Lecture 6
Newton's laws:
The foundation of modern science

- Better data — Tycho Brahe
- Final touch-up of the model — Johannes Kepler
- Promotion of the new model — Galileo Galilei

Still missing: someone to put the pieces together in order to form a coherent physical theory in the modern sense

$\Rightarrow$ Sir Isaac Newton

Sir Isaac Newton (1643-1727)

- Fundamental contributions in optics, physics and mathematics:
  - invented calculus (independently: Leibnitz)
  - invented the mirror telescope
  - discovered than white light is composed of colored light
  - Theory of mechanics
  - Theory of gravity
  - demonstrated that Kepler's laws are a consequence of the theory of mechanics and gravity: *Principia*

Newton's three laws of motion

Newton's first law: A body at rest or in the state of uniform motion will remain at rest or in uniform motion, unless acted upon by a net external force.

Consequences of Newton I

- Following Galileo, a force is required to change motion, but not to maintain it.
- Change in motion means
  - moving faster
  - moving slower
  - changing the direction

Question: How many accelerators has a car ?

Answer: three !

- The accelerator (speeding up)
- The break (slowing down)
- The steering wheel (changing direction)

Short math excursion: Scalars and Vectors

- Scalar: a quantity, which can be completely specified by one single number
- Vector: a quantity, which in addition requires the specification of a direction
- Examples:
  - Scalar: volume, temperature, weight
  - Vector: velocity, acceleration, force

Newton's three laws of motion

Newton's second law (law of interia):

The acceleration of an object is equal to the net force applied to it, divided by its mass.

$$F = m \times a$$

Example: Why can you throw a baseball farther than a bowling ball?

Answer:

- The force you apply to both balls is the same
- The bowling ball has a larger mass [inertia] $\Rightarrow$ the acceleration is smaller

Newton's three laws of motion

Newton's third law: For every action, there is an equal and opposite reaction.

Examples:

- Recoil of a gun
- Jump from a boat onto the shore
- two ice skater pushing each other
- rocket in space

Crash test: all three laws at work

- Initially, car and driver in uniform motion
- Car hits wall
  - Newton 1: wall exerts a force onto the car $\Rightarrow$ car stops
  - Newton 2: car stops $\Rightarrow$ acceleration is large $\Rightarrow$ forces are large $\Rightarrow$ car deforms
- A priori no forces on driver
  - Newton 1: driver keeps on moving on a straight line at constant speed

Crash test: all three laws at work

- driver buckled up: seat belt exerts force onto driver, slows him down (Newton 1+2)
- driver not buckled up: drivers head exerts force onto windshield, bursts it, flies through windshield, keeps on going until he eventually hits ground (Newton 1)

- Newton 3:
  - car bounces back
  - buckled driver falls back into his seat
  - unbuckled driver: windshield exerts force on drivers head, smashes drivers head.

Kepler’s three laws, Newton’s three laws, what is the difference ?

Kepler's three laws

Kepler's first law: Planets orbit the Sun in an ellipse, with the Sun at one focus.

Kepler's second law: The line from the Sun to the planet sweeps out an equal area in an equal time. Thus planets move faster if they are nearer the Sun.

Kepler's third law: The square of the period of the orbit is equal to the cube of the semimajor axis of the ellipse.

Empirical laws

Newton's three laws

Newton's first law: A body at rest or in the state of uniform motion will remain at rest or in uniform motion, unless acted upon by a net external force.

Newton's second law: The acceleration of an object is equal to the net force applied to it, divided by its mass.

Newton's third law: For every action, there is an equal and opposite reaction.

Axioms