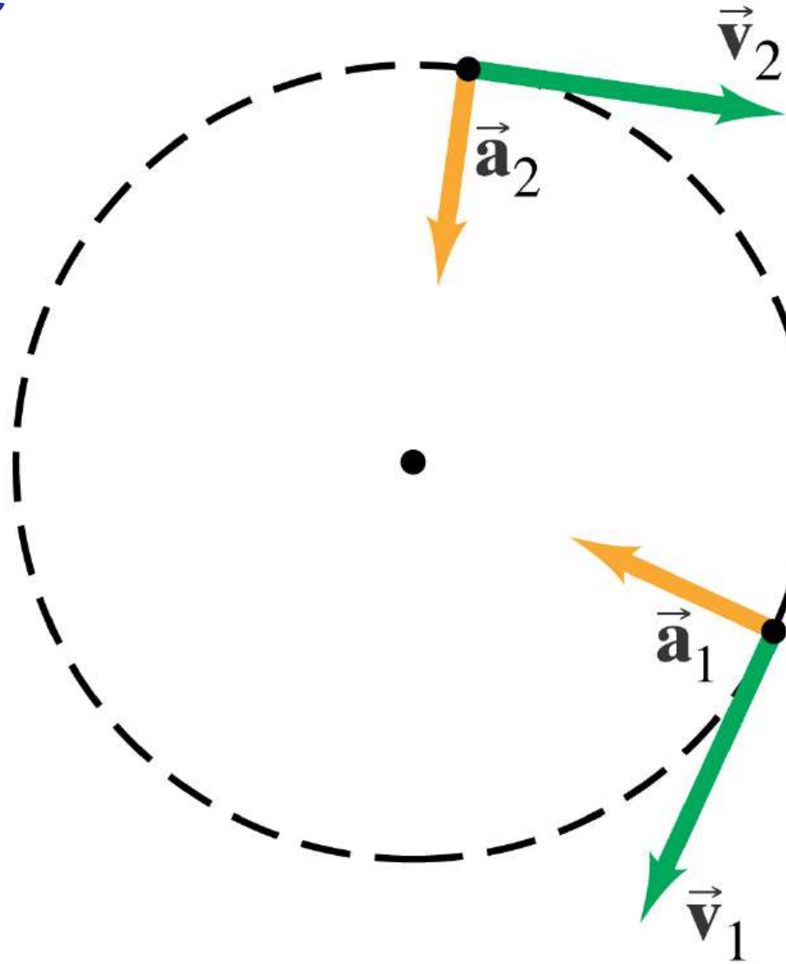
(a)



(c)

5-1 Kinematics of Uniform Circular Motion

This acceleration is called the **centripetal**, or radial, acceleration, and it points towards the center of the circle



5-1 Kinematics of Uniform Circular Motion

- **Frequency** (f) – revolutions per second
- **Period** (T) – time for one revolution

$$T = \frac{1}{f}$$

(on formula sheet)

$$v = \frac{2\pi r}{T}$$

(NOT on formula sheet)
Where does this formula come from?

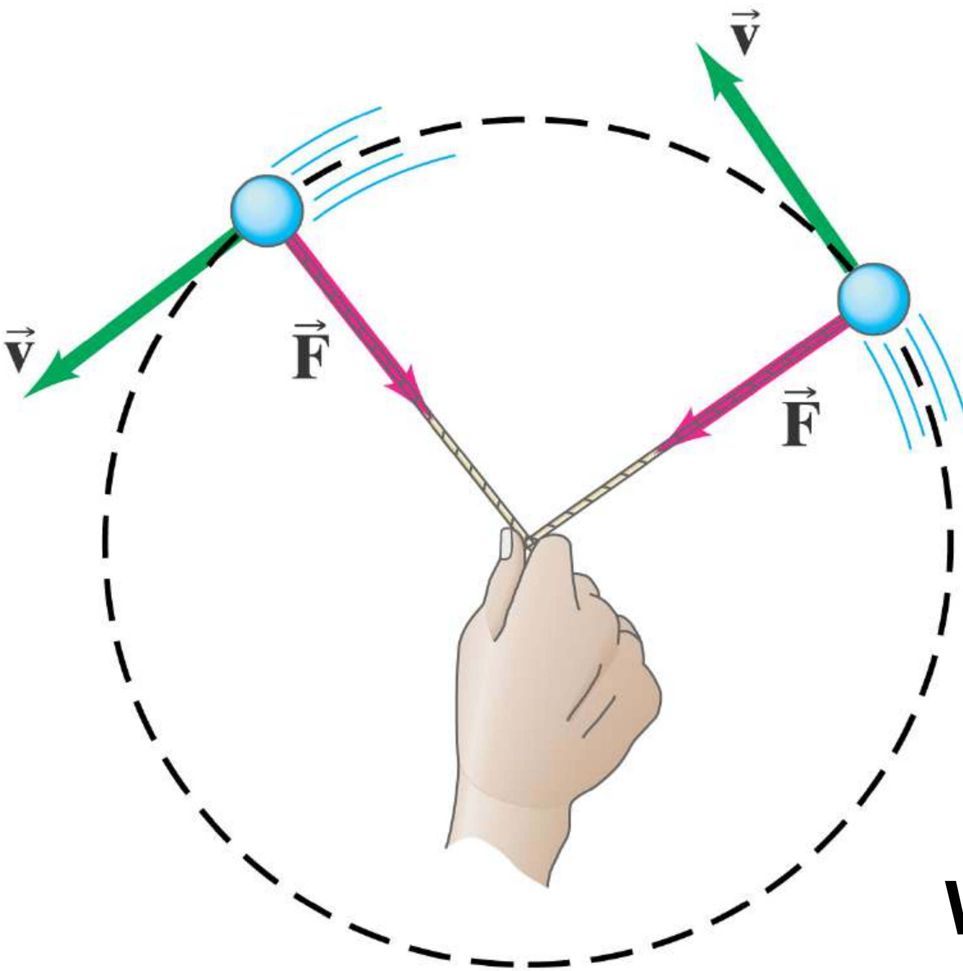
A 150 g ball at the end of a string is revolving uniformly in a horizontal circle of radius 0.600 m. The ball makes 2.00 revolutions per second. What is its centripetal acceleration?

If the string is doubled in length but everything else stays the same, how will centripetal acceleration change?

The Moon’s nearly circular orbit about the Earth has a radius of about 384,000 km and a period of 27.3 days. Determine the acceleration of the Moon toward the Earth. Is this the Moon’s gravity on objects on its surface?

5-2 Dynamics of Uniform Circular Motion

For an object to be in uniform circular motion, there must be a net force acting on it.



We already know the acceleration, so can immediately write the force:

$$\Sigma F_R = m a_R = m\frac{v^2}{r}$$

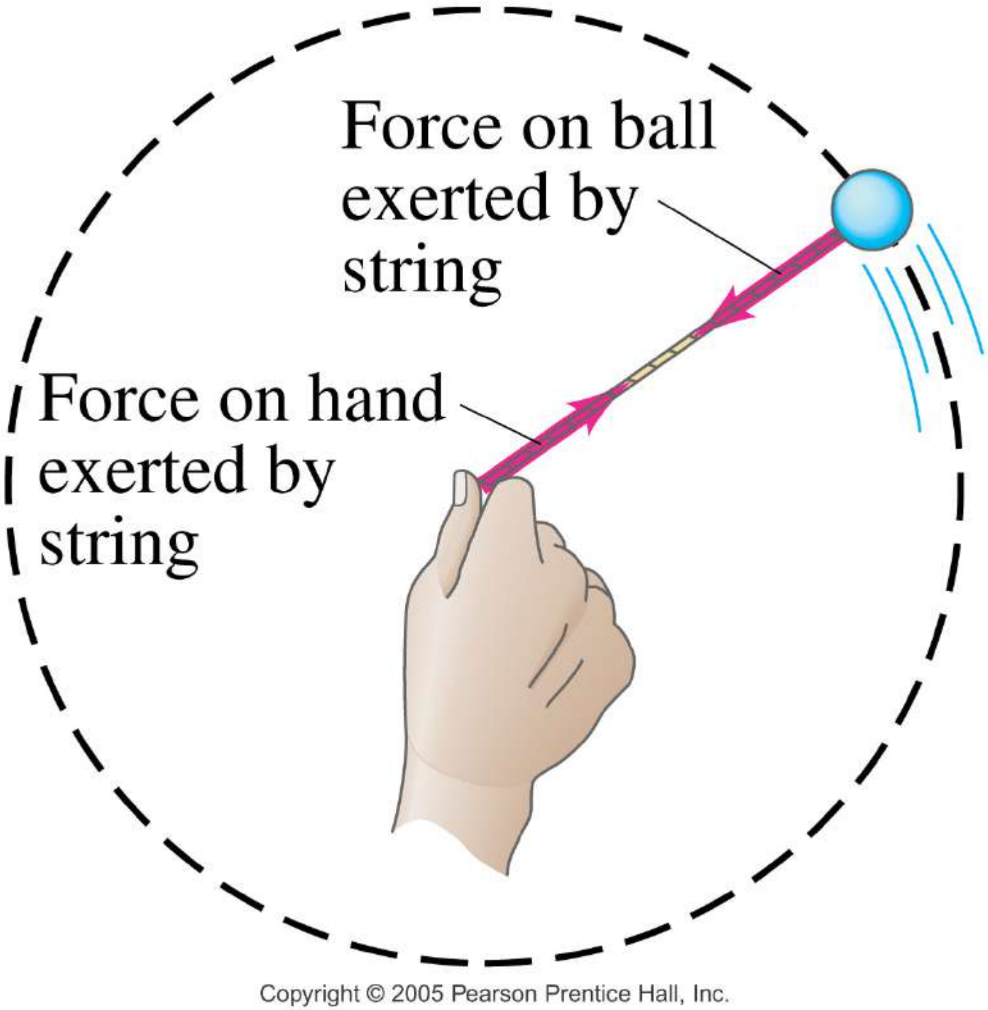
IMPORTANT

(not on formula sheet)

What exerts the force?

