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ASTRONOMY

Chapter 3 ORBITS AND GRAVITY

PowerPoint Image Slideshow

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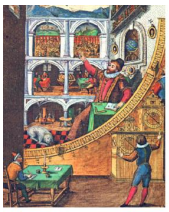
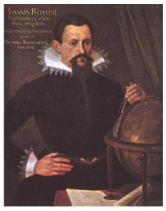
3.1 THE LAWS OF PLANETARY MOTION

- **International Space Station (fig 3.1).** This space habitat and laboratory orbits Earth once every 90 minutes. (credit: modification of work by NASA)

Tyco Brahe's Observatory & Kepler



(a)

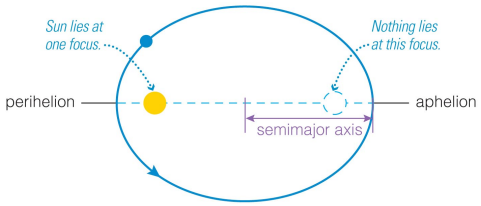


(b)

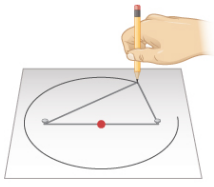
- **Tycho Brahe (1546–1601) and Johannes Kepler (1571–1630).**
  - (a) A stylized engraving shows Tycho Brahe using his instruments to measure the altitude of celestial objects above the horizon. The large curved instrument in the foreground allowed him to measure precise angles in the sky. Note that the scene includes hints of the grandeur of Brahe's observatory at Hven.
  - (b) Kepler was a German mathematician and astronomer. His discovery of the basic laws that describe planetary motion placed the heliocentric cosmology of Copernicus on a firm mathematical basis.

Kepler's three laws of planetary motion?

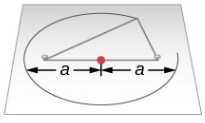
- **Kepler's First Law:** Each planet moves around the Sun in an orbit that is an ellipse, with the Sun at one focus of the ellipse.



Ellipse



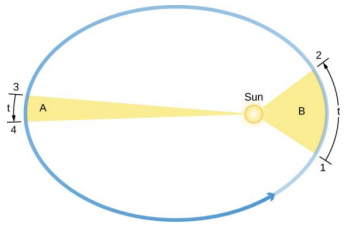
(a)



(b)

- **Drawing an Ellipse (fig 3.4).**
  - (a) We can construct an ellipse by pushing two tacks (the white objects) into a piece of paper on a drawing board, and then looping a string around the tacks. Each tack represents a focus of the ellipse, with one of the tacks being the Sun. Stretch the string tight using a pencil, and then move the pencil around the tacks. The length of the string remains the same, so that the sum of the distances from any point on the ellipse to the foci is always constant.
  - (b) In this illustration, each semimajor axis is denoted by *a*. The distance 2*a* is called the major axis of the ellipse.

- **Kepler's Second Law:** As a planet moves around its orbit, it sweeps out equal areas in equal times.



A planet travels faster when it is nearer to the Sun

- **Kepler's Third Law:** The square of a planet's orbital period is directly proportional to the cube of its orbit.

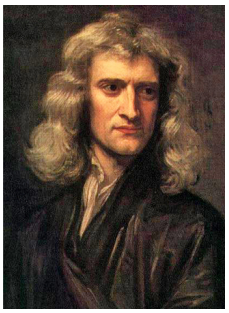
$$p^2 = a^3$$

p = orbital period in years
a = average distance from Sun in AU

More distant planets orbit the Sun at slower average speeds

3.2 NEWTON'S GREAT SYNTHESIS

- **Isaac Newton (1643–1727), 1689 Portrait by Sir Godfrey Kneller.** Isaac Newton's work on the laws of motion, gravity, optics, and mathematics laid the foundations for much of physical science.
- He realized the same physical laws that operate on Earth also operate in the heavens: "one *universe*"



Newton's three laws of motion?

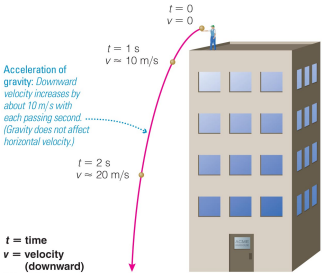
- **first law**: An object at rest (or motion) will remain at rest (or motion) unless it is compelled to change by an outside force.
- **second law**: Force = Mass x Acceleration
- **third law**: For every action there is an equal and opposite reaction.

Definitions

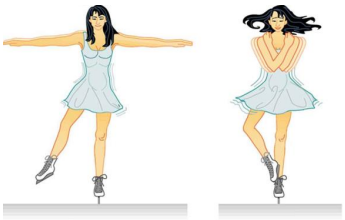
- **Speed:** rate at which an object moves
- **Velocity:** Speed and direction
- **Acceleration:** Change in velocity
- **Force** changes momentum, which generally means an acceleration (change in velocity).
- **Momentum** = mass x velocity
- **Angular momentum:** The rotational momentum of a spinning or orbiting object = mass x velocity x raduis
- **Mass:** quantity of matter
- **Weight:** force acting on mass = mass x gravity
- **Density =** mass / volume

Acceleration of Gravity

- All falling objects accelerate at the same rate (not counting friction of air resistance).
- On Earth, $g \approx 10\ \mathrm{m/s^2}$: speed increases 10 m/s with each second of falling.



Angular Momentum

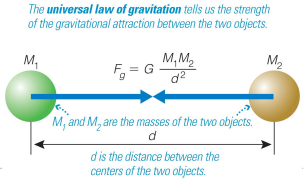


- **Conservation of Angular Momentum (Fig 3.8).** When a spinning figure skater brings in her arms, their distance from her spin center is smaller, so her speed increases. When her arms are out, their distance from the spin center is greater, so she slows down.

3.3 NEWTON'S UNIVERSAL LAW OF GRAVITATION

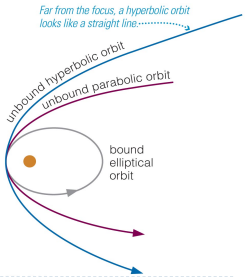
The **Universal Law of Gravitation:**

1. Every mass attracts every other mass.
2. Attraction is *directly* proportional to the product of their masses.
3. Attraction is *inversely* proportional to the *square* of the distance between their centers.



How does Newton's law of gravity extend Kepler's laws?

- 1. Kepler's first two laws apply to all orbiting objects, not just planets.
- 2. Ellipses are not the only orbital paths. Orbits can be:
  - bound (ellipses)
  - unbound
    - parabola
    - hyperbola



Newton's version of Kepler's third law

3. Newton generalized Kepler's third law:
which allows us to calculate the mass of distant objects.

$$p^2 = \frac{4\pi^2}{G(M_1 + M_2)}a^3$$

p = orbital period
a = average orbital distance (between centers)
$(M_1 + M_2)$ = sum of object masses

Links

- Video: Newton (5 min)

Reading

- 3.1
- 3.2
- 3.3