5. Universal Laws of Motion

"If I have seen farther than others, it is because I have stood on the shoulders of giants."

Sir Isaac Newton (1642 – 1727)
Physicist

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5.1 Describing Motion: Examples from Daily Life

Our goals for learning:

- Distinguish between speed, velocity, and acceleration.
- What is the acceleration of gravity?
- How does the acceleration of gravity depend on the mass of a falling object?
- How do you know when a net force is acting on an object?
- Have you ever been weightless? Have you ever been massless?

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Objects in Motion

- **speed** – rate at which an object moves, i.e. the distance traveled per unit time [m/s; mi/hr]
- **velocity** – an object's speed in a certain direction, e.g. "10 m/s moving east"
- **acceleration** – a change in an object's velocity, i.e. a change in either speed or direction is an acceleration [m/s^2]

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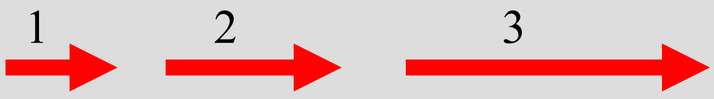
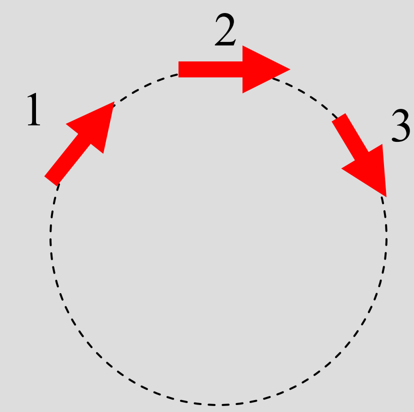
Acceleration

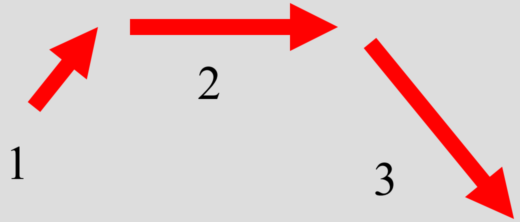
- Acceleration=rate of change of velocity
- Linear acceleration



  - Speed changes, direction does not
- Centripetal acceleration



  - Direction changes, speed does not
- General acceleration
  - Speed and direction change



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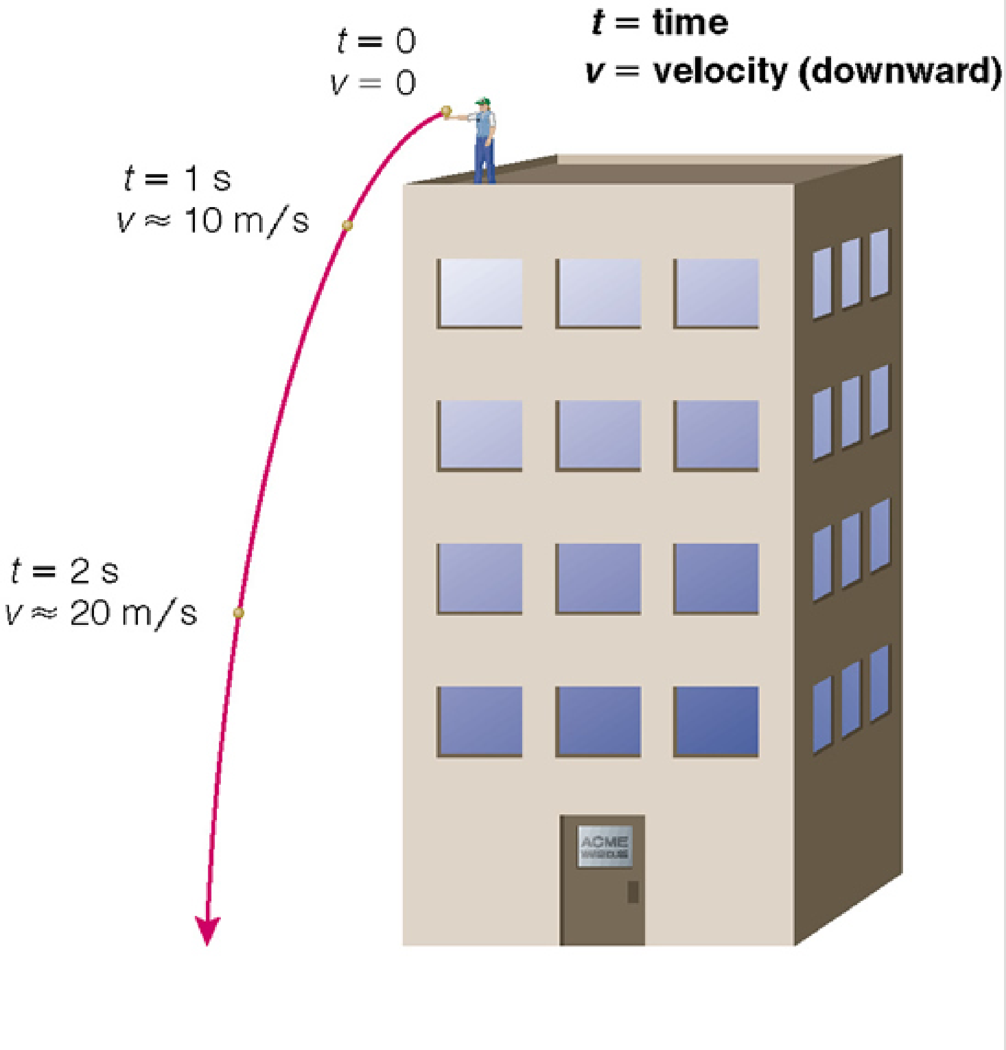
The Acceleration of Gravity

