PHYS 4058

Information Physics

Fall 2024-25

Venue	L1:	Tue & Thu 15:00–16:20	Room CYT G009B
	T1:	Tue 17:30–18:20	Room 4504

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Office hours By appointment

You are welcome to come to my office at any time. I may be busy, but we can always set up an appointment to meet later.

Prerequisite PHYS 3031 (Mathematical Methods in Physics II) or
PHYS 4050 (Thermodynamics and Statistical Physics)

Course Description

This course explores the connections between information theory and physics. Information theory was developed by Shannon in the 1940s as a tool for optimizing communication systems in telephone networks. But how is the concept of entropy used by communications engineers related to that introduced a century earlier in thermodynamics and statistical mechanics? And what does information theory tell us about the physical limits of computation? Topics studied include communication systems, signal and linear system analysis, probability and random variables, discrete information sources, information and entropy, joint and conditional entropy, relative entropy and mutual information, capacity of a noiseless channel, source coding, capacity of a noisy channel, Bayesian probability, maximum entropy and thermodynamics, and Maxwell's demon.

Intended Learning Outcomes

By the end of this course, students should be able to:

1. Define and explain the concepts of information and entropy relevant for communications engineering.
2. Use these concepts to solve basic problems in communication theory, including optimizing the capacity of noiseless and noisy channels.
3. Apply the concept of maximum entropy to derive the basic equations of thermodynamics.
4. Explain how the concept of entropy as a measure of information in communication networks is related to the definition of entropy in terms of heat and temperature in thermodynamics.
5. Analyze the fundamental physical limits on classical computation using the thought experiment of Maxwell's demon.

Textbook

No required textbook

Reference books

C. E. Shannon, "A Mathematical Theory of Communication," *Bell System Technical Journal* **27**, 379–423 and 623–656 (1948).

C. E. Shannon and W. Weaver, *The Mathematical Theory of Communication* (University of Illinois Press, Urbana, 1949).

R. E. Ziemer and W. H. Tranter, *Principles of Communications: Systems, Modulation, and Noise*, 7^{th} ed. (Wiley, Hoboken, NJ, 2015).

J. R. Pierce, *An Introduction to Information Theory: Symbols, Signals and Noise*, 2^{nd} ed. (Dover, New York, 1980).

D. S. Jones, *Elementary Information Theory* (Clarendon, Oxford, 1979).

L. Brillouin, *Science and Information Theory*, 2^{nd} ed. (Academic, New York, 1962).

J. C. A. van der Lubbe, *Information Theory* (Cambridge University Press, Cambridge, 1997).

T. M. Cover and J. A. Thomas, *Elements of Information Theory*, 2^{nd} ed. (Wiley, Hoboken, NJ, 2006).

R. G. Gallager, *Information Theory and Reliable Communication* (Wiley, New York, 1968).

M. A. Nielsen and I. L. Chuang, *Quantum Computation and Quantum Information* (Cambridge University Press, Cambridge, 2000).

E. T. Jaynes, *Papers on Probability, Statistics and Statistical Physics*, ed. R. D. Rosenkrantz (Kluwer, Dordrecht, 1989).

E. T. Jaynes, *Probability Theory: The Logic of Science*, ed. G. L. Bretthorst (Cambridge University, Cambridge, 2003).

H. S. Leff and A. F. Rex, *Maxwell's Demon 2* (IOP Press, Bristol, 2003).

Course Information

All course announcements, assignments, and other course materials will be posted at the PHYS 4058 site on Canvas (https://canvas.ust.hk/).

If you have any questions or comments, you are encouraged to discuss them with me, the TA, and your classmates in the Discussion forum on Canvas.

Assessment and Grading

This course will be assessed using criterion referencing and grades will not be assigned using a curve. Detailed rubrics for each assessment task will be provided separately, outlining the criteria used for evaluation.

Category	Contribution to Course Grade
Online Discussion	10%
Participation	10%
Quizzes	20%
Midterm Exam	25%
Final Exam	35%

Homework assignments will be given out but not graded. The purpose is to give you experience solving problems similar to those on the quizzes and exams.

Quizzes will be held approximately once every two weeks in the tutorials. Participation in tutorial and classroom exercises will also be included.