5-2 Dynamics of Uniform Circular Motion

We can see that the force must be inward by thinking about a ball on a string:

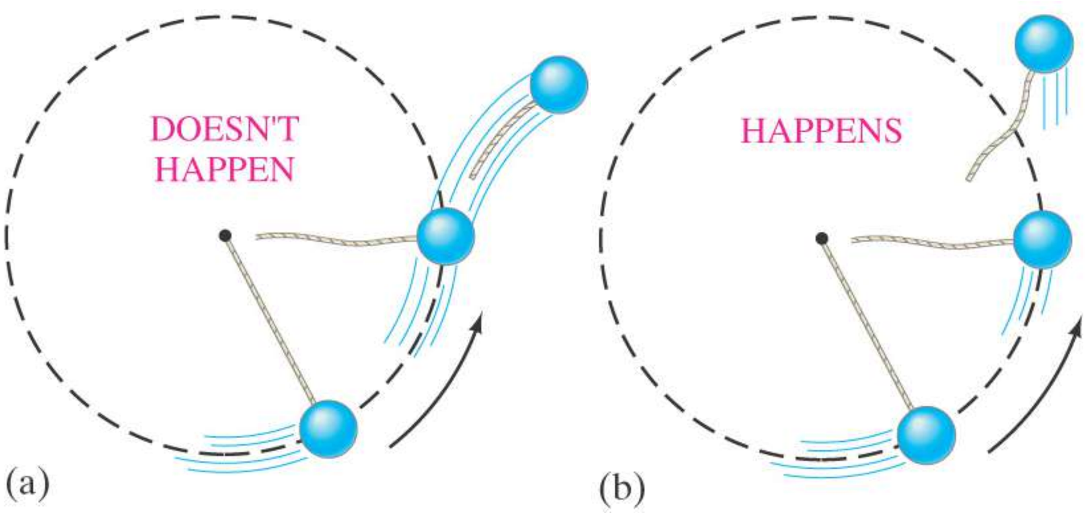


Centripetal force is not a new kind of force. It is a net force. You pull inwardly exerting a force on the ball. The ball exerts an equal and opposite force on the string. This is the outward force your hand feels.

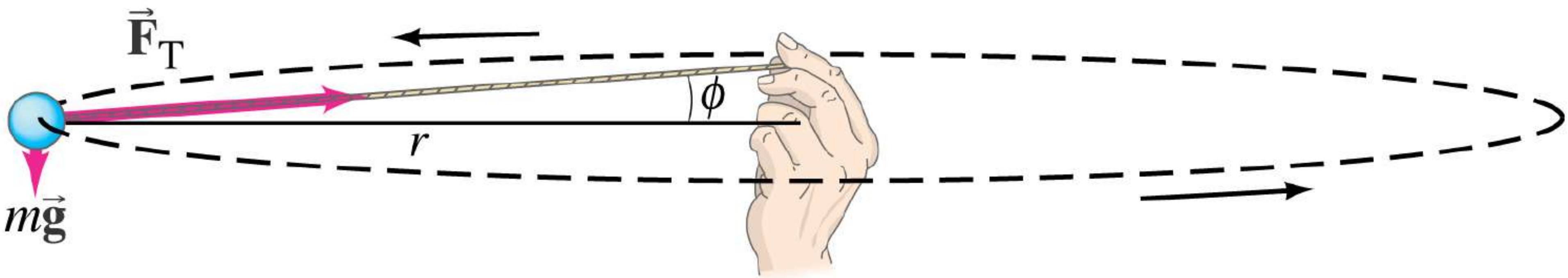
5-2 Dynamics of Uniform Circular Motion

There is **no centrifugal force** pointing outward; what happens is that the natural tendency of the object to move in a straight line must be overcome (**Inertia**).

If the centripetal force vanishes, the object flies off **tangent** to the circle.

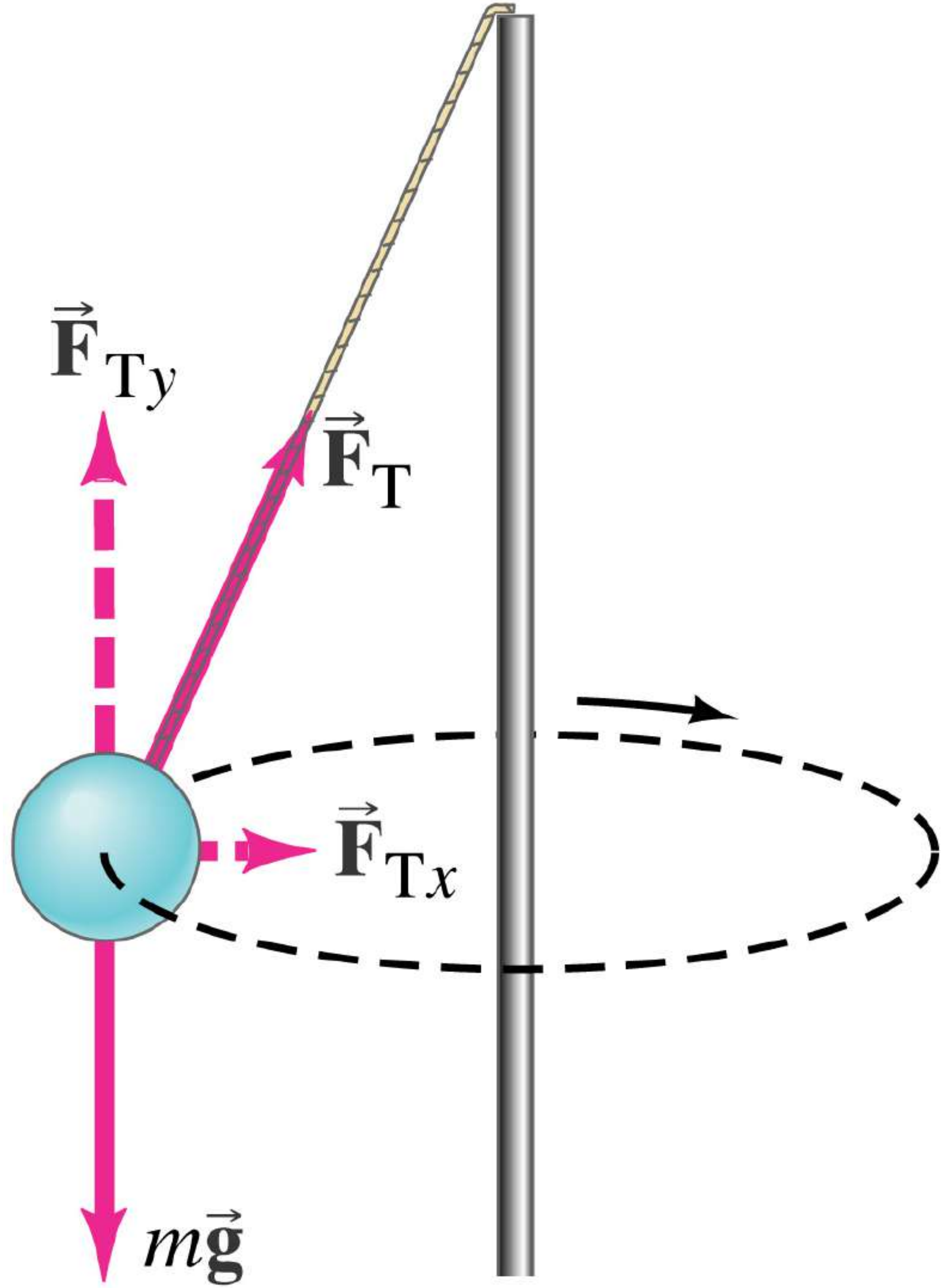


Estimate the force a person must exert on a string from the previous problem.