- As objects fall, they accelerate.
- The acceleration due to Earth's gravity is 10 m/s each second, or $g = 10\ \text{m/s}^2$.
- The higher you drop the ball, the greater its velocity will be at impact.



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The Acceleration of Gravity (*g*)

- Galileo demonstrated that *g* is the same for all objects, regardless of their mass!
- This was confirmed by the Apollo astronauts on the Moon, where there is no air resistance.

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Forces

- Forces change the motion of objects.
- **momentum** – the (mass x velocity) of an object
- **force** – anything that can cause a change in an object’s momentum
- As long as the object’s mass does not change, the force causes a change in velocity, or an…

acceleration

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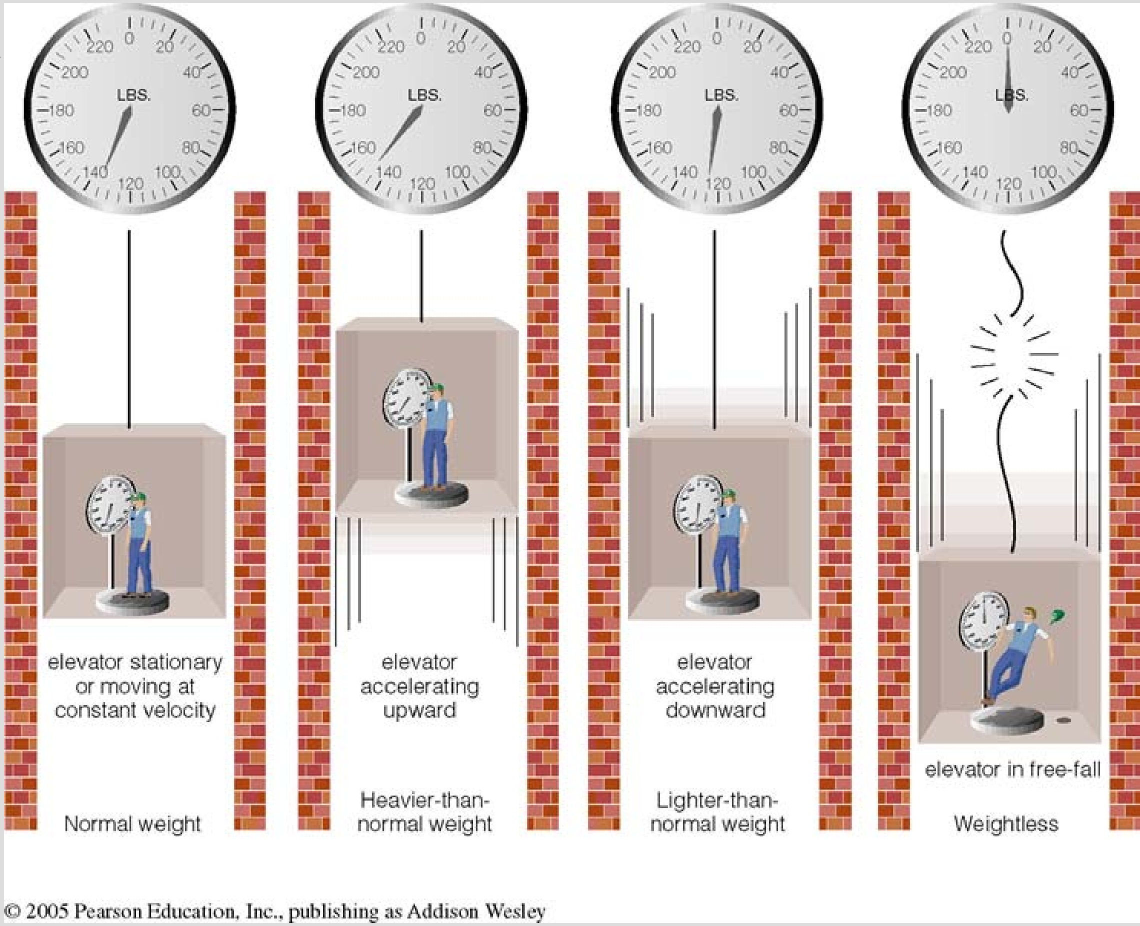
Is Mass the Same Thing as Weight?

