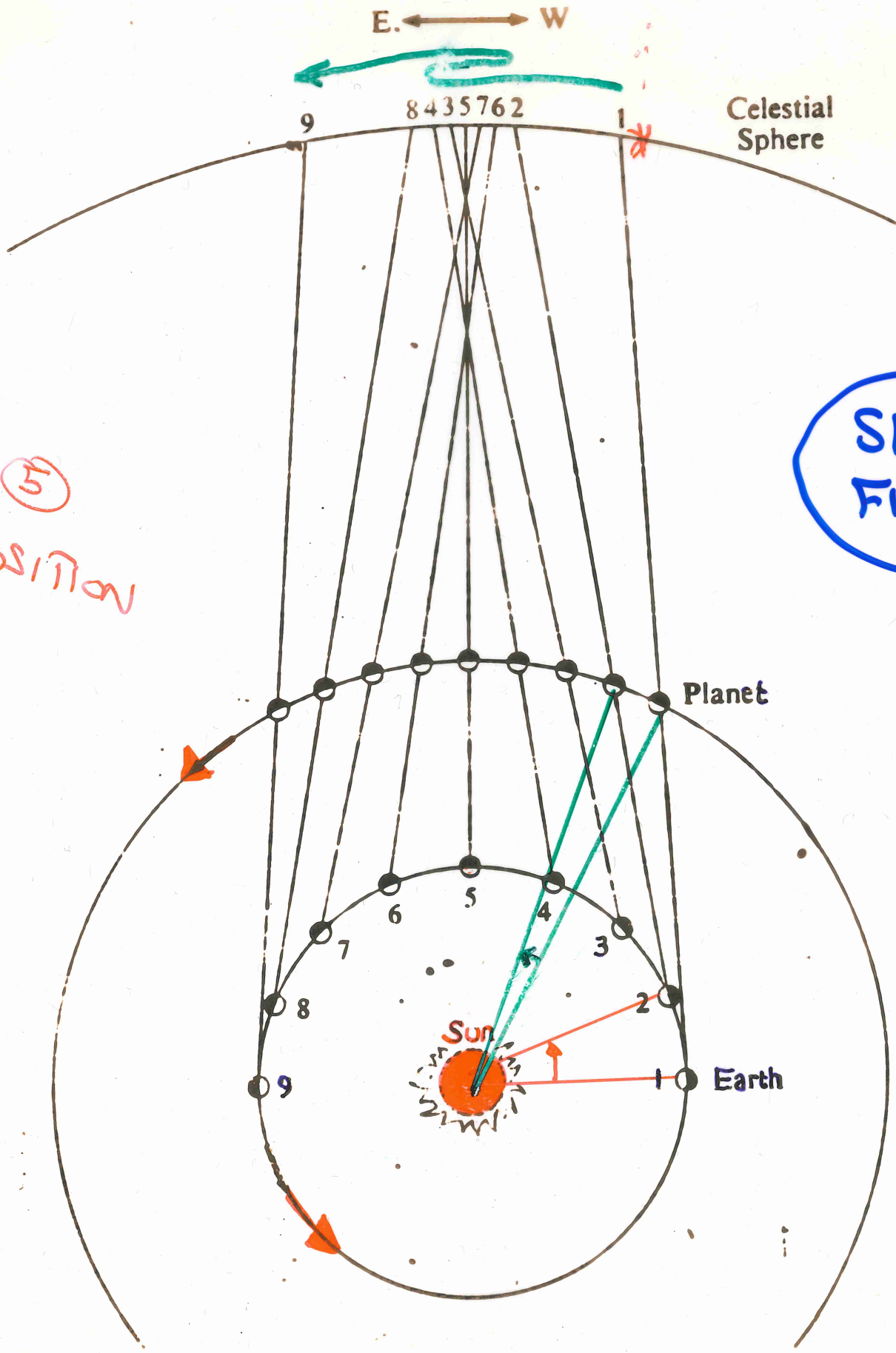
Copernicus

Heliocentric Solar System →

- Scale of planetary system (rel. sizes of orbits)
- Simple explanation of retrograde motion of superior planets (e.g. Mars)
- Calculation of sidereal from synodic periods