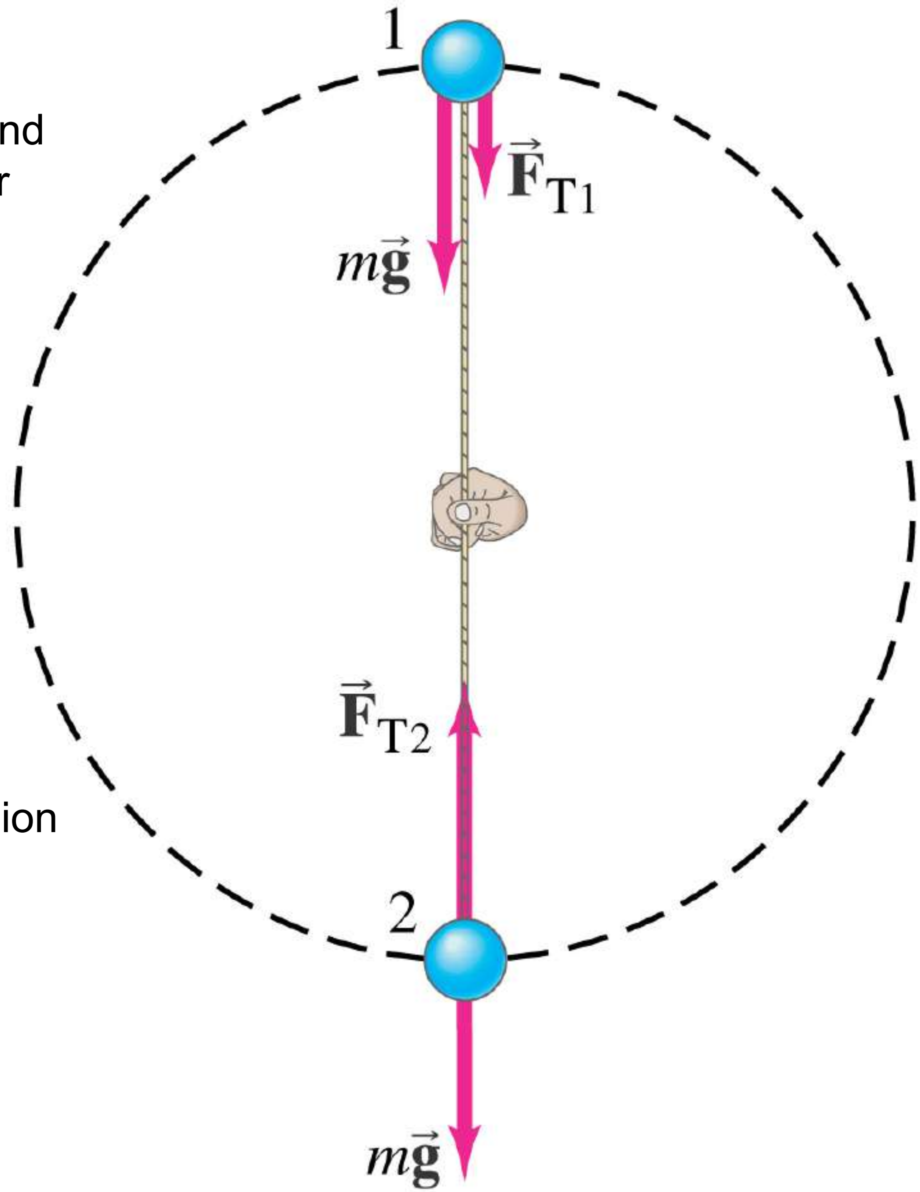
Tension in the cord provides the centripetal acceleration. Technically, the tension is not equal to the net force. However, if the angle is very small, they are very close. Is it possible to ever have a horizontal circle? Why or why not?

In what direction is the acceleration of the ball, and what causes the acceleration?



A 0.150 kg ball on the end of a 1.10 m long cord of negligible mass is swung in a vertical circle. Determine the minimum speed the ball must have at the top of its arc so that the ball continues moving in a circle.

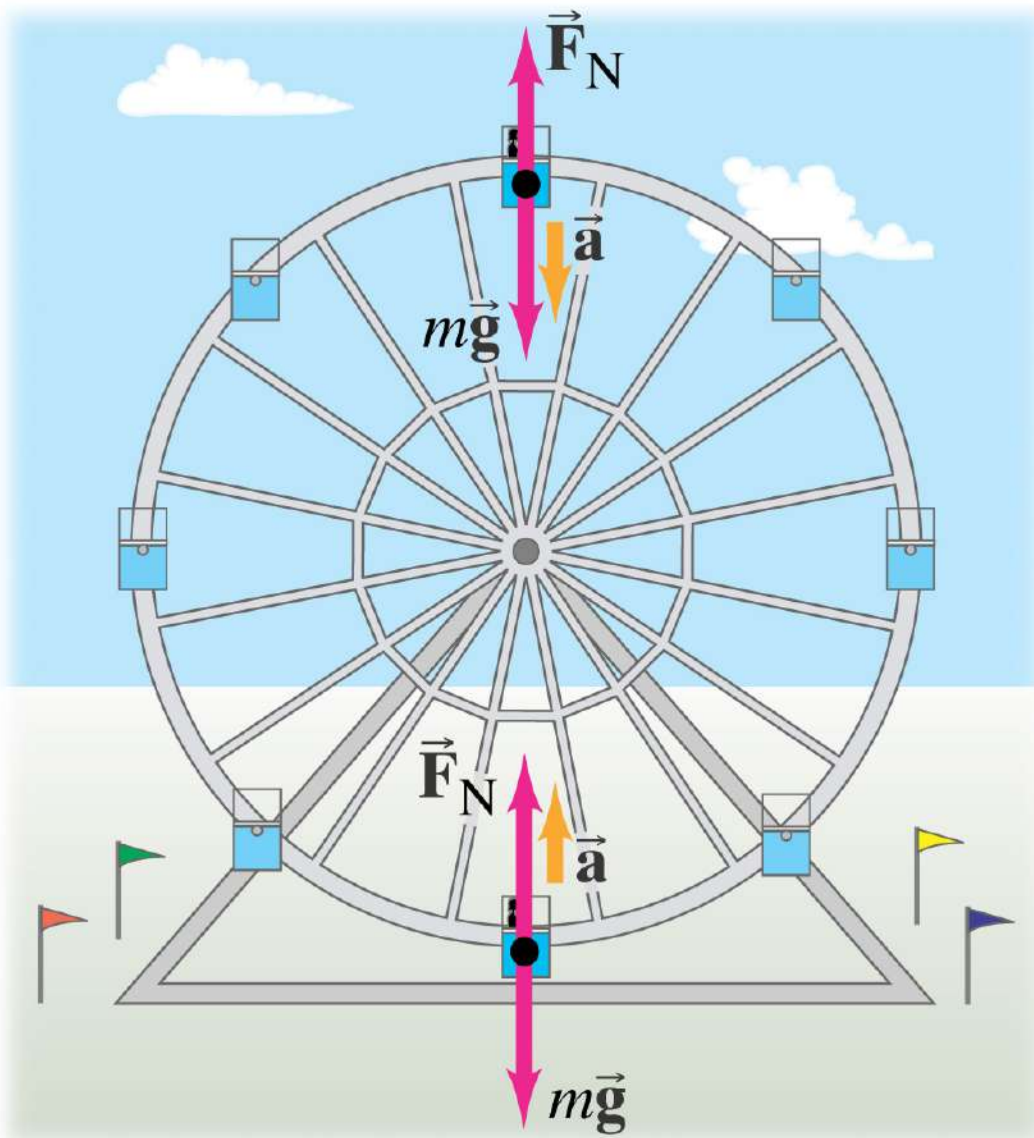
Position 1: gravity and cord tension together provide centripetal acceleration.



Position 2: string tension and gravity acting in opposite directions provide centripetal acceleration.

Calculate the tension in the cord at the bottom of the arc, assuming the ball is moving at twice the speed it had at the top.

