Hewitt/Lyons/Suchocki/Yeh

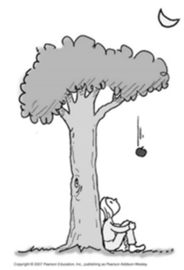
Conceptual Integrated Science

Chapter 5

GRAVITY

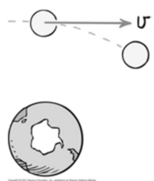
The Legend of the Falling Apple

According to legend, while Isaac Newton was sitting under an apple tree pondering the nature of forces, an apple fell and possibly struck his head. He reasoned that the Moon is falling toward the Earth for the same reason the apple falls—both are pulled by Earth's gravity.



The Fact of the Falling Moon

In ancient times, Aristotle and others believed that stars, planets, and the Moon moved in divine circles, free from forces of Earth.



The Fact of the Falling Moon

The Moon falls around the Earth in the sense that it falls beneath the straight line it would follow if no force acted on it.

The Moon maintains a tangential velocity, which ensures a nearly circular motion around and around the Earth rather than into it. This path is similar to the paths of planets around the Sun.

Newton's Law of Universal Gravitation

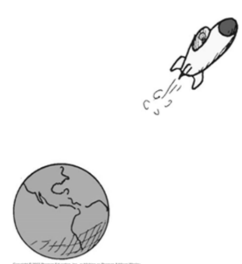
Every body in the universe attracts every other body with a mutually attracting force. For two bodies, this force is directly proportional to the product of their masses and inversely proportional to the square of the distance separating them,

$$F = G\,\frac{m_1 \times m_2}{d^2}$$

Newton's Law of Universal Gravitation

Newton discovered that gravity is universal.

Every mass pulls on every other mass.



Newton's Law of Universal Gravitation

$$F = G\,\frac{m_1 \times m_2}{d^2}$$

The greater m_1 and m_2 $\Rightarrow$ the greater the force of attraction between them.

The greater the distance of separation d, the weaker is the force of attraction—weaker as the inverse square of the distance between their centers.

Gravity and Distance: The Inverse-Square Law

Inverse-square law:

relates the intensity of an effect to the inverse square of the distance from the cause

$$Intensity \approx \frac{1}{distance^2}$$

The greater the distance from Earth, the less the gravitational force on an object.

No matter how great the distance, gravity approaches, but never reaches, zero.

The Universal Gravitational Constant, *G*

G is the proportionality constant in Newton's law of gravitation.

G has the same magnitude as the gravitational force between two 1-kg masses that are 1 meter apart:

6.67×10^{-11} N.

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

Weight and Weightlessness

Weight

is the force exerted against a supporting floor or weighing scale.

Weightlessness

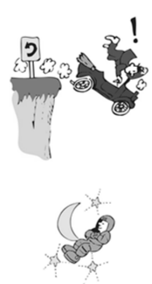
is a condition wherein a support force is lacking—free fall, for example.

Weight and Weightlessness

Example of weightlessness:

Astronaut in orbit

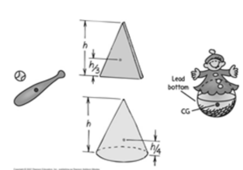
An astronaut is weightless because he or she is not supported by anything. The body responds as if gravity forces were absent, and this gives the sensation of weightlessness.



Center of Gravity

Center of gravity

is the point located at an object's average position of weight.



Center of Gravity

The position of object's center of gravity relative to a base of support determines the object's stability.

Rule for stability:

- If the CG of an object is above or within the area of support, the object is stable.
- If the CG of an object extends outside the area of support, the object is unstable—and it will topple.

Example: Leaning Tower of Pisa

Gravity Can Be a Centripetal Force

Centripetal Force

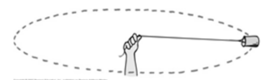
is any force that causes an object to follow a circular path.

Examples:

The Sun pulls its planets in a nearly circular path.

It is possible to whirl an empty tin can in a circular path at the end of a string.

