

Retrospective

Exam Tuesday, May 8, 1:30-4:30pm, here

Open book, open note, open internet

Electronic submission encouraged, blue books available.

You need to bring your own laptop with charged battery!

4 essay questions.

419 Term papers due at midnight, Thursday, May 3.

Overview

- What makes a good theory? How has the answer to this question changed with time?
- What criteria are used to test a theory? The data. The metaphysical organization of the world view (paradigm).
- What determines the historical development of science? Why wasn't the heliocentric theory developed before 1543?
- What can we know?

Ptolemy → Copernicus:

- Why did planetary motion become a problem in the 16th century? The rediscovery of Platonic and Pythagorean philosophy.
- Earth is center → Sun at center. Earth not unique
- Universe is finite → infinite (large). Vacuum
- Pragmatic (ad hoc) explanation → simple mathematics
- Possibility of universal physical law. Galilean relativity.
- Why so much empty space?
- What is the difference between the heavens and the earth?

Kepler's laws:

- The first major triumph of the mathematical paradigm.
- Elliptical motion violates Aristotle's physics, symmetry is not everything.

Aristotle → Galileo/Newton

Galileo

- Systematic, mathematical investigation of phenomena
- Natural position and motion → inertia
- Acceleration is the physically interesting quantity.
- Reality exists independent of our senses (senses can mislead)
- Cause not related to purpose. Mechanical universe.

Newton

- Universal physical law
- Laws of motion. Force. Conservation of momentum.
- Resolution of Ptolemy/Copernicus "debate" with dynamical theory
- Law of gravity. Simple description of many phenomena.

Rules of reasoning: Simplicity, uniformity, induction, empiricism.

Properties of space and time

- Translation and rotation invariance
- Symmetry simplifies problems and leads to conservation laws
- Position and velocity are relative. Acceleration is absolute.
- Substantive vs. relational idea of space and time (Mach foreshadowed)

Unresolved issues in Newtonian physics

- Why inertia?
- How does gravity work (action at a distance?)
- If space--time is absolute why can't we measure it?
- aether. A leftover from Aristotelian physics.
- fields (gravitational, electric, magnetic). Are they real?

Idealism « realism

- Infinite, eternal universe? (Olber's paradox)

Difficulties with determinism and causality

- Technical issues (chaos, equations can't be solved, can we really isolate a system from the rest of the universe?)
- Difficulty making a coherent definition of causality.

Electromagnetic waves and the aether

- Waves require a medium (or do they?)
- Maxwell's equations violate Galilean relativity → aether is required. Look for it.

Thermodynamics

- 2nd law. Order → disorder.
- Statistical mechanics. Probabilistic laws.

Emergent laws. Is the order we see because the underlying laws are simple and deterministic or because of averaging of a deeper reality? A new paradigm.

- Arrow of time?
- Difficulty defining probability in a deterministic world.
- Heat death of the universe.

Failure of searches for the ether → special relativity

- Three decades of searches (when to give up?)
- Many ad hoc theories (*e.g.*, Lorentz-Fitzgerald contraction)
- Special relativity: One simple postulate solves the problem

Relativity changes our view of reality

- No absolute time. No absolute simultaneity.
- Space and time are not as distinct as before
- Motion is more relative than before (aether is completely gone).
- Final unification of electricity and magnetism.
- The meaning of mass has changed. Energy is more fundamental. Massless objects exist.
- There is a speed limit, c . Limits causality. No action at a distance, only local laws.
- Minkowski 4-d geometrical view → general relativity.

General Relativity

Postulate of GR: All frames (even accelerating ones) are OK.

- Principle of equivalence: Inertial mass = gravitational mass
- Light is affected by gravity
- Non-euclidean (curved) geometry.
- Horizons, black holes, and singularities. (big bang)

Consequences:

- Geometry is empirical. Matter determines geometry.
- The universe can't be static.
- Gravitation radiation and boundary conditions. GR doesn't obey Mach's principle. →
Is spacetime real?
- A success in elevating "coincidences" to physical law.
- Poincare's objection. Conventionalism.
- Horizons → loss of knowledge and (maybe) determinism.

Does the Earth go around the Sun?

Quantum Mechanics

Empirical evidence

- Atomic spectra
- Black body spectrum
- Photoelectric effect
- Compton scattering.
- Electron diffraction

All objects have both particle and wave aspects (complementarity).

- Uncertainty principle (Heisenberg)
- Probability (Born). (frequentist or subjectivist?)
- Interference.
- Less determinism.
- Less reality.
- No objective, local theory (hidden variables) can reproduce QM. (Bell's inequality).

EPR experiments

- QM predicts larger correlations than hidden variable theories do.
- Correlations exist without any measurable interaction but without superluminal communication.

Schrödinger's cat experiments

- Why don't we perceive superposition? Interference.
- What constitutes measurement?
- Where is the boundary between QM and classical world?
- Is irreversibility important in measurement?

Quantum Interpretations

- Copenhagen (collapse of wave function). Observer creates reality. Microscopic (QM) objects and macroscopic (classical) apparatus. Where is the dividing line?
- Statistical interpretation. QM is just a recipe for making predictions. Extreme empiricism.
- Irreversibility. Interaction with the rest of universe seems to collapse the wavefunction.
- Bohm-deBroglie pilot wave. How does the wave control the observable part without being observable itself?
- Fatalism. We don't really have any free will.
- Mentalism. Consciousness is special.
- Many worlds. (splitting of universe). What meaning do unobservable worlds have?

What is real? What should we give up

- Local causality?
- Microscopic realism, that is macroscopic counterfactual definiteness.
- Is the wave function real? What does that mean?

