

# Physics/Philosophy 419/420

## Space, Time, and Matter

Catalog description: A philosophical examination of some fundamental concepts and theories of the physical world, such as time, matter, causation, space, and geometry; interpretation of quantum theory.

### Natural Philosophy's traditional questions:

- Is there a human theme to the universe? (not central to the course)
- Is the universe mathematically comprehensible?

### Some themes of this course:

- Why does math work? To what extent should we expect mathematical constructs to represent real objects?
- How do we decide what is real?
- How much can we know?
- Is all knowledge (e.g. geometry & logic) empirical?
- To what extent is causation a meaningful idea?

# Philosophy and Science

"A more contemporary view is that philosophy's role is to serve, not as some ground for the sciences or as some extension of them, but as their critical observer. The idea here is that the particular scientific disciplines use concepts and methods. The relationships of the concepts to one another, although implicit in their use in science, may fail to be explicitly clear to us. It would then be the job of philosophy of science to clarify these conceptual relationships."

*Sklar, Philosophy of Physics, p. 2*

# Thematic organization

What, if anything, do these questions mean?	<u>Philosophy:</u>	How can we test the answers?
	<u>Physics:</u> <ul style="list-style-type: none"><li>• What is the geometry of space-time?</li><li>• What is determined and what is chance?</li><li>• What are things made of?</li></ul>	
How have these questions and their answers developed historically?	Who are we to ask?	What are the implications for the theory of knowledge?

# Organization

## People:

Lecturer: David Ceperley, 2-107ESB, [ceperley@illinois.edu](mailto:ceperley@illinois.edu),

TAs: Charles Byrne, Apoorv Tiwari

See the web page for more information

## Course structure:

**Lectures.** Twice per week. Most lectures will be structured around questions, not around fixed material for you to ingest. I will **not** lecture for the entire time. We will have discussions- either initiated by my questions or by yours. Lecture notes will be posted on Web shortly AFTER lecture, so as not to spoil discussion of those questions which have answers. Posted notes will not include all material from the lecture.

# Grade Components

- Homework. About six weekly essays (500-750 words). Homework will contribute 40% of 419 grade, 62% for 420.
- Term paper. 2500-4000 words on a topic of your choice. The sequence of deadlines is described on the web. The term paper is 35% of the 419 grade.
- Final exam. The exam gives 20% of the 419 grade, 30% for 420.
- In class quizzes make up the remainder of the grade.
- **Extra credit will be given for participation in class discussions for students whose grade is on a borderline.**

# Books

General: These books come close to providing a text. Sklar is most complete but quite dry. Rohrlich is most accessible, but downplays the interesting problems of quantum interpretations.

- *Philosophy of Physics*, by L. Sklar
- *Philosophical Concepts in Physics*, by J.T. Cushing
- *From Paradox to Reality*, by F. Rohrlich

## Recommended:

- *The Copernican Revolution*, by T. S. Kuhn (gives a feel for how one major change in physical outlook occurred).
- *Relativity: the Special and General Theory*, by A. Einstein. (a very accessible introduction to relativity).
- *The Mystery of the Quantum World*, by E. Squires (a fair-minded, up-to-date account of why QM is troubling and the various ways in which one might cope with it).
- *A Brief History of Time*, by S. W. Hawking (hits many of the high points of modern physics in a lively fashion).
- *The Character of Physical Law*, by R. P. Feynman (a set of brief, entertaining lectures that give a feel for how the basic principles look to a thoughtful working physicist).

# Class Survey

## Background and views

Major: science\_\_ (physics\_\_ ) philosophy\_\_ others \_\_

Had special relativity? Y\_\_ N\_\_

Had any quantum mechanics? Y\_\_ N\_\_

Want from 419:

history/methods of knowing\_\_ strange facts\_\_ basic constituents\_\_

Approximate age of universe? (in years)

0- $10^6$  \_\_  $10^6$ - $10^8$  \_\_  $10^8$ - $10^9$  \_\_  $10^9$ - $10^{11}$  \_\_

Approximate age of life on earth? (in years)

0- $10^6$  \_\_  $10^6$ - $10^8$  \_\_  $10^8$ - $10^9$  \_\_  $10^9$ - $10^{11}$  \_\_

Does mind have a non-physical constituent?

Y\_\_ N\_\_ M\_\_

Is there objective reality?

Y\_\_ N\_\_ M\_\_

Is the universe deterministic?

Y\_\_ N\_\_ M\_\_

Does newer science become more correct?