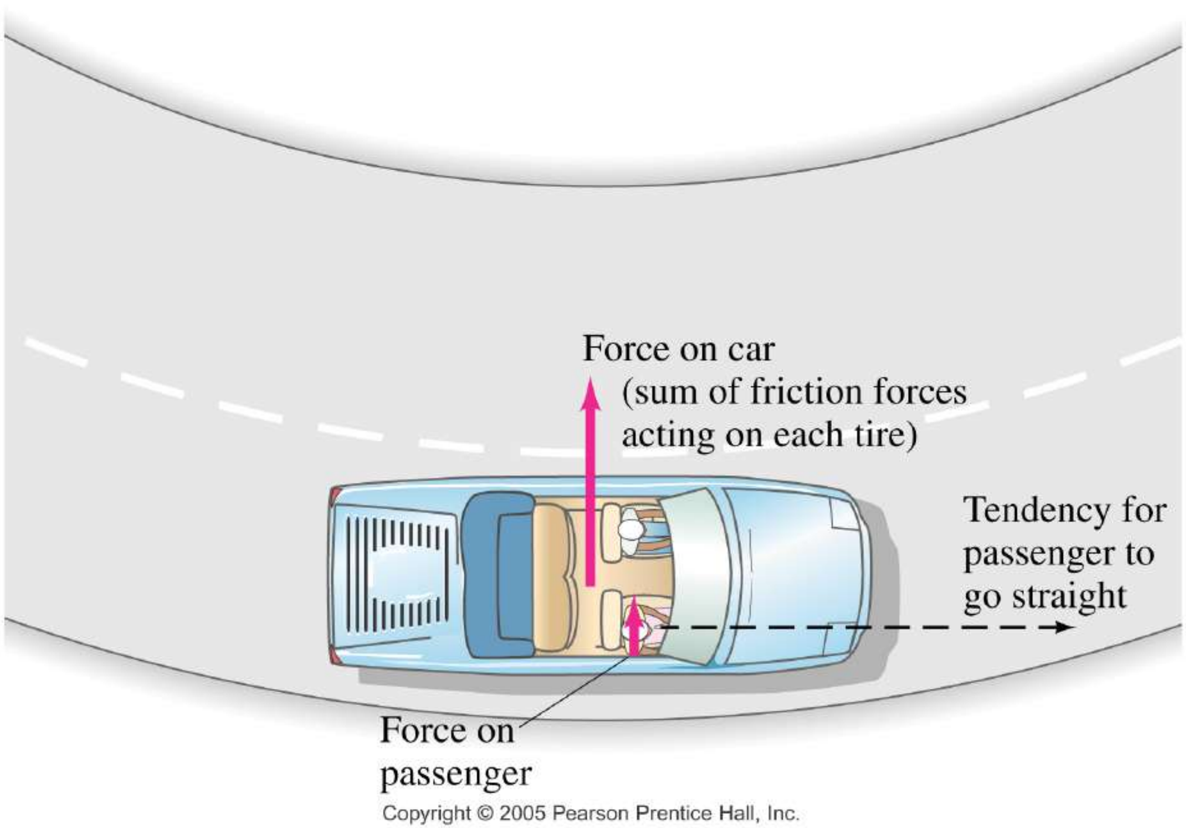
Is the normal force that the seat exerts on the rider at the top of the wheel less than, more than, or the same as the force the seat exerts at the bottom of the wheel?



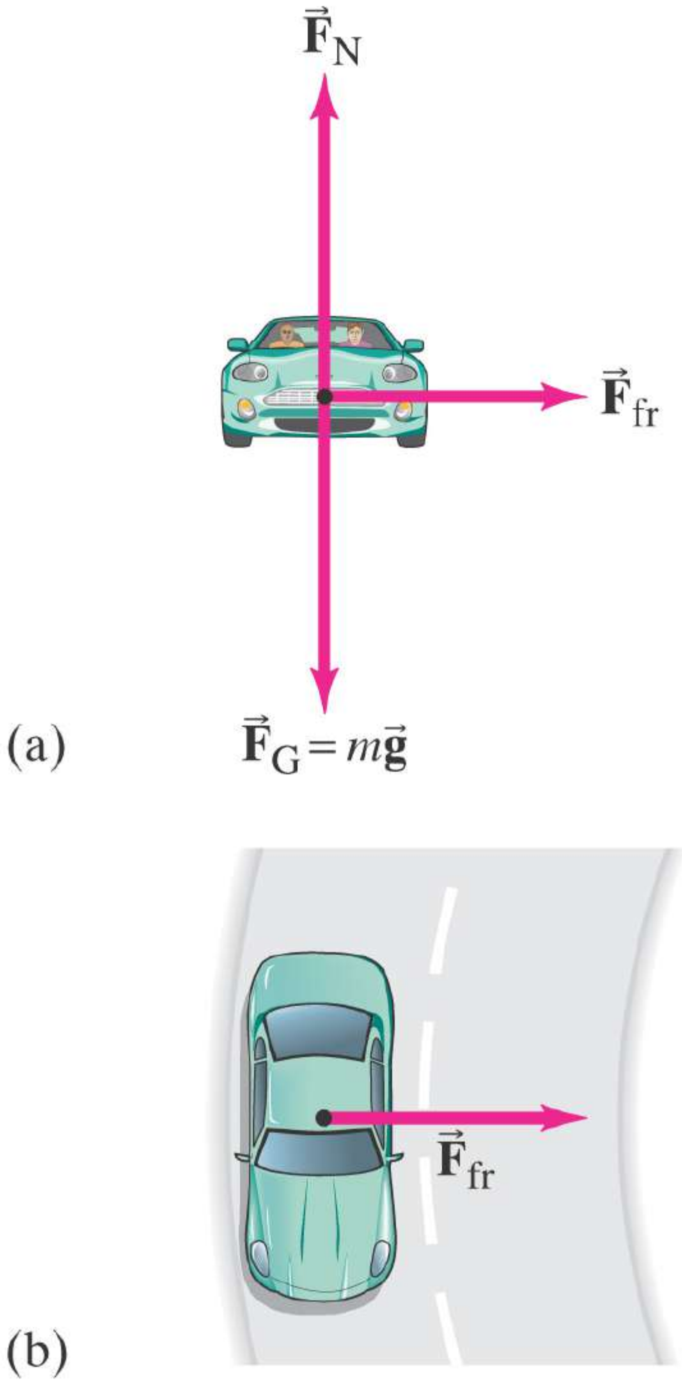
In a tumble dryer, the speed of the drum should be just large enough so that the clothes are carried nearly to the top of the drum and then fall away, rather than being pressed against the drum for the whole revolution. Determine whether this speed will be different for heavier wet clothes than for lighter dry clothes.

5-3 Highway Curves, Banked and Unbanked

When a car goes around a **curve**, there must be a net force towards the center of the circle of which the curve is an arc. If the road is flat, that force is supplied by **friction**.



Forces on a car rounding a curve on a flat road.
(a) Front view, (b) Top view.



5-3 Highway Curves, Banked and Unbanked

If the frictional force is insufficient, the car will tend to move more nearly in a straight line, as the skid marks show.

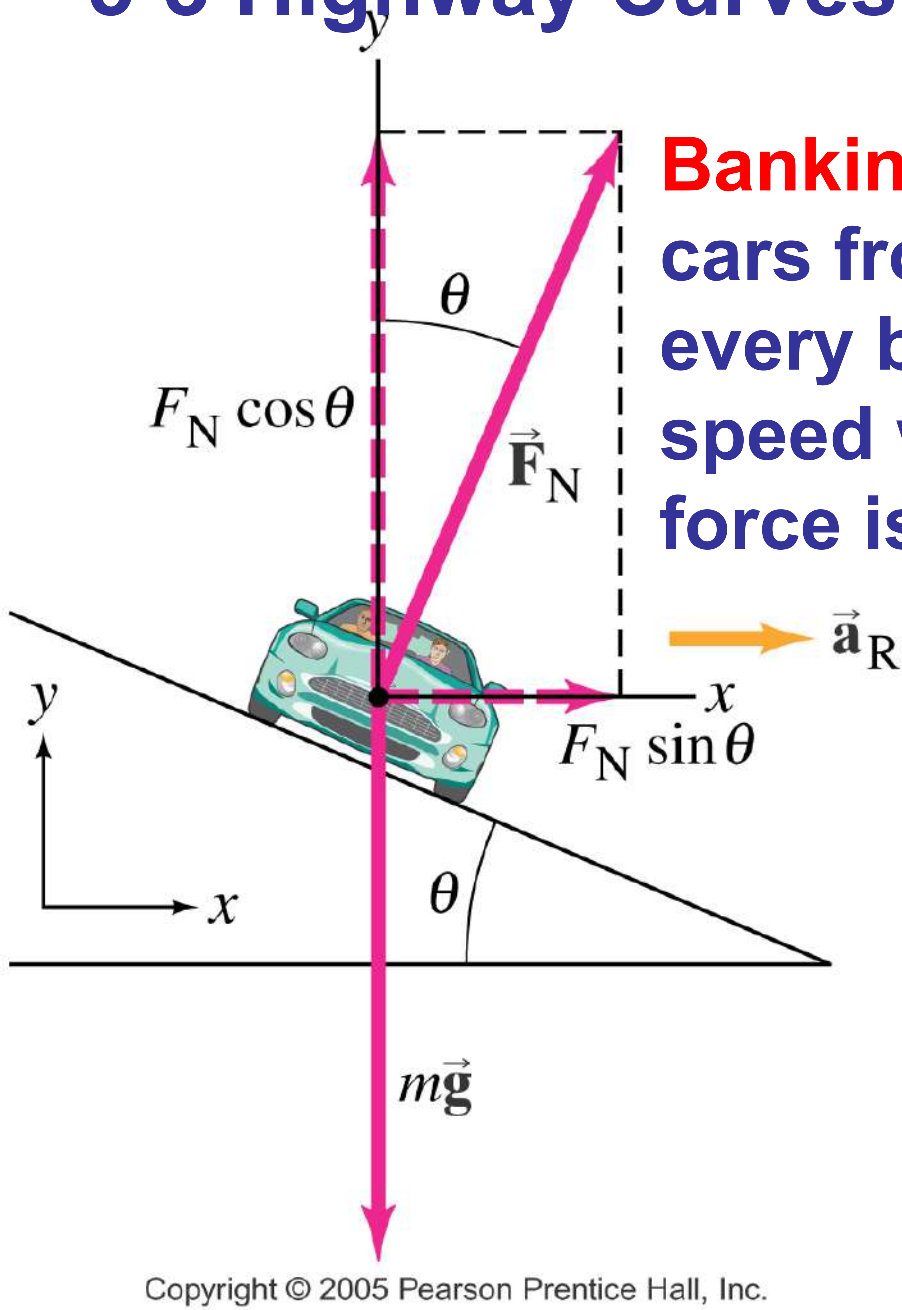
A 1000. kg car rounds a curve on a flat road of radius 50. m at a speed of 50. km/hr. Will the car follow the curve or will it skid if the pavement is dry and the coefficient of static friction is 0.60? What if the pavement is icy and the coefficient of static friction is 0.25?

