MAJOR FIGURES OF THE SCIENTIFIC REVOLUTION

Condensed version of Dr Robert A. Hatch's notes - University of Florida

❖ Nicolas Copernicus (1473-1543)

- The Copernican System
  - Introduced 3 celestial motions
    - Rotation of the earth on its axis
    - The earth and the planets, revolve around the sun.
    - A conical axial motion of earth to explain the fixed orientation of earth in space.
  - A mathematical, not an observational, astronomer, his system was as complex as Ptolemy's.
  - Sought to purify ancient astronomy, not to overthrow Ptolemy.
- Motivation
  - Copernicus was educated in a critical atmosphere that called for the reform of Ptolemaic astronomy and cosmology.
- The Copernican 'Revolution'
  - Its revolutionary aspect lay in its violation of Aristotelian physics and the implicit requirement of a 'new' physics, which caused natural philosophers to think, and look, in a new astronomical frame of reference.

II. Johannes Kepler (1571-1630)

A. Background of Keplerian Astronomy

1. Platonic and Pythagorean elements, especially a mystical sense of mathematical harmony in the cosmos, for example, the use of the five regular polyhedra to account for the planetary orbits, *The Cosmographic Mystery* (1596).

2. The heliocentric Copernican cosmos with uniform circular motion.

3. The mechanical ideas of the Renaissance, particularly "clockwork" as a suggestive conceptual model for celestial physics.

4. Existence of 'powers' such as magnetism and light which could be used to account for the physical force necessary to drive the celestial machine.

5. Kepler was a highly competent mathematician.

B. Kepler and the Tychonic System.

1. Brahe provided Kepler with the best collection of observational (empirical) data in existence.

2. He set Kepler to work on the problem of the orbit of Mars, that is, the planet's nonuniform motion with respect to the center of its orbit:

a. Disregarded the use of equants and epicycles as a solution.
b. Formulated the Area Law: in equal time intervals a planet will sweep out equal areas (Second Law).
c. Kepler settled on the ellipse as an orbital path, that is, planetary orbits are elliptical (First Law).

C. Synopsis of Keplerian Astronomy.

1. A nonempirical, mathematical commitment to the area law and the geometrical cosmos of elliptical orbits--the data were observational but the commitment was philosophical.

2. Introduced a type of 'physical' unity, that is, a solar 'power' or 'virtue' moves the planets in their orbits.

3. The account of elliptical orbits was based on the assumption that the sun and the planets were magnets, an action between "animate souls" which served to attract, or be attracted by, the sun thus drawing the planets into elliptical paths.

4. No quantitative elements have been introduced--a qualitative analysis expressed in terms of mathematical harmonies, for example, the square of a planetary period is proportional to the planet's mean distance from the sun, T [squared] is proportional R [cubed] (Kepler's Third Law).

5. Kepler thought he had penetrated the structural reality of the cosmos and in so doing, was forced to seek a 'new' celestial physics.

III. Galileo Galilei (1564-1642)

A. Intellectual Roots of Galileo's Science.

1. Copernican astronomy and the implicit necessity of a 'new' physics to replace Aristotelian mechanics.

2. A long tradition in mechanics extending from the ancient world and middle ages through the Renaissance (for example, Aristotle, Philoponus, Avempace, the Merton and Parisian schools, Padua), and especially the works of Archimedes.

B. Galileo and Astronomy.

1. Galileo was a confirmed Copernican and given to the concept of circular motion.

2. Galileo wrote for a literate but nontechnical reader in his defense of Copernicus, and not as a professional astronomer--his arguments and evidence were polemical and perhaps propagandistic.

3. Galileo's 'facts' differed from the traditional data of astronomy in that they were derived from qualitative telescopic observations.

4. Observational data obtained with the telescope:

a. Stellar 'population explosion' implying an expanded cosmos.
b. The topography of the moon was similar to, or more pronounced than, that of the earth; the earth-like moon moves around the earth--why can't the earth move around the sun?
c. The phases of Venus were inexplicable in terms of Ptolemaic cosmology; Ptolemaic scheme no longer viable.
d. The satellites of Jupiter, moving with, and approximately in the same plane as the planet, suggested more than one center of rotation in the solar system and, by analogy, the earth's rotation around the sun.
e. Sun spots implied that the heavens are not perfect (to reinforce the argument of the moon's topography); these data were obviously unknown to Aristotle or Ptolemy.