- **mass** – the amount of matter in an object
- **weight** – a measurement of the *force* which acts upon an object



When in "free-fall," you are weightless!!

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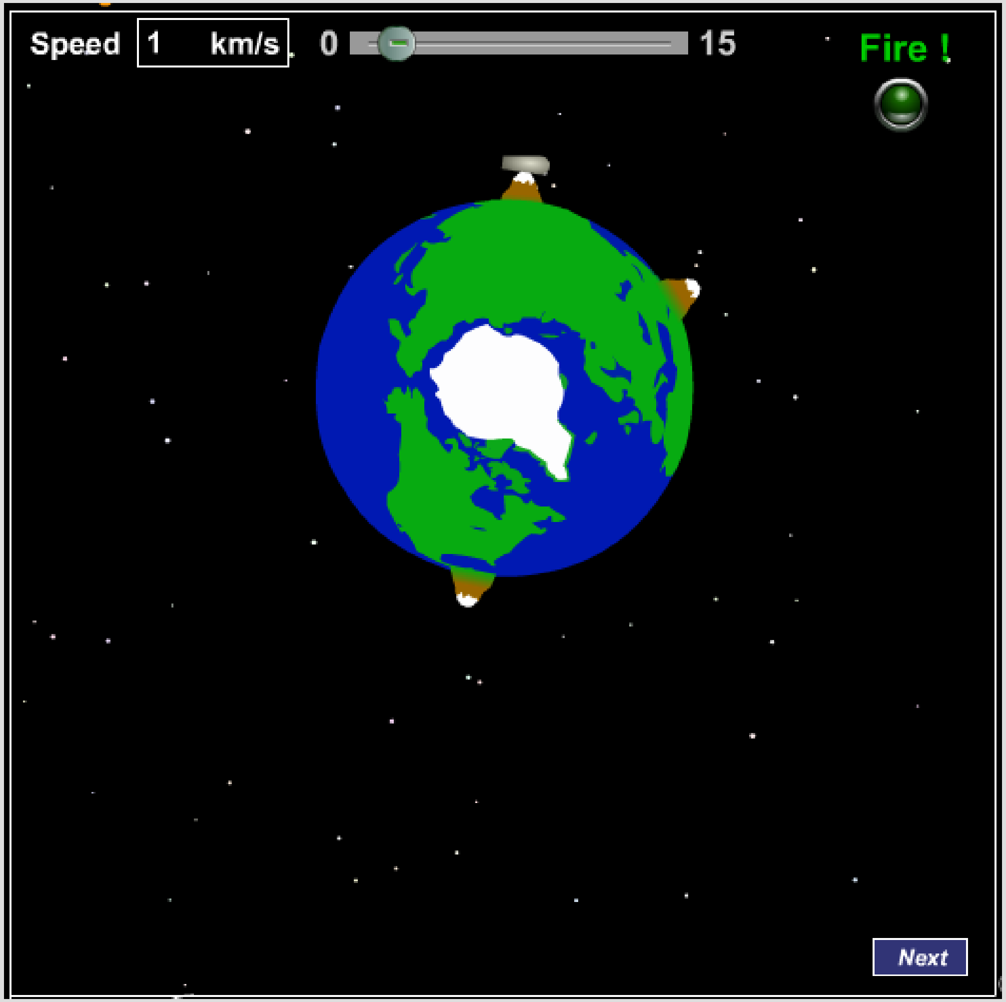
Depending on its initial velocity, the cannonball will either fall to Earth, continually free-fall (orbit), or escape the force of Earth's gravity.



