We will focus on the following problem. How can we explain the temporal asymmetries we experience in everyday life—coffee cools and ice melts, not the reverse; light appears in a room after we flip the switch, not before; we have memories of the past and not the future; we can causally affect the future but not the past—if the underlying laws of physics are symmetric in time, allowing for the time-reversed behavior we never see? Might there be a unified explanation for all these asymmetries? Answering these questions will require looking into the foundations of classical mechanics, statistical mechanics, thermodynamics, electromagnetism, and cosmology. We will also discuss the problem in the context of quantum mechanics.

This problem touches on questions in a variety of areas of philosophy, including philosophy of physics, philosophy of science, and metaphysics. Some of the philosophical issues to be discussed include: What are probabilities in physics? What is a good scientific explanation? What is the relationship between the picture of the world given to us by physics and the one given in ordinary experience? What is the relationship between physics and other sciences? Readings will be drawn from philosophy and physics.

*Note:* this class can be used to count toward the philosophy major or minor.

**Readings**
Required book, available at the bookstore and on reserve at the Alexander Library undergraduate circulation desk:

David Albert, *Time and Chance*

Optional books (at the bookstore and on reserve at Alexander):

Sean Carroll, *From Eternity to Here*  
*The Feynman Lectures on Physics, Volume 1*

All other readings are available at the course website, address given out in class.

**Prerequisites**
A solid high school physics class. Exposure to basic concepts of calculus is helpful, though not required.
Requirements and grading

Attendance and participation; weekly reading; problem sets. Attendance is mandatory. Note that if you miss a class it is your responsibility to get notes and announcements from a classmate. Participation is encouraged. A few problem sets will be given throughout the semester for practice with the physics. These will not involve quantitative reasoning but will focus on physical concepts. Problem sets, participation, and attendance count for 20% of your final grade.

Optional readings: I will not assume that you have read these. They provide either further background information or more advanced discussion.

Exams. Two 5-8 page take-home exams consisting of short-essay questions (each answer 1-2 pages). Each exam counts for 40% of your final grade.

Academic integrity

Each student in this course is expected to abide by the Rutgers University Principles of Academic Integrity. Any work submitted by a student in this course for academic credit will be the student’s own work. For this course, collaboration is allowed in discussing paper topics and exam questions. Papers and exams submitted for credit must be entirely your own work. If you quote or use an idea from another source, you must cite it. More information on Rutgers’ Principles of Academic Integrity is here: http://academicintegrity.rutgers.edu

Course materials posted on the course website or handed out in hard copy are intellectual property belonging to the author. Students are not permitted to buy or sell any course materials without the express permission of the instructor. Such unauthorized behavior constitutes academic misconduct.

Contact details

Office: room 530, Philosophy Department, 106 Somerset St.
Office hours: Friday 9–10am or by appointment

Schedule

Details are subject to change during the semester. Readings are listed by the date on which they will be discussed. We will discuss whether to schedule a make-up class at the end of the term.

January 25: Introduction

Introduction to philosophy of physics and the problem of the direction of time. Symmetry of the fundamental laws, asymmetry of macroscopic phenomena. Asymmetries in the phenomena vs. the asymmetry of time.
Reading: Greene, “Chance and the Arrow” through the middle of p. 8; Price, “The View from Nowhen”

Optional (overviews of issues we will discuss throughout the semester):

February 1: No Class

February 8: Time reversal invariance and instantaneous velocities
Overview of Newton’s laws of motion and gravitation. Atomic hypothesis; energy conservation; determinism. Symmetries in general, time reversal symmetry in particular. Zeno’s arrow paradox and replies; the existence and definition of instantaneous velocity. What is it for a theory to be symmetric in time? Which theories are time reversal symmetric? What might the time reversal symmetry of a theory tell us about the structure of time itself?

Problem set 1 handed out in class; due in class February 15.