C. The Problem of Falling Bodies.

1. His early work in the 1 590s dealt with falling bodies as a problem in dynamics approached in terms of the self-expending impetus theory of Oresme and Avempace, V is proportional to W-R.

2. Inspired by Archimedes and Benedetti, Galileo used hydrostatics as a model for his science.

3. In his later work, Galileo abandoned the dynamical approach in favor of kinematics.

4. He proceeded to clarify, restate, and systematize medieval problems in kinematics while giving them a more complete mathematical expression, for example, problems suggested by the Odd Numbers Law relating distance to time (S proportional to t squared) and velocity to distance (V proportional to S), out of which he came to relate velocity to time (V proportional to T), and eventually, S = 1/2at [squared].

5. After 1609, Galileo's kinematic treatment of an idealized model identified falling bodies as a case of uniformly accelerated motion and thereafter demonstrated it with his inclined plane experiment.

D. Projectile Motion.

1. Galileo's work developed out of the impetus theories of contemporary physics, especially those of Tartaglia and Benedetti.

2. In his later theory (1632), no force is necessary to keep a body moving on a level (frictionless) plane; a body, as such, has no inclination to move or remain at rest, it is indifferent.

3. Thus, if a body is indifferent to motion, no mover is required to sustain movement once a body is in motion.

4. Motion is now a state rather than a process, and rest is motion of zero speed in a continuum.

5. Galileo's conception of inertia as circular motion was an attempt to save Copernican circularity, particularly in the absence of any known force which could 'bend' rectilinear motion into an orbit.

E. Galileo's Method.

1. Galileo argued that theoretical conclusions required experimental verification even if the experimentation was mental rather than empirical.

2. He was a thinker about nature and thought in terms of ideal situations rather than the complexities of the sensate world.

3. Expressed confidence in deductive, reasoned conclusions: Archimedean mathematics applied to physical problems rather than extensive experimental programs.

IV. René Descartes (1596-1650) and the Mechanical Philosophy

A. Background of the Mechanical Philosophy.

1. Derived from ancient atomism but reworked by 17th century thinkers such as Descartes, Gassendi, Huygens, Hooke, and Boyle.

2. Reaction against the animistic philosophies of the Renaissance, notably Hermetism.

3. Conceived as an alternative to existing Aristotelian metaphysics.

B. Basic Tenets of the Mechanical Philosophy.

1. Viewed nature as composed of inert (without quality) matter in motion.

2. All causality involved matter in contact with matter--no action at-a-distance.

C. Cartesian Mechanical Philosophy.

1. Descartes, reacting against Renaissance skepticism, sought to affirm the existence of certain knowledge.

2. The conclusions of mathematics, especially those of geometry, are demonstrable, that is, start with true premises (clear and distinct ideas) and proceed deductively to certain conclusions.

3. Mathematics accepted as a model, though not the essence, of knowledge.

4. Descartes' methodical doubt reduces existing substances to two types:

a. *Res cogitans* (thinking stuff): immaterial thought or mind.

b. *Res extensa* (extended stuff): geometrical extension or matter.

5. All that exists outside the mind is matter: only primary qualities exist, that is, motion, size, shape, number, location, place; secondary qualities are illusory (soft, hard, hot, cold, wet, dry, etc.).
6. The universe is a plenum, that is, it is 'full' with no void possible.
7. Matter is of three types, classified as to size: First matter, fine (chips); second matter, medium (spheres); and third matter, gross (chunks), that is, respectively, material light, aether, and ordinary, visible matter.
8. The interaction between the various forms of matter occur as the result of vortex action; the universe is composed of vortices or whirlpools of matter. Vortices explain the varying periods and uniform orbital directions and inclinations of the planets.
9. Formulated the concepts of rectilinear inertia and the conservation of motion.