Orbits assumed circular



P3

SEEDS FIG 4-10 4-9

AT (5) OPPOSITION

Tycho Brahe

(1546–1601)

Observer *par excellence*

- 20 year sequence of observations of Sun, Moon, planets, and stars *including*

  De Stella Nova

  (now Supernova 1572)

- Proof that heavens were not perfect and unchanging.

Johannes Kepler

Derived 3 laws of planetary motions from Brahe's observations

1. Orbits = ellipses with Sun at one focus
2. "Equal Areas"
3. P^2 (in yrs) = a^3 (in AU)

"It is as if I awoke from sleep and saw a new light."

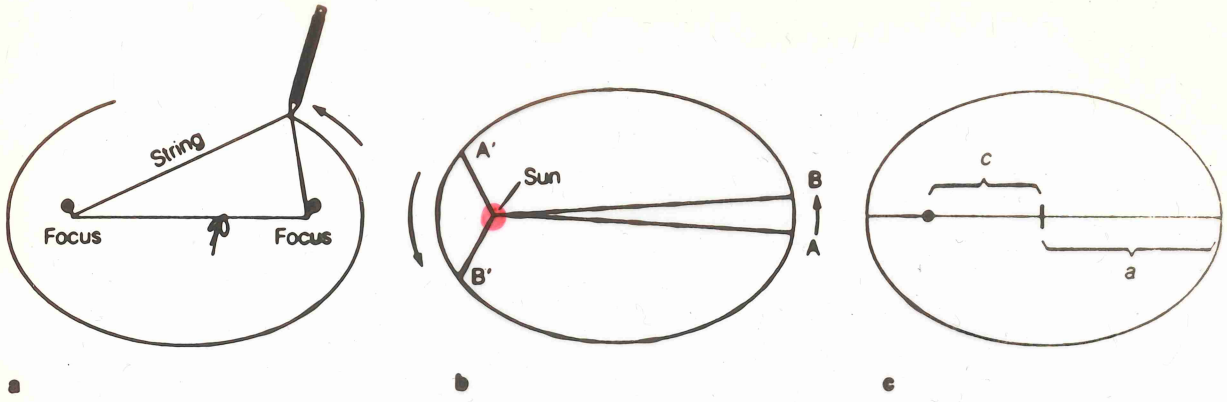


Figure 4-16 (a) Drawing an ellipse with two tacks and a loop of string. (b) Kepler's second law: "A line from a planet to the sun sweeps over equal areas in equal intervals of time." (c) Kepler's third law: The average distance from a planet to the sun equals a, the semimajor axis of its orbit. The eccentricity equals c/a. A circle is an ellipse of eccentricity 0.