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5.2 Newton's Laws of Motion

Our goals for learning:

- What are Newton's three laws of motion?
- Why does a spinning skater spin faster as she pulls in her arms?

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Sir Isaac Newton (1642-1727)

- Perhaps the greatest genius of all time
- Invented the reflecting telescope
- Invented calculus
- Connected gravity and planetary forces

Philosophiae naturalis principia mathematica

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Newton's Laws of Motion

1 A body at rest or in motion at a constant speed along a straight line remains in that state of rest or motion unless acted upon by an outside force.

Law of inertia

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Newton's Laws of Motion

2 The change in a body's velocity due to an applied force is in the same direction as the force and proportional to it, but is inversely proportional to the body's mass.

$$a = F/m \textit{ or } F = m\,a$$

Law of motion

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Newton's Laws of Motion

3 For every applied force, a force of equal size but opposite direction arises.

Law of action/reaction

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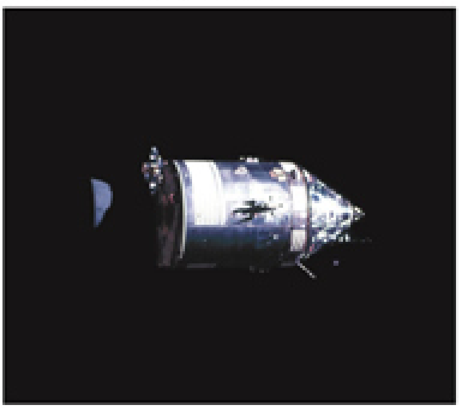
Newton’s Laws of Motion

A baseball accelerates as the pitcher applies a force by moving his arm. (Once released, this force and acceleration cease, so the ball's path changes only due to gravity and effects of air resistance.)

A spaceship needs no fuel to keep moving in space.



A rocket is propelled upward by a force equal and opposite to the force with which gas is expelled out its back.

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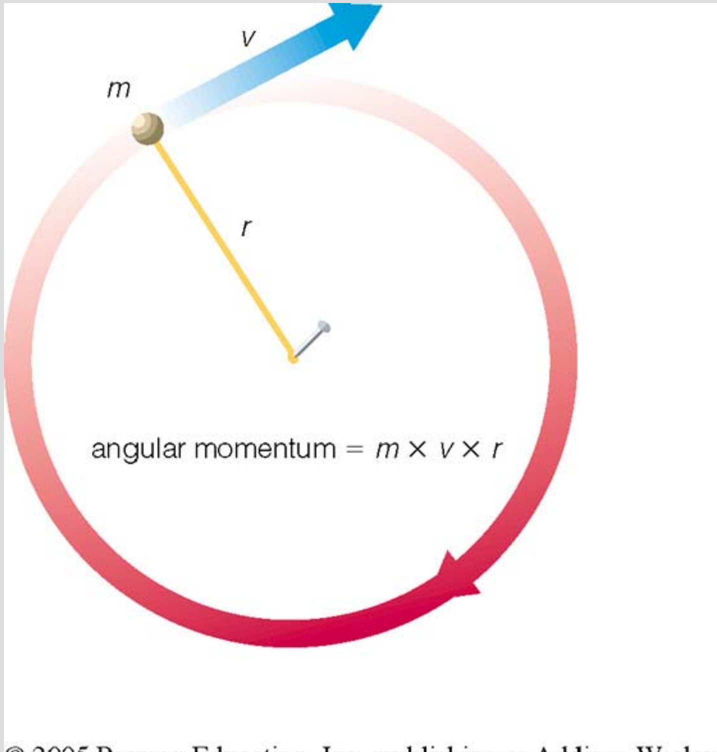
Angular Momentum

- **angular momentum** – the momentum involved in spinning /circling = mass x velocity x radius
- **torque** – anything that can cause a change in an object's angular momentum (*twisting force*)