Y\_\_ N\_\_ M\_\_

Does  $c=2\pi r$ ? (for a circle)

Y\_\_ N\_\_ M\_\_

# Syllabus

See the schedule for detail

- The Aristotelian-Ptolemaic picture of the Universe, and the Copernican revolution.
- The birth of modern mechanics and the philosophical problems raised by it. Action at a distance and the idea of a field. The relation between observation and theory. The role of mathematics. Classical causality and chance.
- The theory of electromagnetism and the ether; the conflict between mechanics and electrodynamics. The special theory of relativity and the reality of space-time.
- General relativity: the new geometry. Philosophical implications.
- Quantum mechanics. "The world is stranger than we can imagine." The apparent death of simple causal, local views. Exploration of meaning of uncertainty principle, relation between theory and observations, attempts at interpretation and/or modification of theory.
- Irreversibility and the "arrows of time."
- Cosmology, beginning and end of time, dark matter and energy.
- Other topics (e.g. grand unification, trends in philosophy of science, quantum computing). **Let me know.**



# Beware of Obvious Arguments!

Some obviously true facts about the physical world (and when they ceased to be obvious):

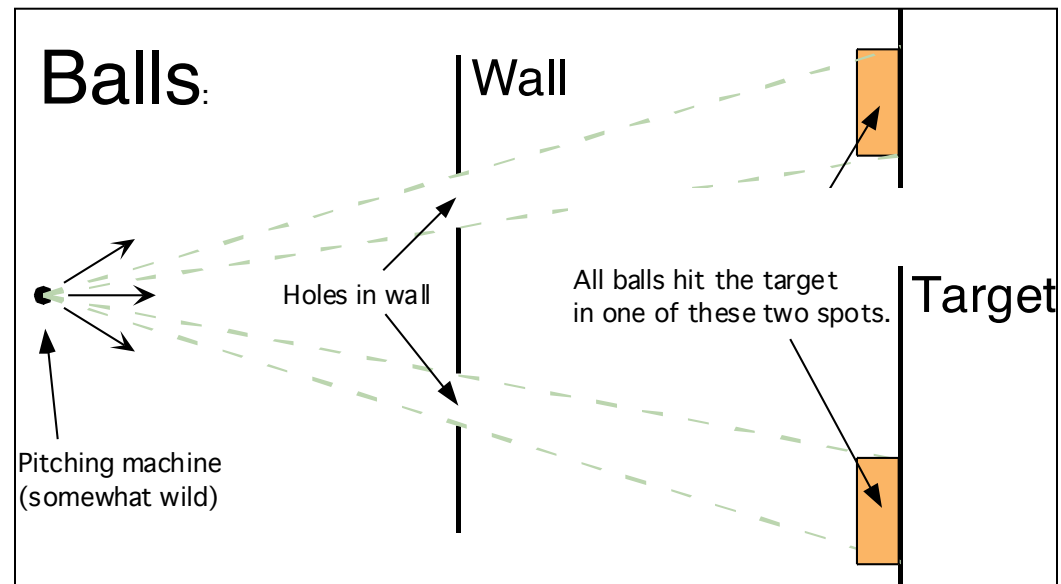
- The Sun goes around the Earth. (Aristarchus, ~250 BC, Copernicus, 1543)
- Bodies on which no forces act come to rest. (Galileo, 1632; Descartes, ~1640)
- For any two events, one of them happens first or they're simultaneous. (Einstein, 1905)
- The outcome of any experiment with completely controlled initial conditions is, in principle, predetermined. (Heisenberg, 1926)
- The universe overall is static. (Hubble, 1933)
- Nature cannot tell left from right. (Lee and Yang, 1956)
- Every spatially separate piece of the world can be described in its own right. (Aspect, 1982)

# Preview: a 'thought experiment'

*The Character of Physical Law* R. P. Feynman Chapter 6

Compare the behavior of balls passing through holes in a wall with waves passing through the same holes

- The balls follow predictable trajectories (straight lines, if no forces are acting) from the source to the target.
- Each ball goes through one hole or the other, not both.
- Each ball hits the target at a localized spot in space and time.



- *The flow through two holes is exactly the sum of the flows through each hole separately (so long as they don't bump into each other)*

# Preview: How about waves?

- Waves don't follow trajectories. They are inherently "spread out" in space.