To keep the can revolving over your head in a circular path you must keep pulling *inward* on the string.



Projectile Motion

Projectile

is any object that moves through the air or through space under the influence of gravity.

Curved path of projectile (parabola)

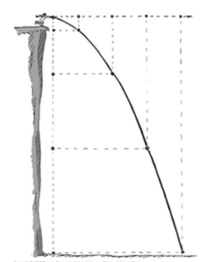
Example:

A stone thrown horizontally curves downward due to gravity.

Projectile Motion

A projectile curves as a result of two motions:

- constant motion horizontally
- accelerated motion vertically

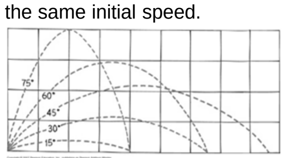


Projectile Altitude and Range

For equal launching speeds, the same range is obtained from two different projection angles—a pair that add up to 90°. Maximum range occurs at 45°.

Example:

The same range occurs for a 75° launch and a 15° launch of the same initial speed.



The Effect of Air Drag on Projectiles

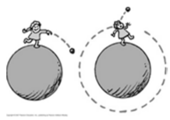
- With air resistance,
  both range and altitude are decreased.
- Without air resistance,
  the speed lost going up is the same as the speed gained while coming down.

Fast-Moving Projectiles—Satellites

Satellite

is any projectile moving fast enough to fall continually around the Earth.

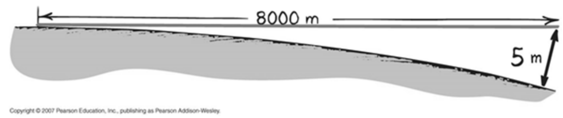
To become an Earth satellite, the projectile's horizontal velocity must be great enough for its trajectory to match Earth's curvature.



Fast-Moving Projectiles—Satellites

The Earth's curvature drops a vertical distance of

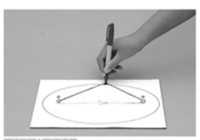
5 meters for each 8000 m tangent to the surface. So to orbit Earth, a projectile must travel 8000 m in the time it takes to fall 5 m.



Elliptical Orbits

Ellipse

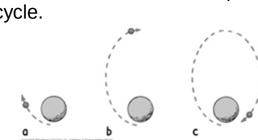
The oval path followed by a satellite. The closed path taken by a point that moves in such a way that the sum of its distances from two fixed points (called *foci*) is constant.



Elliptical Orbits

Speed of a satellite in an elliptical orbit varies:

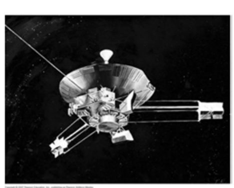
- Near Earth it initially starts greater than 8 km/s and overshoots a circular orbit and travels away from Earth.
- Gravity slows it down until it no longer moves away from Earth.
- Then it falls toward Earth gaining the speed it lost in receding. It follows the same oval-shaped path in a repetitious cycle.



Elliptical Orbits

Escape Speed

The speed that a projectile, space probe, or similar object must reach in order to escape the gravitational influence of the Earth or of another celestial body to which it is attracted.



Elliptical Orbits

The escape speed of a body is the initial speed given by an initial thrust, after which there is no force to assist motion.

From Earth's surface, escape speed is ***11.2 km/s***.

Table 5.1 Escape Speeds from the Surfaces of Bodies in the Solar System

Astronomical Body	Mass (in Earth masses)	Radius (in Earth radii)	Escape Speed (km/s)
Sun	333,000	109	620
Sun (at a distance of Earth's orbit)		23,500	42.2
Jupiter	318.0	11.0	60.2
Saturn	95.2	9.2	36.0
Neptune	17.3	3.47	24.9
Uranus	14.5	3.7	22.3
Earth	1.00	1.00	11.2
Venus	0.82	0.95	10.4
Mars	0.11	0.53	5.0
Mercury	0.055	0.38	4.3
Moon	0.0123	0.27	2.4