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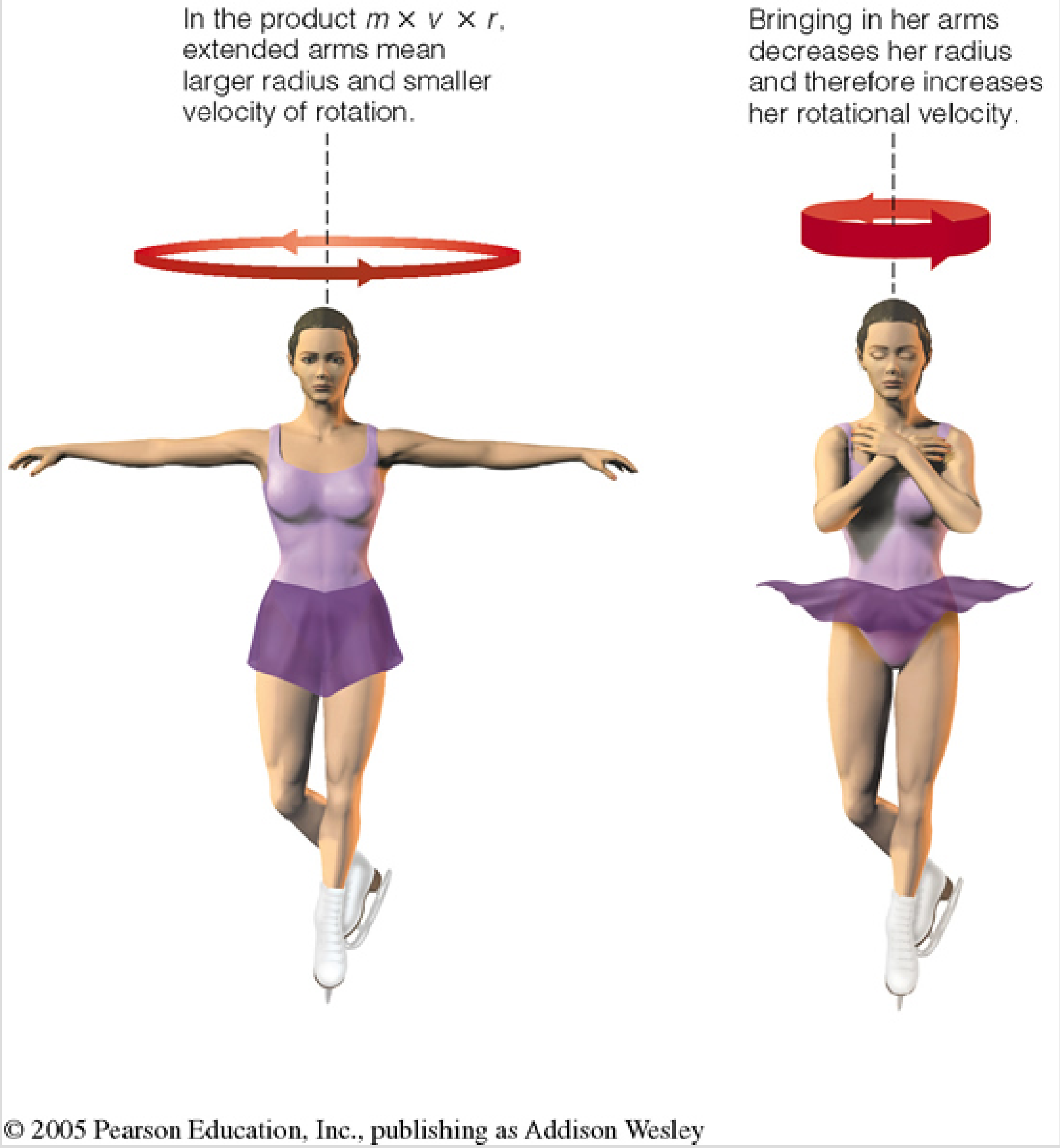
Conservation of Angular Momentum

- In the absence of a net torque, the total angular momentum of a system remains constant.



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5.3 The Force of Gravity

Our goals for learning:

- What is the universal law of gravitation?
- What types of orbits are possible according to the law of gravitation?
- How can we determine the mass of distant objects?