PLANETARY ORBITS ARE ALMOST CIRCULAR

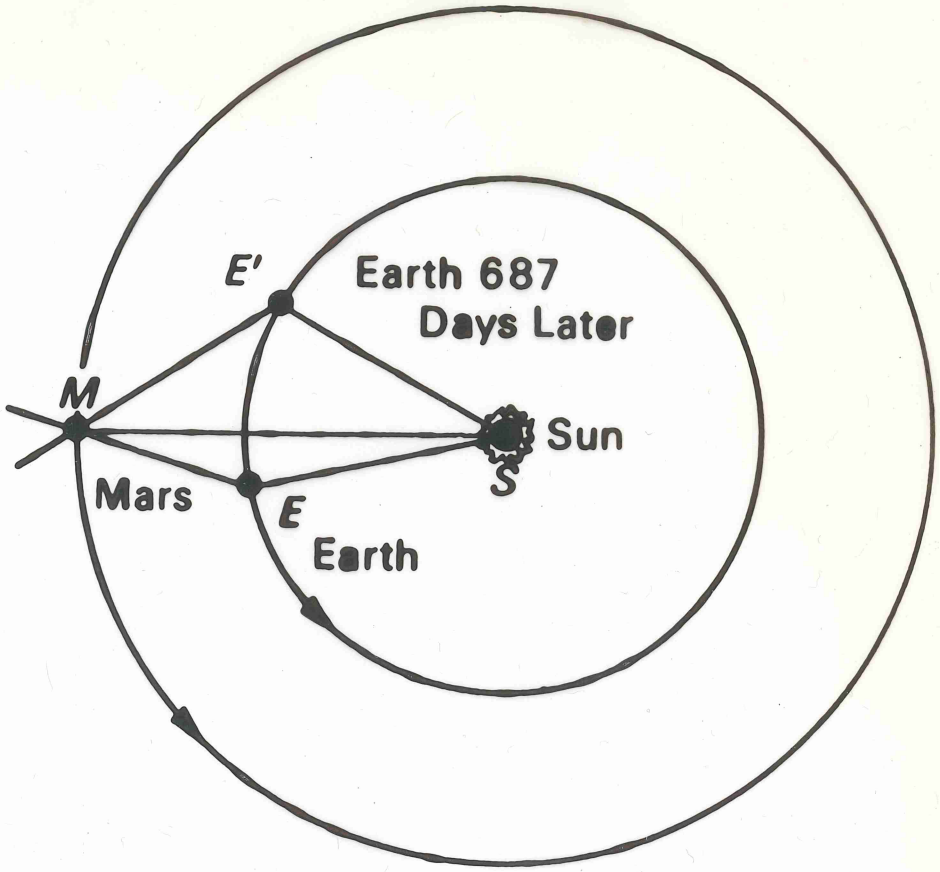


Fig. 6.10. *In 687 days the earth moves 42° less than 2 complete revolutions; thus angle ESE' is 42°. The angle between sun and Mars at both times is found by observation. The distance of Mars in astronomical units may then be found.*

KEPLER'S 3RD LAW

Planet	a ('RADIUS' (AU))	P (PERIOD (yrs))	a^3	P^2	a^3/P^2
Mercury	0.387	0.241	0.058	0.058	1.0
Venus	0.723	0.615	0.378	0.378	1.0
Earth	**1.0**	**1.0**	**1.0**	**1.0**	**1.0**
Mars	1.523	1.88	3.53	3.53	1.0
Jupiter	5.20	11.86	140.6	140.7	1.0
Saturn	9.54	29.46	868.3	867.9	1.0

OCCAM'S RAZOR

IT IS VAIN TO DO WITH MORE WHAT CAN BE DONE WITH LESS.