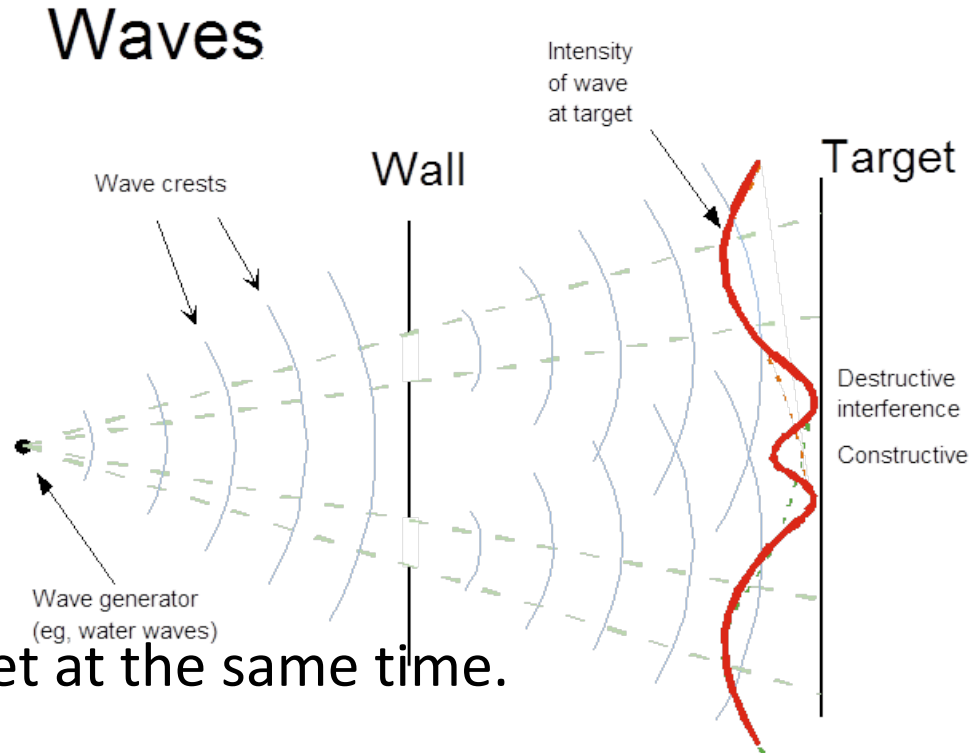
- The wave goes through both holes, not just one.

- The waves don't hit the target at localized spots or times.

They hit different parts of the target at the same time.

- Waves interfere with each other.

***The result (measured as rate of energy input) of the combination of two waves might be larger, smaller, or the same as the sum of the two waves separately.***



# How do electrons behave?

## As particles or as waves?

- They hit the target at localized spots and times, just like the balls.
- But the rate at which they hit some region is NOT the sum of the rates through the two separate holes!
  - and the way in which the rates vary from place to place looks exactly like the interference pattern of a wave!
- So if the electron goes through BOTH holes (needed for interference), you should be able to look and see it go through both.
  - But when you look (say with light) you see electrons go through either hole but not both at once.
  - And the interference pattern disappears!

# Is that inconsistent?

- An electron seen to go through just one hole does not interfere with the nothing that went through the other hole.
- When interference is seen, there is no direct evidence that the electron did not go through both holes.
- But which type of behavior it shows depends on whether you measure its passage through the holes.
- So it's consistent, but strange.

It seems (for now) that whether an electron behaves like a particle or like a wave depends on how closely it is examined!

# First probes of this puzzle.

- You might imagine looking more gently-say with a dimmer light. You see some electrons go through just one hole- and they show no interference. Other electrons seem to sneak through without affecting the light. They show interference!
  - So you've just shown that you can mix the two types of behavior, not reconcile them.
- You might try using a different color light. It turns out if you use very long-wavelength light, you still can see it bounce off the electrons, and the interference pattern does survive.
  - But the light is so long-wavelength that it gives too fuzzy an image to let you see which hole the electron went through.
- This is one of several conspiracies of nature against common sense. We'll return to this issue later in the course.
  - The common phrase “wave-particle duality” will be neither necessary nor sufficient to cope with such effects.
  - Something much more revolutionary is required.

# Coming Up

- Next we'll begin to discuss the conceptual revolutions wrought by Copernicus, Kepler, Galileo, ....
  - Readings for Thursday: (reading assignments listed on the web)
    - Rohrlich, ch. 1-4
    - Sklar, pp. 1-18
    - Cushing ch. 4
- Homework for Friday Jan. 19: (homework assignments are on the web)
  - **Does the Earth go around the Sun or does the Sun go around the Earth? How do you know? Give some evidence to support your argument.**
  - Because this is the first assignment (and very rushed!), you do not need to cite reading material. If you remember an argument but cannot recall where you saw it, use it anyway. Later in the course, you will be expected to cite sources for information, and give credit for other's arguments.
  - At most 750 words.
  - Read the homework guidelines, on the homework page. They will give you an idea how to structure your essays.