EVOLUTION OF PHYSICAL THEORIES

PHENOMENON OBSERVED

DEVELOP THEORY: MODELING

NEW PHENOMENA OBSERVED

EXPLAINED BY THEORY?

YES

GOOD THEORY

NO

BAD THEORY
SIMPLICITY AND COMPLEXITY IN NATURE

• SOME SUCCESS STORIES:
  - Human-scale physics: MOTION
    ELECTRICITY AND MAGNETISM
    HEAT

• PHYSICS OF THE VERY SMALL:
  - Quantum physics: ATOMS
    MOLECULES
    ELEMENTARY PARTICLES

• PHYSICS OF THE VERY LARGE:
  - Astrophysics/Cosmology: STARS (life and death)
    CHEMISTRY OF UNIVERSE
    EVOLUTION OF UNIVERSE

• SOME (PRESENT) FAILURES:
  - Complex Phenomena: WEATHER
    BRAIN
    LIFE
    HUMANS

Reductionism has been VERY successful…Why?
There is simplicity in the apparent complexity of Nature

• It is possible to understand and predict the behavior of many phenomena with simple, general laws (e.g. gravity)

Physics is the method by which we uncover this simplicity

Understanding Nature → Search for Laws of Physics

How did it all start? And where?
THE PRE-SOCRATICS (ca. 620-470 BCE)
Questions about Nature answered within Nature

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<th>1. IONIAN SCHOOL: Miletus</th>
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<th>4. ATOMISTIC SCHOOL: Abdera</th>
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<td>All things made of atoms</td>
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<td>• Democritus  • Leucippus</td>
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I. Ionian School:

• Questions are asked, answers debated
• What is the stuff cosmos is made of?

Thales of Miletus (ca. 624-545 BCE)

- First to suggest single substance: WATER
- Universe is a living organism (unifying Nature with body)
- Search for simplicity in Nature
- Earth is a circular disk surrounded by water

Anaximander of Miletus (ca. 611 - 546 BCE)

- Universe is infinite in extension and duration
- Raw material is unknown substance: all things born from it and return to it
- “Boundless: The cosmic breath”
- First mechanical model of cosmos
Anaximenes of Miletus

Air is basic stuff: Different densities --> different substances
fire --> water --> earth --> stones
Stars attached to crystalline spheres (key idea in astronomy for 2,000 years…)

Heraclitus of Ephesus (fl. Ca. 500 BCE); “The Obscure”

“All things are in flux and nothing is stable” (river)
Balance in cosmos achieved from tension between opposites
“logos” (bow and arrow)
Basic substance is fire: Transformation
Emphasis in **PROCESS: BECOMING**

IONIANS ➔ BECOMING
II. Eleactic School: (fl. 5th BCE in Elea, Italy)

Parmenides of Elea (ca. 515 - 450 BCE)
* Radical Monism: There is one Being, Immutable
  ➞ change is second-rate reality
* Eon: Cosmic Deity - ungenerated, all-pervading
* What IS cannot change for… **BEING**
* Physics as search for immutable laws
* Zeno and his paradoxes of motion

III. Pythagorean School: (fl. 6th - 5th BCE in Croton, Italy)

Mathematical mysticism: “All is number”
  all things have forms, and forms are described by numbers

Pythagoras of Samos (ca. 585 - 510 BCE)
* Legendary; possibly pupil of Anaximander
* Synthesis of philosophy and religion: rational and mystical
* Knowledge is gateway to the Divine:
  numbers are the bridge between human reason and
  divine mind
* Self-transcendence through the beauty of numbers (“ekstasis”)

Pitch of note depends on length of string

* pleasing sounds correspond to simple ratios: 2/1 - Octave
  3/2 - Fifth
* expression of quality as quantity: mathematization of sensorial experience
* beauty (HARMONY) can be expressed mathematically
* Numbers have form:

\[ 4 = \begin{array}{c}
\end{array} \quad 6 = \begin{array}{c}
\end{array} \]

* get square numbers by adding odd numbers:
  \[ 1 + 3 = 4 + 5 = 9 + 7 = 16 + 9 = 25 \ldots \]

* The harmony of the spheres
* Earth is spherical
IV. Atomistic School: (fl. 4th BCE)

* All things are made of indivisible, fundamental dense bricks: atoms
* Reconciliation of change and immutability

**CHANGE**
(Heraclitus)

**IMMUTABILITY**
(Parmenides)

*Quantitative change - qualitative immutability
→ synthesis of being and becoming
*Leucippus (fl. 450-420 BCE): basic ideas
*Democritus (ca. 460-370 BCE): The Laughing philosopher
  - detailed elaboration; infinitely many, infinitely many shapes moving in the Void
  - compare with modern atoms: not infinite in number, not indivisible, not hard
* extension to humans, emotions; liberation from fear; Lucretius