What does QM say about the arrow of time? Collapse of wave function (measurement) seems to imply an asymmetry, but a symmetrical formulation can be made. (Collapse is only an interpretation, not physically observable.)

Cosmology

The universe is expanding. **Will it stop? Why is the density so close to critical?**

- Connection between density and geometry.
- Finite universe in space and time.

Evidence : Hubble expansion (age) Cosmic microwave background (universe was hot) Element abundance, Mass distribution (structure).

Questions

- What kind and how much stuff is there? Dark matter.
- Will the universe collapse?
- Why was universe so homogeneous at early times?
- Why was entropy so low at early times?

QM, SR, and the nature of the vacuum

- Virtual particles (uncertainty principle) in the vacuum.

Cosmological implications

- Symmetry restoration in early (hot) universe.
- Possibility of false vacuum.

Do physical laws uniquely determine the universe, without having to specify initial conditions?

Inflation

- Period of false vacuum → exponential expansion.
- Explains several features of universe: homogeneity, flatness, low entropy

Anthropic principle

- Our existence biases the measurements we make.
- Must the universe be such that we can (do) exist?
- Do we live in a special part of the universe?

Nature of scientific theory

What does "correctness" mean?

- Agreement with observation is important. However...
- What is observable? (time comparison?)
- Meanings of statements are often changed.
- Theory vs. interpretation.

What does "preferable" mean?

- Plausible? No
- Conservative? Sometimes
- Simple? An aesthetic judgement. Is general relativity simpler than Euclid?

What is the relationship between theory and reality?

When a law appears to be violated, what does it mean?

- It really is wrong, and we need to modify it.
- We have neglected something important.

Predictability of future experiments is sociologically the strongest way of distinguishing between various explanations.

What is the relationship between Physics and Philosophy?

- Intuitively obvious notions can be wrong!!
 - Copernicus: the earth is moving
 - Einstein: absolute time doesn't exist; space and time are unified and curved
 - Bohr-Bell: there may be no deep reality
- Rationalist/idealist approach [Plato, Aristotle, Leibnitz, Kant ...] is wrong. Dogmatic statements are often wrong. We cannot figure out the universe by thinking hard (Einstein is a counter example)
- Is philosophy reduced to semantics or history? "*The sole remaining task for philosophy is the analysis of language*" Wittgenstein. It should stay out of physics.
- Philosophy is a critical observer of science to clarify fundamental aspects. Physics is the best science to study the scientific process because there are many well-tested theories.
- What has physics contributed to our understanding?
 - New models and paradigms of thinking about the world (2 sphere model, mechanism, statistical mechanics, quantum mechanics, relativity, big bang model ...)
 - We have several extremely good models: quantum mechanics, electron-magnetism,... Does this mean that they are real?
 - Many famous physicists have raised philosophical questions [Newton, Mach, Einstein, Bohr, Feynman, Hawking ...]
- How does physics fit into our understanding of the world around us: all fields depend to some extent on our interaction with the world and our hidden assumptions.

Kuhn's Postscript

The Structure of Scientific Revolutions

Compared with the notion both philosophers of science and laymen, however, this position lacks an essential element. A scientific theory is usually felt to be better than its predecessors not only in the sense that it is a better instrument for discovering and solving puzzles but also because it is somehow a better representation of what nature is really like. One often hears that successive theories grow ever closer to, or approximate more and more closely to, the truth. Apparently generalizations like that refer not to the puzzle-solutions and the concrete predictions derived from a theory but rather to its ontology, to the match, that is, between the entities with which the theory populates nature and what is “really there.” Perhaps there is some other way of salvaging the notion of ‘truth’ for application to whole theories, but this one will not do. There is, I think, no theory-independent way to reconstruct phrases like ‘really there’; the notion of a match between the ontology of a theory and its “real” counterpart in nature now seems to me illusive in principle. Besides, as a historian, I am impressed with the implausability of the view. I do not doubt, for example, that Newton’s mechanics improves on Aristotle’s and that Einstein’s improves on Newton’s as instruments for puzzle-solving. But I can see in their succession no coherent direction of ontological development. On the contrary, in some important respects, though by no means in all, Einstein’s general theory of relativity is closer to Aristotle’s than either of them is to Newton’s.

Kuhn's Postscript

5. Exemplars, Incommensurability, and Revolutions

....I have argued that the parties to such debates inevitably see differently certain of the experimental or observational situations to which both have recourse. Since the vocabularies in which they discuss such situations consist, however, predominantly of the same terms, they must be attaching some of those terms to nature differently, and their communication is inevitably only partial. As a result, the superiority of one theory to another is something that cannot be proved in the debate.

Debates over theory-choice cannot be cast in a form that fully resembles logical or mathematical proof. In the latter, premises and rules of inference are stipulated from the start. If there is disagreement about conclusions, the parties to the ensuing debate can retrace their steps one by one, checking each against prior stipulation. At the end of that process one or the other must concede that he has made a mistake, violated a previously accepted rule. After that concession he has no recourse, and his opponent's proof is then compelling. Only if the two discover instead that they differ about the meaning or application of stipulated rules, that their prior agreement provides no sufficient basis for proof, does the debate continue in the form it inevitably takes during scientific revolutions. That debate is about premises, and its recourse is to persuasion as a prelude to the possibility of proof. Nothing about that relatively familiar thesis implies either that there are no good reasons for being persuaded or that those reasons are not ultimately decisive for the group. Nor does it even imply that the reasons for choice are different from those usually listed by philosophers of science: accuracy, simplicity, fruitfulness, and the like.