PHILOSOPHY 426, PHILOSOPHY OF PHYSICS: THE DIRECTION OF TIME
Spring 2020
T 1:10pm–4:10pm, 115 Scott Hall
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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 laws of physics are symmetric in time, allowing for the reversed behavior we never see? Might there be a unified explanation for all these asymmetries, and if so, what does this say about the status of physics as a science and the nature of time itself? Answering these questions will require looking into the foundations of classical mechanics, statistical mechanics, thermodynamics, electromagnetism, and cosmology. Some of the philosophical issues to be discussed: 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 by ordinary experience? What is the relationship between physics and other sciences?

READINGS
Required book (available at the bookstore and on reserve at the Alexander Library undergraduate circulation desk): David Albert, *Time and Chance*
All other required readings are available on the Canvas course site. Optional readings are genuinely optional, providing either additional background or more advanced discussion.

PREREQUISITES
At least a solid high school physics class.

REQUIREMENTS AND GRADING
Attendance and participation; weekly reading. Participation and attendance count for 20% of your final grade. Attendance is mandatory. Note that if you miss a class it is *your responsibility* to get notes and announcements from a classmate. Weekly readings may not be very long, but they can be difficult. It is recommended that you read each assignment once before class meets and again afterward.
Exams. Two take-home exams comprising short-essay questions. Each exam counts for 40% of your final grade.

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 questions on problem sets and exams. Problem sets 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.

OFFICE HOURS

Friday 9:30-10:30am by Skype or by appointment at another time; email me in advance to set up a meeting.

SCHEDULE

Details are subject to change during the semester. Readings are listed by the date on which they will be discussed.

January 21: INTRODUCTION

Introduction to the 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 itself.

Reading: Greene, "Chance and the Arrow" through the middle of p. 8; Loewer, "Philosophy of Physics"; Price, "The View from Nowhen"

Optional: Callender, "Thermodynamic Asymmetry in Time," available at `http://plato.stanford.edu/entries/time-thermo/`; North, "Time in Thermodynamics"

January 28: TIME REVERSAL INVARIANCE AND INSTANTANEOUS VELOCITIES

Newton's laws of motion and gravitation. The atomic hypothesis; conservation principles; 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 nature of time itself?

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

Optional: North, "Two Views on Time Reversal"

February 4: TIME REVERSAL AND INDETERMINISTIC THEORIES

What it is for an indeterministic theory to be symmetric under time reversal and what might this tell us about the structure of time? Is there a difference from the deterministic case?

Reading: Arntzenius, "Indeterminism and the Direction of Time" (skip the parts involving quantum mechanics); "Mirrors and the Direction of Time" secs. 1–2

February 11: DETERMINISM AND TIME REVERSAL SYMMETRY

Is Newtonian mechanics really deterministic and time-reversal invariant? 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.

Reading: Section 4.1 of Hoefer, "Causal Determinism," available at
`https://plato.stanford.edu/entries/determinism-causal/`;
Hutchison, "Is Classical Mechanics Really Time-Reversible and Deterministic?"; Norton, "The Dome: An Unexpectedly Simple Failure of Determinism"

Optional: Malament, "Norton's Slippery Slope"; Wilson, "Determinism and the Mystery of the Missing Physics"

February 18 and 25: 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.

Reading: Albert ch. 2 and ch. 3

March 3: THE PAST HYPOTHESIS
Midterm exam handed out in class; due in class March 10.

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

Reading: Albert ch. 4; Feynman, "The Distinction of Past and Future"; Greene, "Chance and the Arrow" pp. 8-18

Optional: Price, "'More Apt to Be Lost than Got': The Lessons of the Second Law"

March 10: OBJECTIONS TO THE PAST HYPOTHESIS

Midterm exam due in class.
Objections to the past hypothesis account of thermodynamics. The multiverse and baby universes; Boltzmann brains; explaining initial conditions; probabilistic reasoning.

