ARISTOTELIAN PHYSICS

- Aristoteles (Aristotle) (384-322 BC) had very strong influence on European philosophy and science;
  - everything on Earth made of (mixture of) four elements: earth, water, air, fire
  - every element has a “natural place”:
    - earth at center of Earth,
    - water above earth,
    - air above water,
    - fire above air;
  - celestial bodies (stars, planets, Moon) made from fifth element, “ether”, which also fills space between them; ether is perfect, incorruptible, weightless;
  - two kinds of motion of things on Earth: “*natural*” and “*violent*” motion
  - *natural motion*: things tend to move towards their natural place - natural motion happens by itself, needs no push/pull (e.g. stone falls).
  - *violent motion*: = motion contrary to natural motion; needs effort (external push or pull)
  - *celestial motion* = natural motion of ether;
    natural motion of bodies made from ether is circular motion, regular and perpetual

Problems with aristotelian physics:

- Galileo Galilei's thought experiments and real experiments:
  - falling bodies:
    - according to Aristoteles, heavy bodies (contain more earth element) fall faster than lighter bodies
    - observation: fall equally fast if they have same shape and size
    - Galilei: difference in speed of differently shaped falling bodies due to air resistance
  - thought experiment about two falling bodies - "reductio ad absurdum":
    - consider two bodies, one light (L), one heavy (H)
      Aristoteles: L falls more slowly than H $\Rightarrow$ L put under H should slow down fall of H; $\Rightarrow$ H with L under it should fall more slowly than H alone; but (L + H) heavier than H alone $\Rightarrow$ should fall faster than H alone $\Rightarrow$ contradiction.
  - pendulum: ball suspended on string reaches same height as that to which it was lifted to set it in motion (not quite; - due to friction);
    height independent of path (pendulum with shortened string)
  - ball rolling on inclined plane:
    - ball rolling down inclined plane speeds up;
    - ball rolling up slows down; rate of slowing down depends on steepness of incline: less steep $\Rightarrow$ longer distance travelled; extrapolation to zero slope of incline: ball will go on forever

GALILEI'S NEW SCIENCE

- Galileo Galilei (1564 - 1642) -- founder of modern science;
  - new methods introduced by Galilei include:
    - controlled experiments designed to test specific hypotheses
    - idealizations to eliminate any side effects that might obscure main effects
    - limiting the scope of enquiry - consider only one question at a time;
    - quantitative methods - did careful measurements of the motion of falling bodies.
  - from observations and thought experiments, generalizes to two new laws:
- **LAW OF INERTIA**:
  - without external influence (force) acting on it, a body will not change its speed or direction of motion; it will stay at rest if it was at rest to begin with.
  - inertia = property of bodies that makes them obey this law, their ability to maintain their speed (or stay at rest)
- **LAW OF FALLING**:
  - if air resistance is negligible, any two objects that are dropped together will fall together; speed of falling independent of weight and material.

NEWTONIAN MECHANICS

- Starting from law of inertia (René Descartes, Galileo Galilei), Isaac Newton developed a new way of looking at nature.
- Principia Mathematica Philosophiae Naturalis (1687) (Mathematical Principles of Natural Philosophy):
  - based on a small number of concepts and principles,provide a clear and quantitative explanation of a vast array of phenomena.
  - give a unification of our view of nature - the first major synthesis of science
  - explain: motion of bodies on Earth and in heaven (falling bodies, Moon, planets, comets,...
  - key concepts:
    - velocity
    - acceleration,
    - force
    - inertial mass, gravitational mass
  - key principles:
    - law of inertia (Newton's 1st law of motion)
    - law of motion (forces) (Newton's 2nd law of motion)
    - law of force pairs (action=reaction) (Newton's 3rd law of motion'')
    - law of gravity

FORCE

- law of inertia: no force $\Rightarrow$ no acceleration;
- if acceleration - there must be force;
- we say: *body exerts force on another if it forces the other body to accelerate;*
- note there is some circularity in this definition, but definition is justified by its usefulness and predictive power;
- force is not a property of a body;
- if more then one force acting $\Rightarrow$ effects add $\Rightarrow$forces add -- “net force”;
- acceleration is in direction of net force; two or more forces can compensate (“balance”) each other (e.g. two equally strong forces acting in opposite directions)
- kinds of forces:
  - push, pull, shove, kick, tap
  - friction, air resistance
  - gravity
  - electric
  - magnetic
- Aristotelian view: *forces cause velocity*
  (force necessary to maintain uniform motion).
- Newtonian view: *forces cause acceleration*
  (force necessary to change motion)

Forces, Newton's 2nd law

- Observations:
  - stronger force $\Rightarrow$ larger acceleration
  - more "massive" object $\Rightarrow$ smaller acceleration
  - apply more than one force $\Rightarrow$ net force determines acceleration
  - inertia = resistance of object against being accelerated;
    (inertial) mass = measure of amount of inertia,
    observed to be proportional to amount of matter -- set them equal;
  - unit of mass = kilogram = kg (original definition: = mass of 1 liter of water)
- observations can be summarized by: **Newton's 2nd law:** $F = k\,m\,a$
  - k = proportionality constant; by choice of units, can make $k = 1$
  - note that F, a are vectors, and acceleration a is in direction of force F
  - unit of force = newton; 1 newton = 1 kg m s^{-2}
  - in English system: unit of force = pound = 4.448 N
  - note: the mass m in Newton's 2nd law is the "inertial mass"
- weight vs mass:
  - mass of object = quantity of its inertia;
  - weight of an object = net gravitational force on an object; depends on environment;
  - our weight on the Moon is 1/6 of that on the surface of the Earth;
  - our weight on a high mountain is smaller than at sea level;
  - our weight in a satellite in orbit around Earth = 0;
  - *our mass is always the same.*

Newton’s 3rd law (Law of force pairs - action and reaction)

- “actio = reactio’’
  - when a body exerts a force on a second body, the second body exerts an equally strong force on the first body, directed opposite to the first force;
- examples:
  - apple and Earth:
    - Earth exerts force on apple $\Rightarrow$ apple exerts force on Earth;
    - Earth's large mass $\Rightarrow$ Earth's acceleration very small
  - book on table: 2 pairs of forces:
    - Earth exerts gravitational force on book, book exerts gravitational force on Earth.
    - book exerts force (= its weight) on table; table exerts equal and opposite force on book (“contact force”, “normal force”)
    - net force on book = 0 $\Rightarrow$ book stays at rest on table (does not fly away, does not fall through table)
    - (contact force caused by interaction of electrons in atoms of book with those in table)
  - walking: exert force on ground $\Rightarrow$ ground exerts force on you;
    rowing, driving, recoil of a gun, rocket propulsion
- Note:
  - Newton’s 3rd law closely related to *momentum conservation*