The midterm exam will be held on Thursday 24 October 2024 during the regular lecture hours.

Final Grade Descriptors

Grades	Short Description	Elaboration on subject grading description
A	Excellent Performance	Demonstrates a comprehensive grasp of information theory and its connections to physics. Exhibits expertise in problem-solving and can explain fundamental concepts clearly at a deep level.
B	Good Performance	Shows good knowledge and understanding of information theory and its connections to physics. Exhibits competence in problem-solving and can explain fundamental concepts thoroughly.
C	Satisfactory Performance	Possesses adequate knowledge of information theory and its connections to physics. Exhibits competence in dealing with familiar problems and can explain most fundamental concepts at a basic level.
D	Marginal Pass	Has threshold knowledge of the core subject matter and limited problem-solving ability. Limited ability to explain fundamental concepts at the most elementary level.
F	Fail	Demonstrates insufficient understanding of the subject matter and lacks the necessary problem-solving skills.

Communication and Feedback

Assessment marks for individual assessed tasks will be communicated via Canvas within ten working days of the due date (i.e., within two weeks if there are no holidays). Feedback on assignments will include comments on strengths and areas for improvement. Students who have further questions about the feedback including marks should consult the TA or instructor within five working days after the feedback is received.

AI Policy

You are welcome to use generative AI tools such as ChatGPT during the learning process, although you should bear in mind that they often give wrong answers to physics questions. Asking questions in this way about the homework problems will be treated the same as discussing homework problems with your classmates. It is allowed, but you should apply some critical thinking to the answers you receive. You will be better off if you try as hard as you can to solve the homework problems without any help, because this will give you much better preparation for the quizzes and exams. In the quizzes and exams, you will be required to solve problems without any help from other people or from generative AI tools.

Classroom Discussion

I like to encourage a lively public discussion and debate in my lectures. If there is anything in the lectures that you don't understand, or if you have any questions or comments at any time, please don't hesitate to raise your hand and ask me. In fact, if you contribute to the discussion you will be awarded **bonus points**, which will be added to your grade at the end of the semester and may **increase your grade** by as much as 5%. You will *never* be penalized for asking questions (or for not asking questions); the only possible effect is to *increase* your grade. Extra points will be awarded for anyone who finds a mistake in my lecture material and tells me about it during the lecture.

Online Discussion

Ten percent of your grade will be determined by your level of participation in the online Discussion forum in Canvas. You can get up to 10% just by posting one nontrivial[1] question, comment, or answer every week in the forum. The actual amount depends on the level of your contribution, with more credit awarded for substantial contributions. If you post more than once per week, a maximum of one additional post can be carried over and used in other weeks.

If the forum is running as intended, most questions should be answered by your fellow students. The TA and course instructor will only intervene when a wrong answer seems to be accepted or when no students are able to provide a complete answer. The Discussion forum should be used to discuss questions that arise as you are trying to understand the course materials, not to seek (or give) help on solving the homework problems. Of course, questions are likely to arise as you are trying to solve the homework problems, but you should formulate your question in terms of general concepts rather than the details of a particular problem.

The purpose of the discussion forum is to have people talking to each other about questions that are of interest to them, not to have ChatGPT talking to itself about questions that are of interest to no one. Therefore, credit will not be awarded for questions or answers that show obvious signs of being generated by AI. One obvious sign is a long perfectly written essay that introduces lots of ideas we have not talked about in lecture without any definitions. Another is that both questions and answers tend to be very boring.

If you introduce any new concepts that we have not talked about previously, you must define everything clearly so that other students can understand. You must also cite any sources you used to find the information presented in your post, whether it is an AI tool, a web page, a journal article, or a book. Presenting ideas of others as if they were your own is called plagiarism, which is a violation of academic integrity.

[1] Nontrivial means, in part, that the question or comment should be about physics, not about how the course is run.

Academic Integrity

In this course, you are expected to adhere to the university's academic integrity policy. You are also expected to uphold HKUST's Academic Honor Code and to maintain the highest standards of academic integrity. The University has zero tolerance of academic misconduct. Please refer to Academic Integrity | HKUST – Academic Registry for the University's definition of plagiarism and ways to avoid cheating and plagiarism.