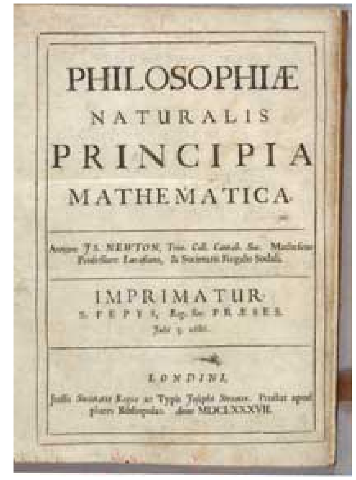
Newton’s Laws of Motion & Gravity—14 Sept

Isaac Newton (at 47) by Godfrey Kneller
Trustees of the Portsmouth Estate
www.huntington.org/LibraryDiv/Newton/Newtonexhibit.htm

- *De Revolutionibus Orbium Coelestium*, Copernicus, 1543
- *Astronomia Nova*, Kepler, 1609
- *Philosophiae Naturalis Principia Mathematica*, Newton, 1687
- Nature and Nature's laws lay hid in night:/ God said, Let Newton be! and all was light. —Newton’s epitaph by Alexander Pope
- Newton: Same laws apply to a falling apple & moving planet.
- Description of motion
- Gravity $\propto 1/R^2$ implies K’s 3rd Law

Copernicus	1473–1543
Columbus sails	1492
Tycho Brahe	1546–1601
Shakespeare	1564–1616
Johannes Kepler	1571–1630
Jamestown	1607
King James Bible	1611
Harvard College	1636
Isaac Newton	1642–1727
George Washington	1732-1799



PHILOSOPHIÆ
NATURALIS
PRINCIPIA
MATHEMATICA
IMPRIMATUR
LONDINI

“Natural” Motion for Newton & Aristotle

- Natural motion is motion that needs no explanation: the object naturally moves that way.
- Aristotle: For heavenly objects, natural motion is motion in a circle with the same speed. For base objects, natural motion is rest.
  - A book falls off the table and comes to rest on the floor. This needs no explanation because rest is the natural state.
- Newton: Natural motion is moving at the same speed in the same direction.
  - Newton’s First Law: In the absence of a force, an object moves at the same speed in the same direction.

1. A book falls off the table and lands on the floor. For Newton, what is natural?
   a. The book is on the floor.
   b. The book is halfway to the floor.
   c. The book is just starting to fall.
   d. I push the book off the table.

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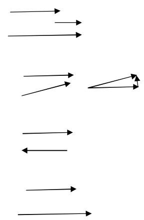
2. Venus moves around the sun in a circle at the same speed. Does Newton consider this motion natural?
   a. Yes, Venus is a heavenly object.
   b. Yes, the speed is the same.
   c. No, the direction is not always the same.
   d. No, Venus is not at rest.

Newton's Second Law

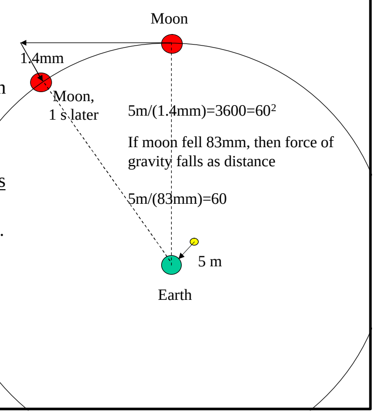
- Newton's First Law: In the absence of a force, an object moves at the same speed in the same direction.
- Newton's Second Law tells how to find the motion if there is a force.
  - *Force = mass x acceleration*
    F = m x a
  - Acceleration is change in velocity divided by amount of time
- Q3 The velocity changed in
  a. Case A only
  b. Case B only
  c. Neither cases A nor B
  d. Both cases A and B
- Q4 The acceleration is greatest for which case?

- Case A
  - Velocity at start
  - Velocity after 1 s
- Case B
  - Velocity at start
  - Velocity after 1 s
- Case C
  - Velocity at start
  - Velocity after 1 s
- Case D
  - Velocity at start
  - Velocity after 2 s



Newton discovers the law of gravity

- Newton was sitting under an apple tree and looking at the moon. An apple falls on his head. Newton realizes the moon and the apple fall for the same reason. He does a quick calculation and concludes that the force of gravity decreases as the square of the distance.
  - In a second, an apple falls 5 m.
  - The moon stays up in the sky. What does Newton mean by "the moon falls?"
  - The moon is 60 times farther from the center of the earth than the apple.



Newton Implies Kepler's 3rd Law

- Easier derivation: Assume orbit is a circle. Ignore numerical constants such as π or 2.
  - Newton's Law of Gravity: Force between sun and planet
    Force = G $mass_{Sun}$ $mass_{Planet}$/$Distance^2$; $F = G M m/R^2$
  - Newton's 2nd Law
    Force = $mass_{Planet}$ acceleration; $F = m a$
  - $G M m/R^2 = m a$; mass of planet cancels out.
  - Velocity is approximately R/P, where P is period. (It is exactly $2\pi R/P$.)
  - Acceleration, change in velocity/time, is approximately (R/P)/P.
  - $G M /R^2 = a = R/P^2$
  - $P^2 = R^3/(G M)$
- More accurate derivation

$P^2 = 4 \pi^2/G \ R^3/(M_{sun}+m_{planet})$

$4\pi^2/G = 2\times10^{30}$ kg $yr^2/AU^3 = 1 M_{sun} yr^2/AU^3$

Summarizing Questions

- What did Newton learn about Kepler's 3rd law that Kepler did not know?
- Does $P^2 = R^3$, where P is the period in years and R is semi-major axis in AU apply to a planet in orbit around another star?