5-3 Highway Curves, Banked and Unbanked

As long as the tires do not slip, the friction is static. If the tires do start to slip (that is the wheels lock and stop rotating), the friction is kinetic, which is bad in two ways:

1. The kinetic frictional force is smaller than the static.
2. The static frictional force can point towards the center of the circle, but the kinetic frictional force opposes the direction of motion, making it very difficult to regain control of the car and continue around the curve.

5-3 Highway Curves, Banked and Unbanked



Banking the curve can help keep cars from skidding. In fact, for every banked curve, there is one speed where the entire centripetal force is supplied by the horizontal component of the **normal** force, and no friction is required. This occurs when:

$$F_N \sin\theta = m\frac{v^2}{r}$$

For a car traveling with speed v around a curve of radius r, determine a formula for the angle at which a road should be banked so that no friction is required. What is this angle for a freeway off-ramp curve of radius 50. m at a design speed of 50. km/hr?

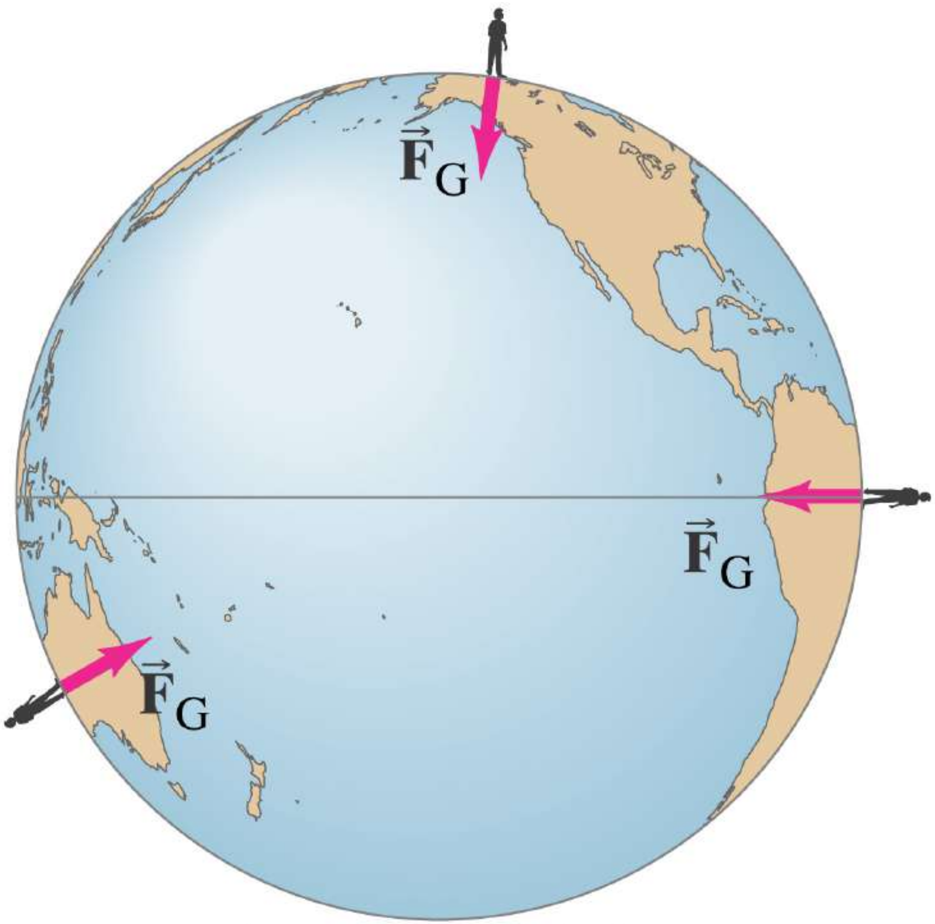
A 1200 kg car rounds a curve of radius 70. m banked at an angle of 12°. If the car is traveling at 90. km/h, will a friction force be required and, if so, how much?

To negotiate an unbanked curve at a faster speed, a driver puts a couple of sand bags in his van to increase the force of friction between the tires and the road. Will the sand bags help?

Can a heavy truck and a small car travel safely at the same speed around an icy, banked-curve road?

5-6 Newton's Law of Universal Gravitation

If the force of gravity is being exerted on objects on Earth, what is the **origin** of that force?



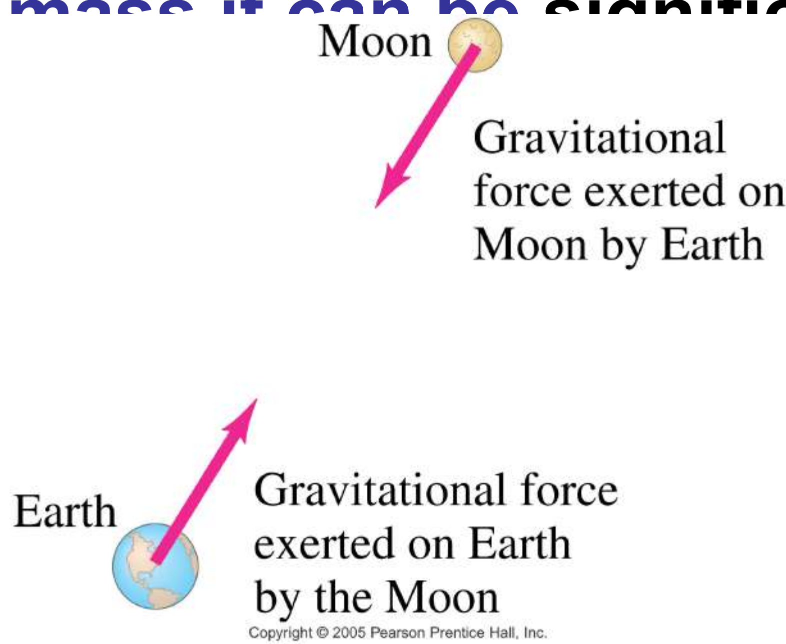
Newton's realization was that the force must come from the **Earth**.

He further realized that this force must be what keeps the **Moon** in its orbit.

5-6 Newton's Law of Universal Gravitation

The gravitational force on you is one-half of a Third Law pair: the **Earth** exerts a **downward** force on you, and you exert an **upward** force on the Earth.

When there is such a **disparity** in masses, the reaction force is undetectable, but for bodies more equal in mass it can be **significant**.



5-6 Newton's Law of Universal Gravitation

Therefore, the gravitational force must be proportional to **both** masses.

By observing planetary orbits, Newton also concluded that the gravitational force must decrease as the **inverse** of the **square** of the distance between the masses.