Reading: Carroll, excerpts from *From Eternity to Here*

Optional: Earman, "'The Past Hypothesis': Not Even False"

NOTE: Classes below will be conducted live via Webex during the regularly scheduled meeting times. The link to the meeting site is in an announcement on Canvas. The class meeting will take the first two hours of the regularly scheduled period; the last hour will be optional, left open for additional discussion or one-on-one meetings as needed.

March 24: 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 only after we flip the switch. 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: Sec. 5 of Frisch, "(Dis-)Solving the Puzzle of the Arrow of Radiation"; North, "Understanding the Time-Asymmetry of Radiation"

Optional: Frisch, "A Tale of Two Arrows"

March 31 and April 7: COUNTERFACTUAL ASYMMETRY

How can we explain the fact that the future counterfactually depends on the past and not vice versa?

Reading: Lewis, "Counterfactual Dependence and Time's Arrow" (without post-scripts); Elga, "Statistical Mechanics and the Asymmetry of Counterfactual Dependence"
Optional: Post-scripts to Lewis

April 14: ASYMMETRIES OF KNOWLEDGE AND INTERVENTION

How can we explain the fact that we have knowledge of the past and not the future, and that we can affect things in the future but not the past? Can we account for these in a similar way to the other asymmetries?
Reading: Albert ch. 6
Optional: Albert, "The Difference between the Past and the Future"; Loewer, "Counterfactuals and the Second Law"

April 21: QUANTUM MECHANICS

Does quantum mechanics make a difference to the explanation of thermodynamics? Overview of quantum mechanics and Albert's argument that it does.
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 28: QUANTUM MECHANICS (CONTINUED); OPEN DISCUSSION

Final exam handed out; due by email by the end of the day May 8.
Continue discussing last week's reading; then open discussion on any material from the semester in preparation for the final exam.

STUDENT WELLNESS SERVICES

Just In Case Web App. http://codu.co/cee05e. Access helpful mental health information and resources for yourself or a friend in a mental health crisis on your smartphone or tablet and easily contact CAPS or RUPD.

Counseling, ADAP & Psychiatric Services. (848) 932-7884, 17 Senior Street, New Brunswick, NJ 08901, www.rhscaps.rutgers.edu/. CAPS is a University mental health support service that includes counseling, alcohol and other drug assistance, and psychiatric services staffed by a team of professional within Rutgers Health services to support students' efforts to succeed at Rutgers University. CAPS offers a variety of services that include: individual ther-

apy, group therapy and workshops, crisis intervention, referral to specialists in the community and consultation and collaboration with campus partners.

Violence Prevention & Victim Assistance. (848) 932-1181, 3 Bartlett Street, New Brunswick, NJ 08901, `www.vpva.rutgers.edu/`. The Office for Violence Prevention and Victim Assistance provides confidential crisis intervention, counseling and advocacy for victims of sexual and relationship violence and stalking to students, staff and faculty. To reach staff during office hours when the university is open or to reach an advocate after hours, call 848-932-1181.

Disability Services. (848) 445-6800, `https://ods.rutgers.edu/`, Lucy Stone Hall, Suite A145, Livingston Campus, 54 Joyce Kilmer Avenue, Piscataway, NJ 08854. Rutgers University welcomes students with disabilities into all of the University's educational programs. In order to receive consideration for reasonable accommodations, a student with a disability must contact the appropriate disability services office at the campus where you are officially enrolled, participate in an intake interview, and provide documentation: `https://ods.rutgers.edu/students/documentation-guidelines`.

If the documentation supports your request for reasonable accommodations, your campus' disability services office will provide you with a Letter of Accommodations. Please share this letter with your instructors and discuss the accommodations with them as early in your courses as possible. To begin this process, please complete the Registration form on the ODS web site at: `https://ods.rutgers.edu/students/registration-form`.

Scarlet Listeners. (732) 247-5555, `http://www.scarletlisteners.com/`. Free and confidential peer counseling and referral hotline, providing a comforting and supportive safe space.