WILLIAM OF OCCAM

1300-1349

Galileo Galilei

1st astronomical use of telescope

- Phases of Venus
- Jovian satellites
- Sunspots

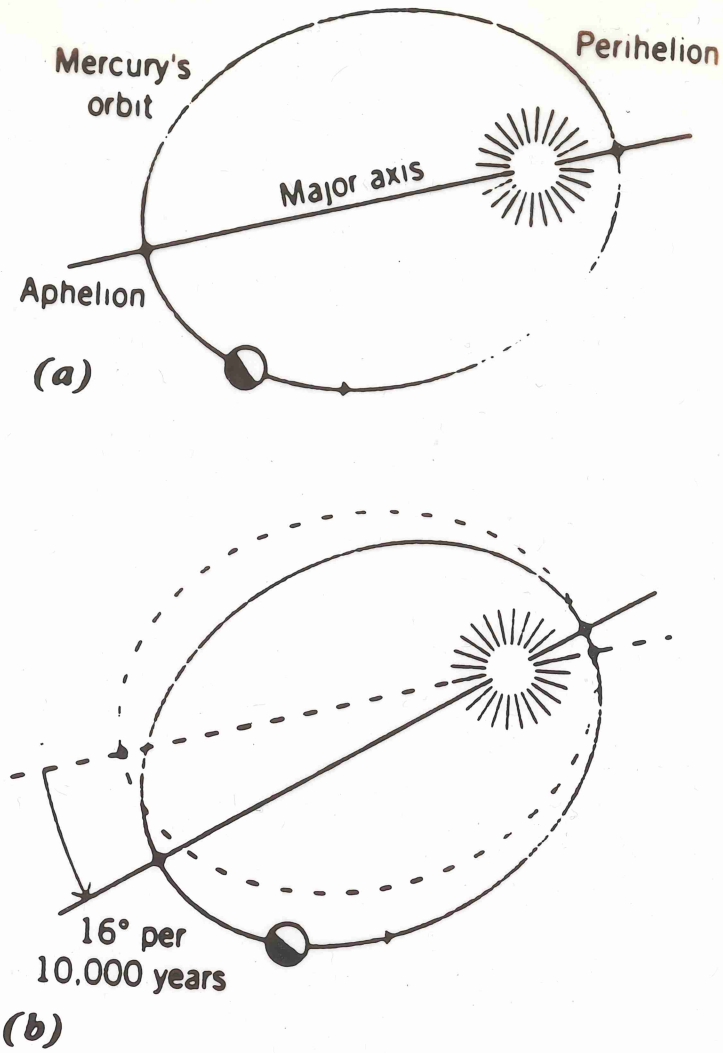


FIGURE 7.11 Perihelion advance of Mercury's orbit. The major axis of the orbit (*a*) rotates in space with respect to the stars (*b*), covering an angle of about 16° every 10,000 years.

Isaac Newton

Facts → But why?

Model

3 laws of motion
Gravitation
} Kepler's 3 laws

Predictions based on Model

Discovery of Neptune

Observations ≠ Model predictions

Mercury's orbit

Albert Einstein

General Theory of Relativity explained Mercury's orbit

"It was necessary to observe the stars for many centuries, recognize in their appearances the real motions of Earth, ascend to the laws of planetary motions, and from these laws to the principle of universal gravitation, and redescend at last from this principle to the complete explanation of all celestial phenomena even in their smallest details. This is what the human mind has accomplished in Astronomy."

Pierre Simon de Laplace
1749 – 1827

"There were those who began to regard it as a science which, from its very perfection, had ceased to be interesting—whose tale of discoveries was told."

Agnes M. Clerke

A Popular History of Astronomy During the Nineteenth Century

1885

NEWTON'S LAWS OF MOTION

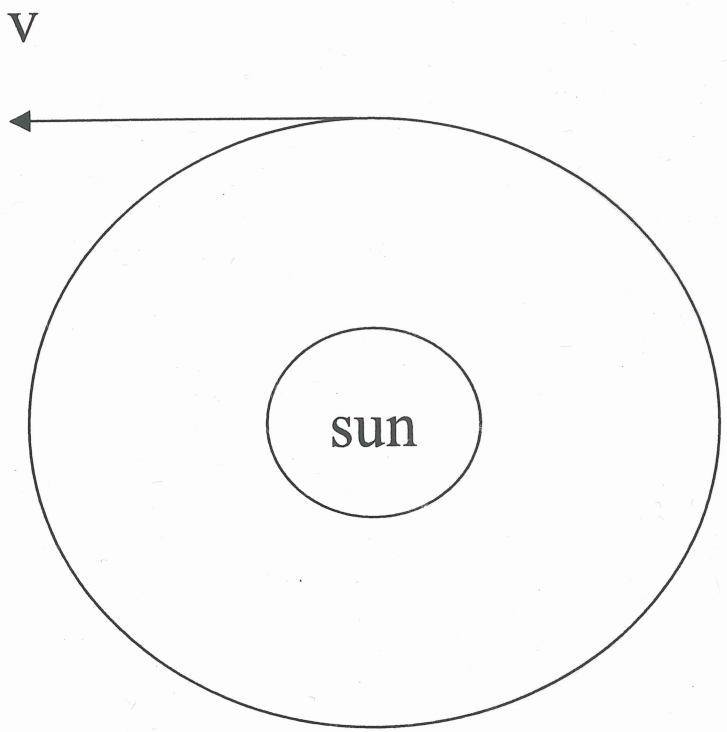
1. Object continues at rest or uniform motion in straight line unless force is applied.