In its final form, the Law of Universal Gravitation reads:

$$F = G\frac{m_1 m_2}{r^2}$$

(on formula sheet)

where

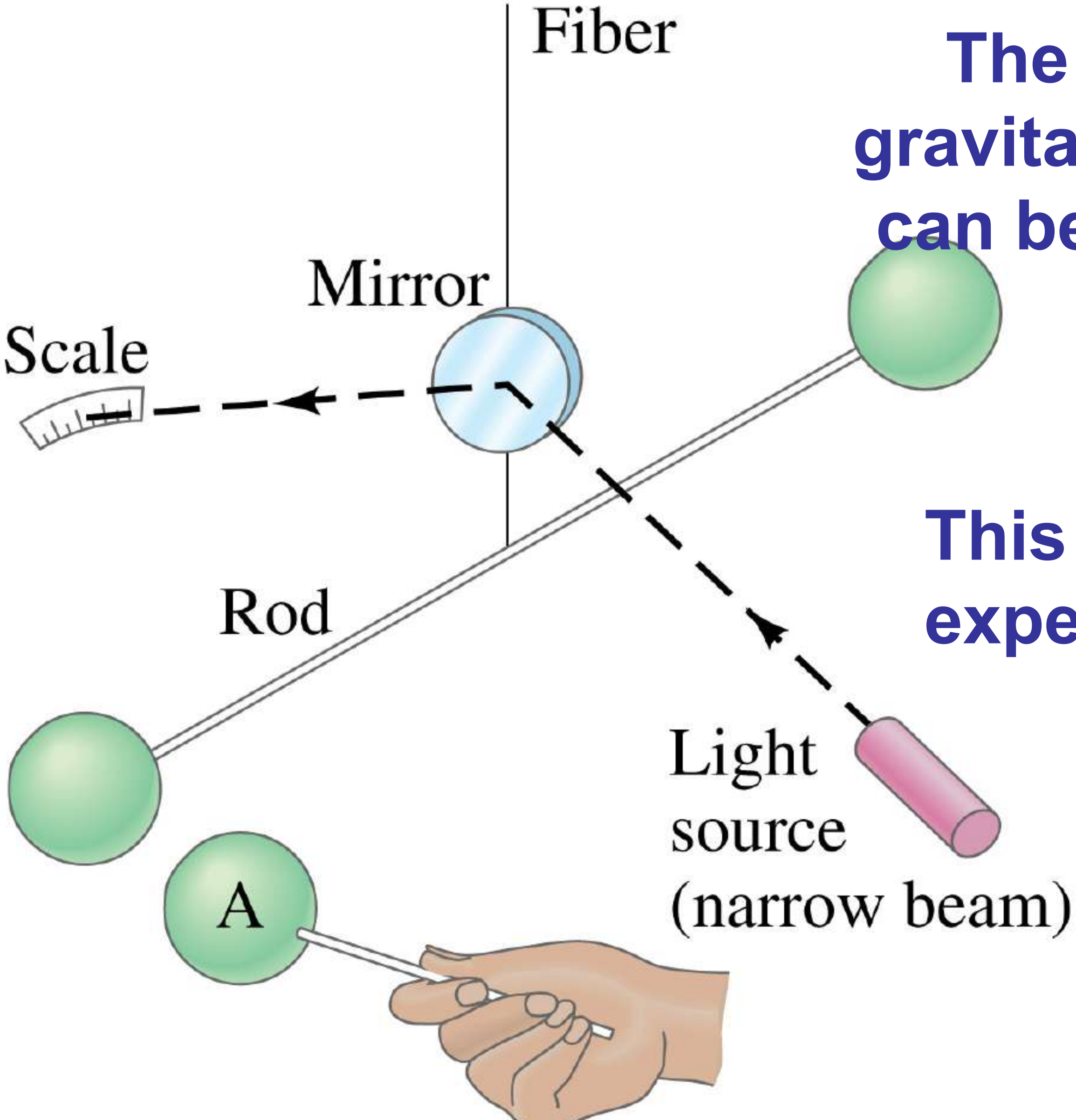
$$G = 6.67 \times 10^{-11}\ \mathrm{N \cdot m^2/kg^2}$$

Newton showed, using calculus, that for two uniform spheres, r is the distance between the centers of the spheres. When the objects are small compared to the distance between them (such as the Earth and the Sun), we can consider them to be point particles.

5-6 Newton's Law of Universal Gravitation

The **magnitude** of the gravitational constant *G* can be measured in the laboratory.

This is the **Cavendish** experiment.



What is the force of gravity acting on a 2000. kg spacecraft when it orbits two Earth radii from the Earth's center?

Find the net force on the Moon due to the gravitational attraction of both the Earth and the Sun assuming they are at right angles to each other.

5-7 Gravity Near the Earth's Surface; Geophysical Applications

Now we can relate the **gravitational constant** to the **local acceleration** of gravity. We know that, on the surface of the Earth:

$$F_g = mg = G\frac{m m_E}{r_E^2}$$

Solving for *g* gives:

$$g = G\frac{m_E}{r_E^2}$$

Now, knowing *g* and the radius of the Earth, the mass of the Earth can be calculated:

$$m_E = \frac{g r_E^2}{G} = \frac{(9.80\ \mathrm{m/s^2})(6.38 \times 10^6\ \mathrm{m})^2}{6.67 \times 10^{-11}\ \mathrm{N \cdot m^2/kg^2}} = 5.98 \times 10^{24}\ \mathrm{kg}$$

5-7 Gravity Near the Earth's Surface; Geophysical Applications

TABLE 5–1
Acceleration Due to Gravity at Various Locations on Earth

Location	Elevation (m)	g (m/s^2)
New York	0	9.803
San Francisco	0	9.800
Denver	1650	9.796
Pikes Peak	4300	9.789
Sydney, Australia	0	9.798
Equator	0	9.780
North Pole (calculated)	0	9.832

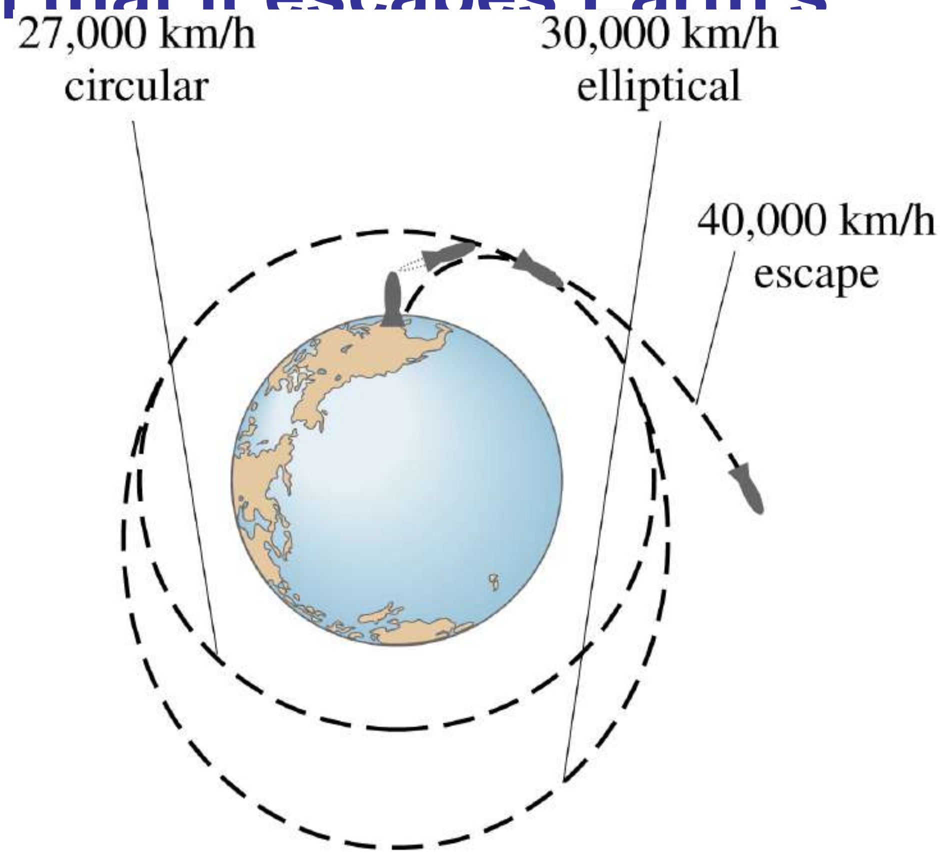
The acceleration due to gravity varies over the Earth's surface due to altitude, local geology, and the shape of the Earth, which is not quite spherical.

Estimate the value of g on the top of Mt. Everest (29,035 ft above sea level).

What is the acceleration of gravity for the space shuttle traveling at 7700 m/s (17,300 mi/h or Mach 23) at an altitude of 380 km?