V. Francis Bacon (1561-1626) and the Baconian Method

A. Opposition to Scholastic and Renaissance Philosophy: The Idols.

1. The Tribe: weaknesses of human nature, that is, prejudice, passions, limited mental and sensory faculties.

2. The Cave: weaknesses of environment, that is, education, habit, prejudice, predisposition of approach to philosophical-scientific questions.

3. The Market Place: semantic difficulties arising from confusing words with things.

4. The Theatre: philosophical systems or theories which direct the mind beyond the data of experience to unsupported generalities.

B. Basic Assumption: The Simplicity of Nature.

1. Scientific progress is a matter of finding the correct method, that is, the correct method is equivalent to truth:

a. If nature is approached in the appropriate manner, the truth can be found.

b. Error is the result of defective methods.

2. The ultimate goal of science is practical utility for the benefit of mankind.
3. The method is the 'tool' of the intellect: it enables the mind to overcome its weaknesses, and can compensate for disparity of mental ability.

4. The function of method is to collect data from the natural world and refashion it (the bee)--it is not just empirical cataloguing (the ant) and it is not a matter of pure speculation (the spider).

C. The Baconian Method.

1. The basic premise: observe nature with the senses--proceed inductively from observations (data) to generalities (axioms), and form deductive conclusions which can be tested by experimental evidence.

2. The method of exclusion:

a. Tabulate all possible causes of an observed effect.

b. Observe nature to see what causes actually exist in the given physical circumstances.

c. Exclude all but one, that is, the result of the crucial experiment.

VI. Isaac Newton (1642-1727) and the Newtonian Synthesis

A. Elements of the Synthetic, "New" Physics.

1. Galileo's idealized formulation of the law of freely falling bodies, d = 1 /2at [squared].

2. Galileo's analysis of terrestrial inertia: a body is indifferent to uniform rectilinear motion and is as 'natural' as rest.

3. Descartes' conception of rectilinear inertia existing in Euclidean space and the implied rejection of privileged spatial position.

4. Kepler's 'discovery' of his three laws of celestial motion, especially the The Third Law, T squared is proportional to the mean Radius cubed.

5. Huygens' and Borelli's work on centrifugal forces, terrestrial and celestial respectively, suggested an inverse square relationship, as well as the analogy from light made explicit by Boulliau.

B. The Problem and the Test Case: Lunar Motion.

1. Lunar motion was essential to both Aristotle and Newton:

a. The lunar orbit was the demarcation line for the Aristotelian two-world system (sublunar/superlunar regions).

b. The connection of lunar-terrestrial motion under the same principle was the crux of the Newtonian argument.

2. Newtonian assumptions:

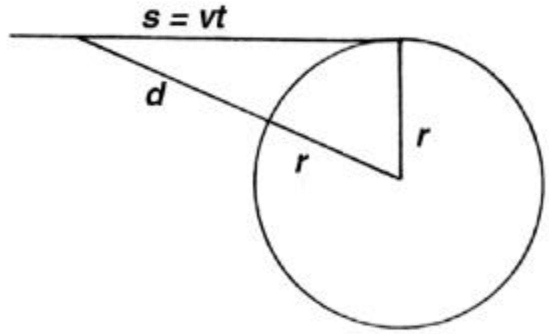
a. The Copernican hypothesis: the earth is a planet.

b. The hypothesis that inter-planetary space is empty, that is, free space.

3. The problem was to explain the configuration of planetary orbits, that is, what mechanism or force can account for the orbital alteration of a planet's rectilinear path.

C. The Moon's Orbit and the Unification of Terrestrial-Celestial Physics.

1. Problem of translating the moon's rectilinear acceleration into the centripetal acceleration necessary to account for the lunar orbit--assume circular Copernican orbits.



$$(r+d)^2 = r^2 + (vt)^2$$

$$ra = v^2$$

$$a = \frac{v^2}{r} \text{ (= centripetal acceleration)}$$

2. Problem of demonstrating that lunar acceleration represents a ratio equivalent to that of free fall on the earth, implying the same gravitational force: the inverse square law.