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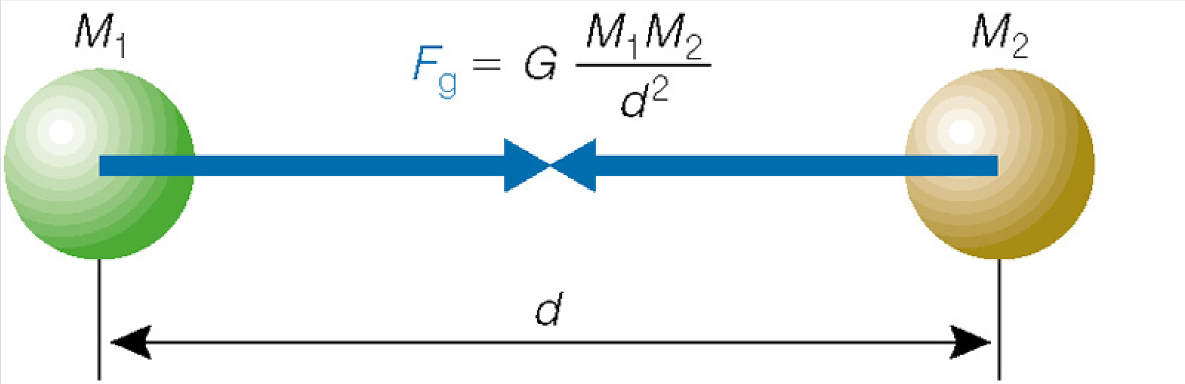
Universal Law of Gravitation

Between every two objects there is an attractive force, the magnitude of which is directly proportional to the mass of each object and inversely proportional to the square of the distance between the centers of the objects.



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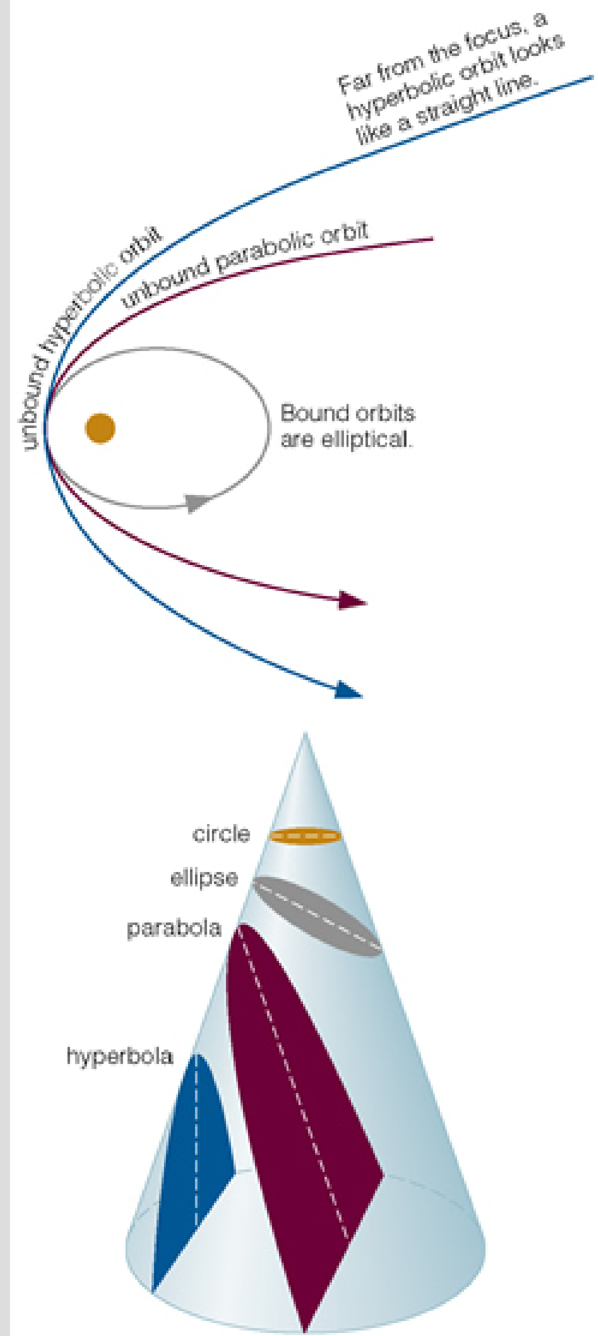
Orbital Paths

- Extending Kepler's Law #1, Newton found that ellipses were not the only orbital paths.
- possible orbital paths
  - ellipse (bound)
  - parabola (unbound)
  - hyperbola (unbound)
- Circle is special case of an ellipse



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Newton's Version of Kepler's Third Law

Using the calculus, Newton was able to derive Kepler's Third Law from his own Law of Gravity.

In its most general form:

$$P^2 = 4\pi^2 a^3 / G (m_1 + m_2)$$

If you can measure the orbital period of two objects (P) and the distance between them (a), then you can calculate the sum of the masses of both objects ($m_1 + m_2$).

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