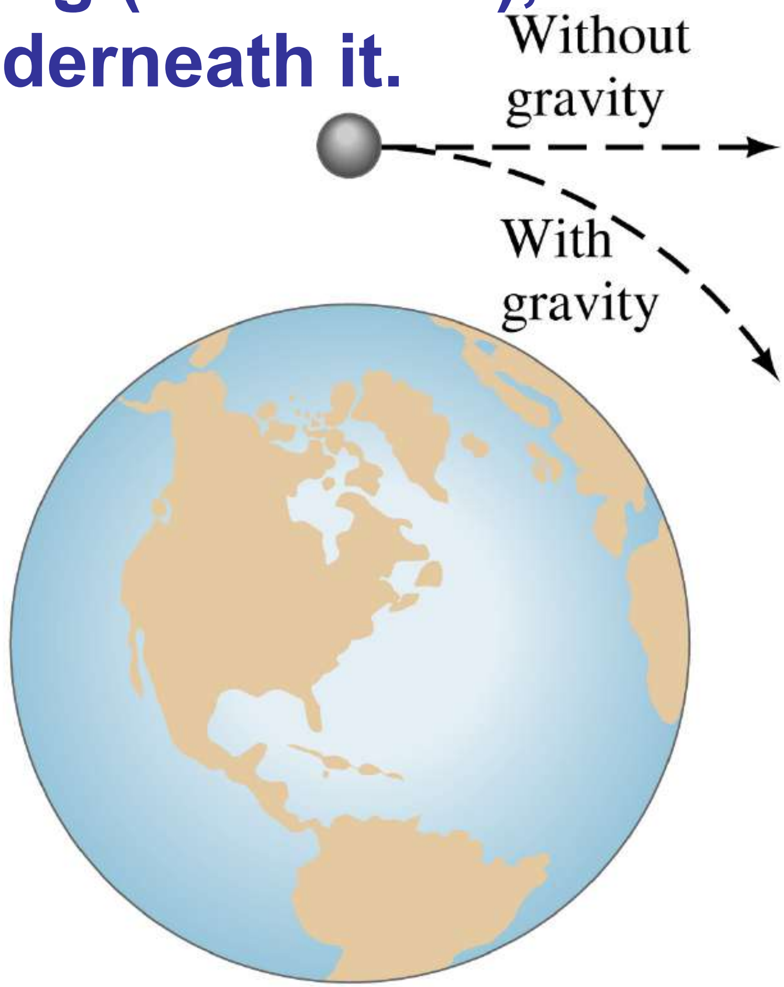
5-8 Satellites and "Weightlessness"

Satellites are routinely put into orbit around the Earth. The **tangential speed** must be high enough so that the satellite does not return to Earth, but not so high that it escapes Earth's gravity altogether.



5-8 Satellites and "Weightlessness"

The satellite is kept in **orbit** by its **speed** – it is continually falling (in **free fall**), but the Earth curves from underneath it.



A geosynchronous satellite is one that stays above the same point on the Earth, which is possible only if it is above a point on the equator? Why?

What height above the Earth's surface is the satellite? How fast is it going?

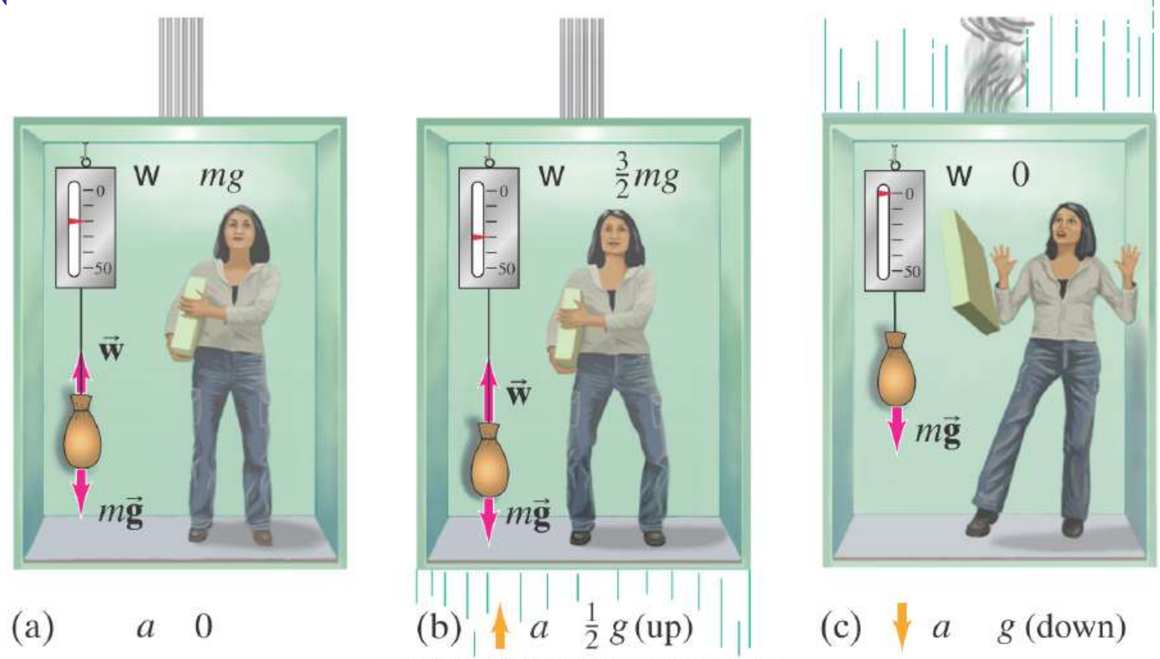
Two satellites orbit the Earth in circular orbits of the same radius. One satellite is twice as massive as the other. Which of the following statements is true?

- The heavier satellite moves twice as fast as the lighter one.
- The two satellites have the same speed.
- The lighter satellite moves twice as fast as the heavier one.
- The heavier satellite moves four times as fast as the lighter one.

5-8 Satellites and “Weightlessness”

Objects in orbit are said to experience **weightlessness**. They do have a gravitational force acting on them, though!

The satellite and all its contents are in **free fall**, so there is no **normal force**. This is what leads to the experience of weightlessness.



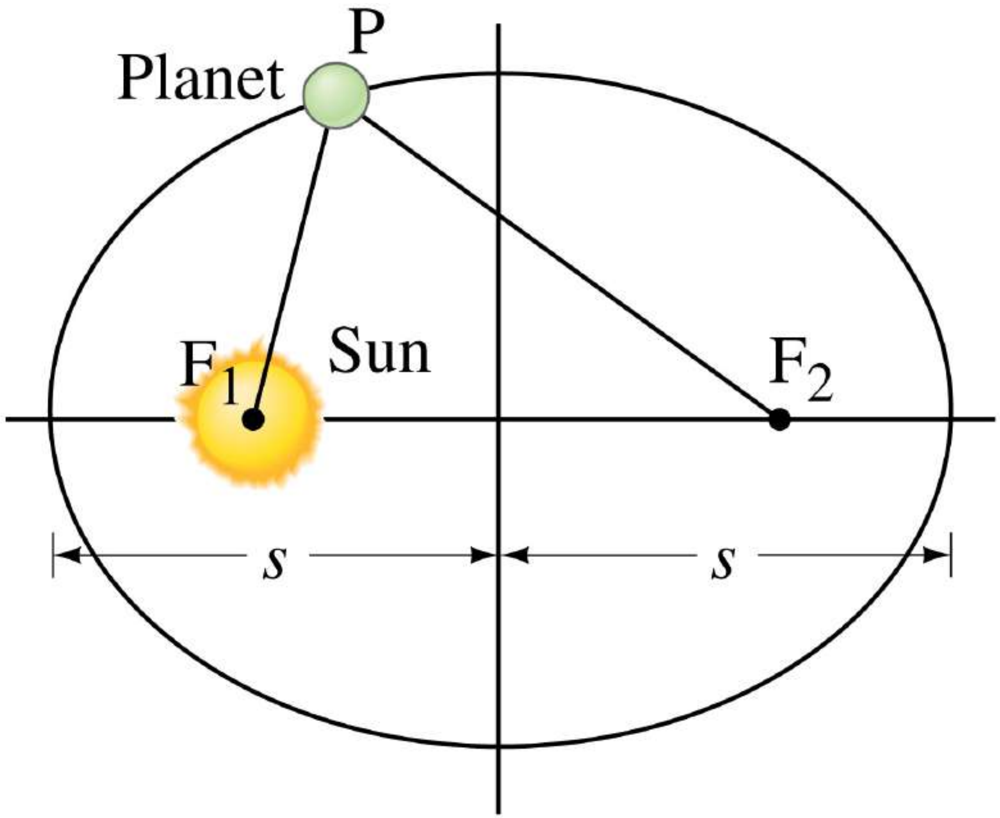
5-8 Satellites and "Weightlessness"

More properly, this effect is called **apparent** weightlessness, because the gravitational force still exists. It can be experienced on Earth as well, but only briefly:

5-9 Kepler’s Laws and Newton's Synthesis

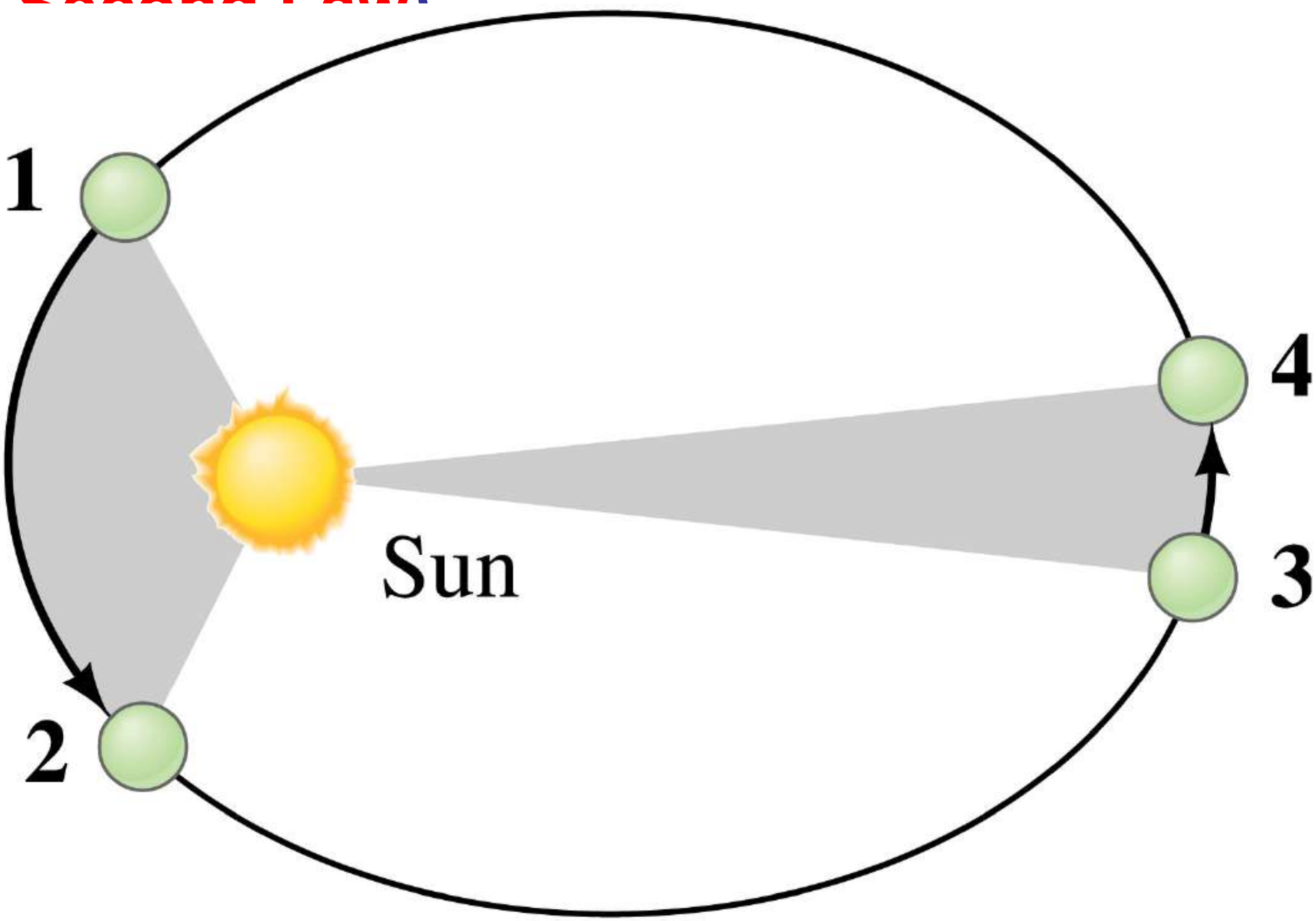
Kepler’s laws describe planetary motion.

The orbit of each planet is an ellipse, with the Sun at one focus (Kepler’s First Law).



5-9 Kepler's Laws

An imaginary line drawn from each planet to the Sun sweeps out equal areas in equal times (Kepler's Second Law)



If 1 to 2 is the same time as 3 to 4, what does that mean about the speed of the planet?

5-9 Kepler's Laws

The ratio of the square of a planet's orbital **period** is proportional to the cube of its mean **distance** from the Sun.

TABLE 5–2 Planetary Data Applied to Kepler's Third Law

Planet	Mean Distance from Sun, s (10^6 km)	Period, T (Earth years)	s^3/T^2 (10^{24} km^3/y^2)
Mercury	57.9	0.241	3.34
Venus	108.2	0.615	3.35
Earth	149.6	1.0	3.35
Mars	227.9	1.88	3.35
Jupiter	778.3	11.86	3.35
Saturn	1427	29.5	3.34
Uranus	2870	84.0	3.35
Neptune	4497	165	3.34
Pluto	5900	248	3.34

5-9 Kepler's Laws

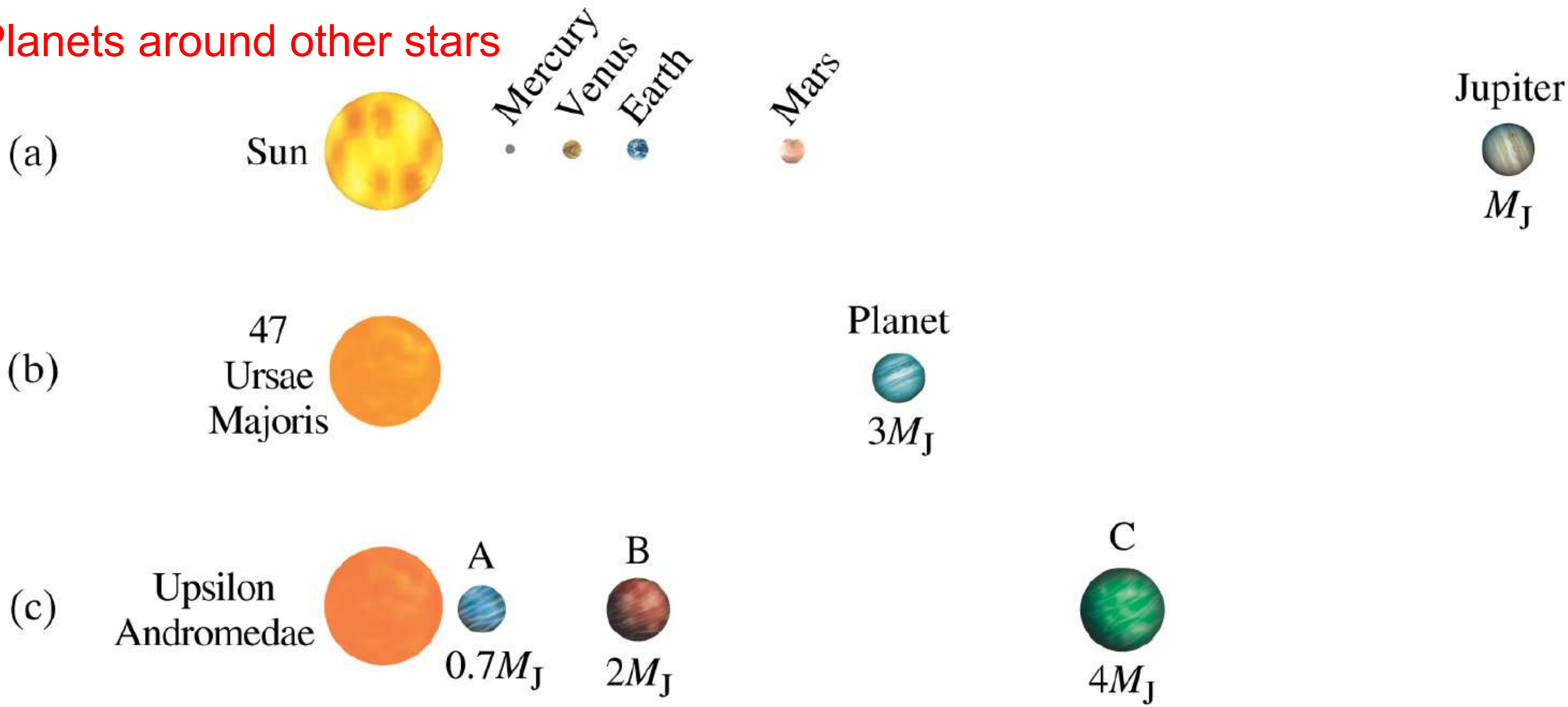
Kepler's Third Law

$$\left(\frac{T_1}{T_2}\right)^2 = \left(\frac{r_1}{r_2}\right)^3$$

5-9 Kepler's Laws

Perturbations in the orbit of Uranus led to the discovery of Neptune. Much smaller perturbations in the orbit of Neptune led to the discovery of Pluto.

Planets around other stars



5-10 Types of Forces in Nature

Modern physics now recognizes four fundamental forces:

1. **Gravity**
2. **Electromagnetism**
3. **Weak nuclear force** (responsible for some types of radioactive decay)
4. **Strong nuclear force** (binds protons and neutrons together in the nucleus)

5-10 Types of Forces in Nature

So, what about friction, the normal force, tension, and so on?

Except for gravity, the forces we experience every day are due to electromagnetic forces acting at the atomic level.