$a = \frac{v^2}{r}$ (= centripetal acceleration)

$T^2 = Kr^3$ (= Kepler's Third Law)

For a circular orbit: $V = \frac{s}{t}$, $s = 2\pi r$ (= circumference, or

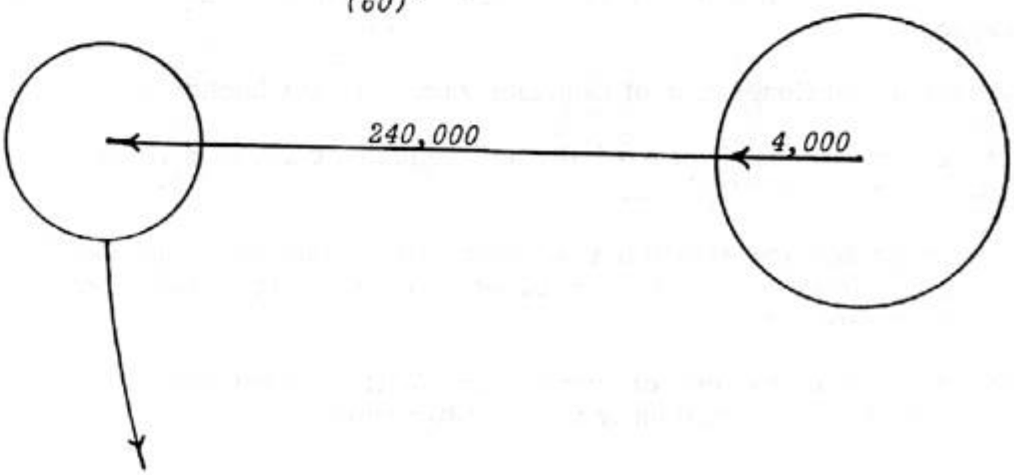
period, for a circular orbit) $V = \frac{2\pi r}{T}$

$$a = \frac{4\pi^2 r^2}{T^2 r} = \frac{4\pi^2 r}{T^2} = \frac{4\pi^2 r}{Kr^3} = \left(\frac{4\pi^2}{K}\right) \cdot \frac{1}{r^2}$$

$$A_m = \frac{V^2}{R} = .00898 \text{ feet/second}^2$$

(by observation)

$$A_e = \frac{V^2}{R} = \frac{32 \text{ feet/second}^2}{(60)^2} = .00898 \text{ feet/second}^2$$



3. Problem of justifying the mathematical treatment of the earth's total mass as concentrated in a single mass point at the earth's center; Newton's solution rested upon his invention of the calculus, his "fluxions", which could be used to consider the intricacies of the problem.

4. The final stage was to transfer the concept of force for a planetary orbit in relation to the sun, based on the moon-earth test case to a universal, reciprocal gravitational relationship which applied to all matter

D. Components of Newtonian Physics.

1. *Matter:* an infinite number of separate, hard, and unchangeable particles which are not identical.

2. *Motion:* the relational state which moves particles from place to place in an infinite void of free space without affecting them.

3. *Space:* the infinite homogeneous void in which the particles, and the bodies they form, move.

4. *Attraction:* the undefined unifying force which is not a constructive element but rather a "hyperphysical" power or mathematical statement describing how the universal components are connected.

E. The Destruction of the Aristotelian Cosmos.

1. Considerations of such concepts as perfection, harmony, teleology, formal and final causality, and value are removed from scientific discussion.

2. The world was no longer viewed as finite and hierarchically ordered: quantitative considerations replace qualitative ones.

3. The celestial and terrestrial worlds are no longer philosophically and scientifically distinct; astronomy and physics have been geometrically unified.

F. The Mathematical Generation of Homogeneous, Abstract Euclidean Space.

1. The common sense world of the pre-Galilean cosmos is replaced by an idealized mathematical universe.

2. Newtonian science attempted to synthesize mathematics and experiment: the integration of theory and experience under the 'direction' of the inverse square law.

3. The Newtonian pattern of empirical-deductive knowledge provided both physical and intellectual unity for the 18th-century universe. Alexander Pope suggested:

Nature and nature's laws
Lay hid in night,
And God said
'Let Newton be'
And all was light.

The Enlightenment is sometimes called 'Newton's Century.'