2. Acceleration(=change of direction and/or velocity) proportional to force applied and inversely proportional to mass:

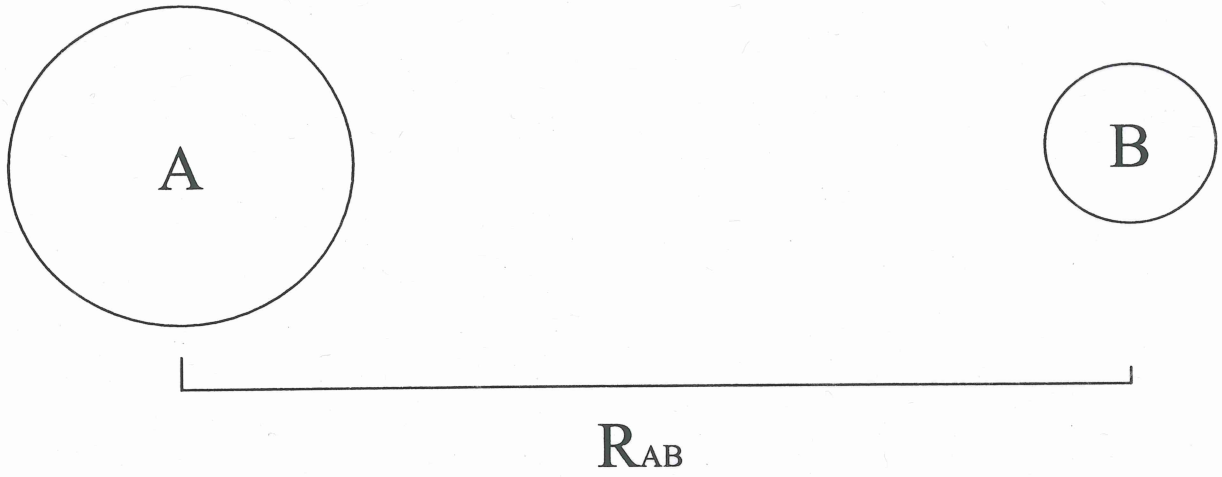
Force = Mass x Acceleration

3. To every action, there is an equal and opposite reaction.

Orbital motion implies acceleration(change of direction)



Gravitation



Attractive Force:

$$F_A = F_B = G \frac{M_A M_B}{R_{AB}^2}$$

Newton's

- Laws of Motion
- Law of Gravitation

predict

Kepler's Three Laws

PLANET IN ORBIT AROUND SUN

Force on planet:

$$F_{pl} = G \frac{M_{pl} M_{sun}}{R_{orbit}^2}$$

Acceleration of planet:

$$a_{pl} = \frac{F_{pl}}{M_{pl}} = G \frac{M_{sun}}{R_{orbit}^2}$$

which is independent of the planet's ***mass.***

By determining the sidereal period and orbital radius, we can calculated M_{sun}.

How do we estimate the mass of a planet?

DISCOVERY OF NEPTUNE

- Uranus discovered accidentally in 1781
- Uranus from new and old observations found to depart from predicted orbit
- Inference: additional planet pulling on Uranus
- Planet's position predicted by Leverrier(Paris) and John Couch Adams(Cambridge). Neptune found by J.G.Galle(Berlin) in 1846.