Reading: Albert ch. 1; Arntzenius, “Are There Really Instantaneous Velocities?” secs. 1–4

Optional: Feynman 1.2, chs. 7–10; notes on calculus

February 15: Newtonian determinism and time reversal symmetry
Is Newtonian mechanics both deterministic and time-reversal invariant as ordinarily thought? Arguments that it is not. Space invaders and Norton’s dome; time reversal symmetry; idealizations in physics; Newtonian systems. Friction and dissipative forces; conservation of energy and other conservation laws.

Problem set 1 due in class.


February 22: Time reversal and indeterministic theories
What it is for an indeterministic theory to be symmetric under time reversal, and what does this tell us about time itself? Is there a difference from the deterministic case? Do chances themselves develop asymmetrically in time?

Reading: Arntzenius, “Indeterminism and the Direction of Time” secs. 1–2 and “Mirrors and the Direction of Time” secs. 1–2

Optional: North, “Two Views on Time Reversal”

March 1 and March 8: Thermodynamics and statistical mechanics
Overview of thermodynamics and statistical mechanics. The second law of thermodynamics; entropy; Maxwell’s demon; phase space; probability in statistical mechanics. The relationship between thermodynamics and statistical mechanics.

Problem set 2 handed out in class March 1; due in class March 15.
Reading: Albert ch. 2 and ch. 3
Optional: Feynman chs. 39, 44, 46

March 15: The past hypothesis
Can classical statistical mechanics account for the asymmetry of thermodynamics? The reversibility objections and the past hypothesis. Big bang cosmology; gravity and entropy.

Problem set 2 due in class.
Reading: Albert ch. 4; Feynman, ch. 5 of The Character of Physical Law; Greene, “Chance and the Arrow” pp. 8–18

March 29: Objections to the past hypothesis
Objections to the past hypothesis account of thermodynamics. The multiverse and baby universes; Boltzmann’s brains; explaining initial conditions; probabilistic reasoning.

Optional: Earman, “The Past Hypothesis’: Not Even False”

April 5: No Class

April 12: The wave asymmetry
If we drop a pebble in a pond, we see waves ripple outwards to the edge of the pond after we drop the pebble, not before. We see light appear in a room after
we flip the switch, not before. In general, waves diverge from their sources; we don’t see waves converge on their sources. How can we explain this asymmetry if the laws governing waves are symmetric in time? Is there a similar explanation available to that of the other observed asymmetries?

**Reading:** Frisch, “(Dis-)Solving the Puzzle of the Arrow of Radiation”; North, “Understanding the Time-Asymmetry of Radiation”

**Optional:** Feynman chs. 28-29; Frisch, “A Tale of Two Arrows”

April 19: **Quantum mechanics**

Does quantum mechanics make a difference to the explanation of thermodynamics? Overview of quantum mechanics and Albert’s argument that it does.

- **Problem set 3 handed out in class; due in class April 26.**
- **Reading:** Albert ch. 7
- **Optional:** Price, “Boltzmann’s Time Bomb”; North, “What is the Problem about the Time-Asymmetry of Thermodynamics?—A Reply to Price”

April 26: **The asymmetries of knowledge and intervention**

If I were to do something different now, the future, but not the past, would be different. How can we explain the fact that the future counterfactually depends on the past, and not vice versa? How can we explain the fact that we have knowledge of the past and not the future, and that we can generally affect things in the future but not the past? Can we account for these in a similar way to the other asymmetries? Can Albert’s version of statistical mechanics explain all the macroscopic asymmetries we have considered? If so, then what is the status of this statistical mechanics as a scientific theory, and how does it relate to other scientific theories?

- **Problem set 3 due in class.**
- **Reading:** Albert ch. 6
- **Optional:** Lewis, “Counterfactual Dependence and Time’s Arrow” with postscripts; Elga, “Statistical Mechanics and the Asymmetry of Counterfactual Dependence”

May 3: This will either be a catch-up day or we will discuss a topic of your choosing. Possibilities include the passage of time; Maxwell’s demon; the status of statistical mechanics as a science; the nature of probability in statistical mechanics.