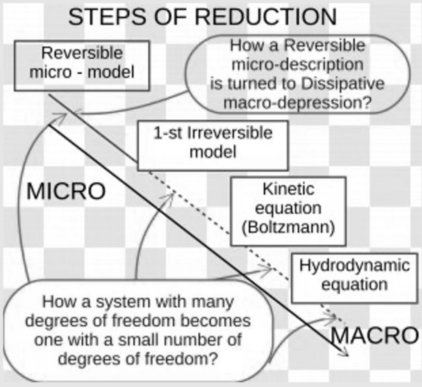
(Complementary)
Statistical Physics



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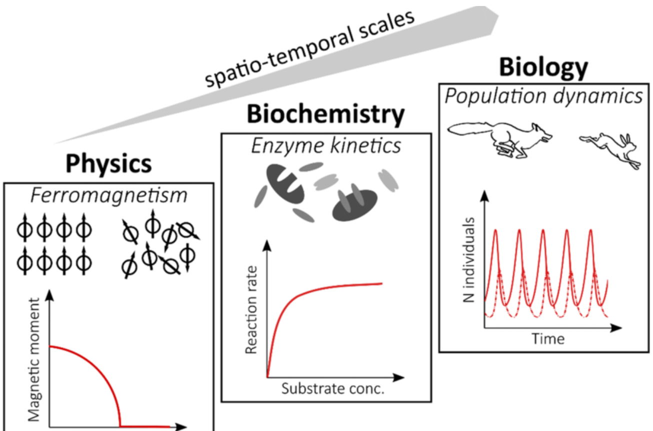
Emergence over the length scales



Mathematical laws for emergent behaviours

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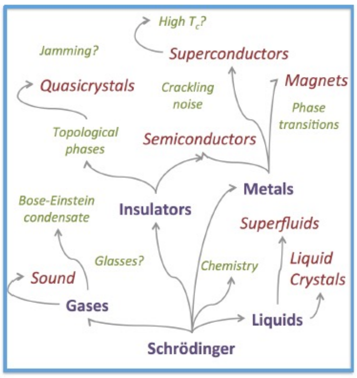

ig. 1.2 **Emergent.** New laws describing macro-
opic materials emerge from complicated microscopic
ehavior [47].

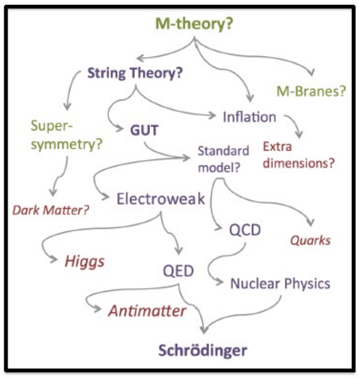

Fig. 1.3 Fundamental. Laws describing physics at lower energy emerge from more fundamental laws at higher energy [47].

Emergence of the physical laws

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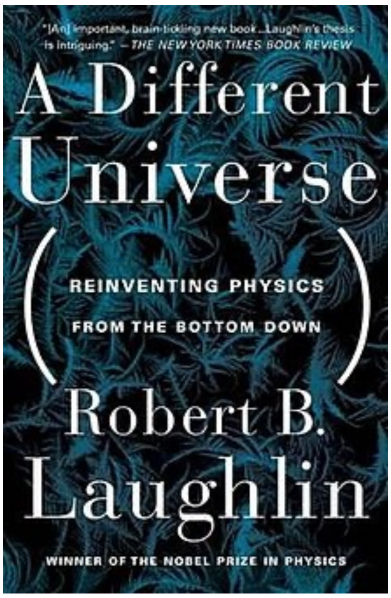

The book emphasizes the study of macroscopic phenomena, sometimes called emergence, over the ever-downward dive into theoretically fundamental ideas such as string theory, which at some point become empirically irrelevant by having no observable consequences in our world.

The arguments come full circle with modern dark energy ideas suggesting that spacetime or the vacuum may not be empty, but rather (for all we can observe) a medium, a possibility ironically glimpsed even by Einstein whose career began with demolishing the similar but too-simplistic notion of ether with his special relativity work.

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Many particle systems

Many-particle systems often admit an (analytical) statistical description when their number becomes large.

In that sense they are simpler than few-particle systems. This feature has several diferent names – the law of large numbers, ergodicity, etc. – and it is one of the reasons for the spectacular successes of statistical physics.

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- Apply the methods of Statistical Physics to a wide range of problems.
- Lectures based on Ch 3-6 of Modern Classical Physics by Kip Thorne e Roger Blandford.
- Avoid repetition of previously taught subjects like Thermodynamics and the formalism of Statistical Physics.

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Contents

1. Kinetic Theory and Statistical Mechanics
   - 1.1 Phase Space and Distribution Function
     - Examples: Newtonian Number Density in Phase Space, Relativistic Number Density in Phase Space, Distribution Function f (x, v, t) for Particles in a Plasma, Distribution Function Iv/v3 for Photons
   - 1.2 Thermal-Equilibrium Distribution Functions (derived earlier, only stated here)
   - 1.3 Isotropic Distribution Functions and Equations of State
     - Examples: Equations of State for a Nonrelativistic Hydrogen Gas, Relativistic Density, Pressure, Energy Density, and Equation of State, Equation of State for a Relativistic Degenerate Hydrogen Gas, Equation of State for Radiation
   - 1.4 Evolution of the Distribution Function: Liouville's Theorem, the Collisionless Boltzmann Equation, and the Boltzmann Transport Equation
     - Examples: Transport Coefficients, Diffusive Heat Conduction inside a Star, Order-of-Magnitude Analysis, Analysis Using the Boltzmann Transport Equation
   - 1.4 Statistical Mechanics in the Presence of Gravity
     - Examples: Galaxies, Black Holes, The Universe, Structure Formation in the Expanding Universe: Violent Relaxation and Phase Mixing
     - Examples: Information Gained When Measuring the State of a System in a Microcanonical Ensemble, Information in Communication Theory, Examples of Information Content, Some Properties of Information, Capacity of Communication Channels
   - 1.5 Entropy and Information

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2. Random Processes
   - 2.1 Random Variables and Random Processes
   - 2.2 Probability Distributions & Ergodic Hypothesis
   - 2.3 Markov Processes and Gaussian Processes
   - 2.4 Correlation Functions and Spectral Densities
     - Examples: Physical Meaning of Spectral Density, Light Spectra and Noise in a Gravitational Wave Detector.
   - 2.5 Cross Correlation and Correlation Matrix

3. Filtering Random Processes
   - 3.1 Filters, Their Kernels, and the Filtered Spectral Density
     - Examples: Brownian Motion and Random Walks

4. Fluctuation-Dissipation Theorem
   - 4.1 Elementary Version of the Fluctuation-Dissipation Theorem; Langevin Equation, Johnson Noise in a Resistor and Relaxation Time for Brownian Motion
   - 4.2 Generalized Fluctuation-Dissipation Theorem; Thermal Noise in a Laser Beam's Measurement of Mirror Motions; Standard Quantum Limit for Measurement Accuracy and How to Evade It

5. Fokker-Planck Equation
   - 5.1 Fokker-Planck for a 1-Dimensional Markov Process
   - 5.2 Optical Molasses: Doppler Cooling of Atoms
   - 5.3 Fokker-Planck for a Multidimensional Markov Process; Thermal Noise in an Oscillator

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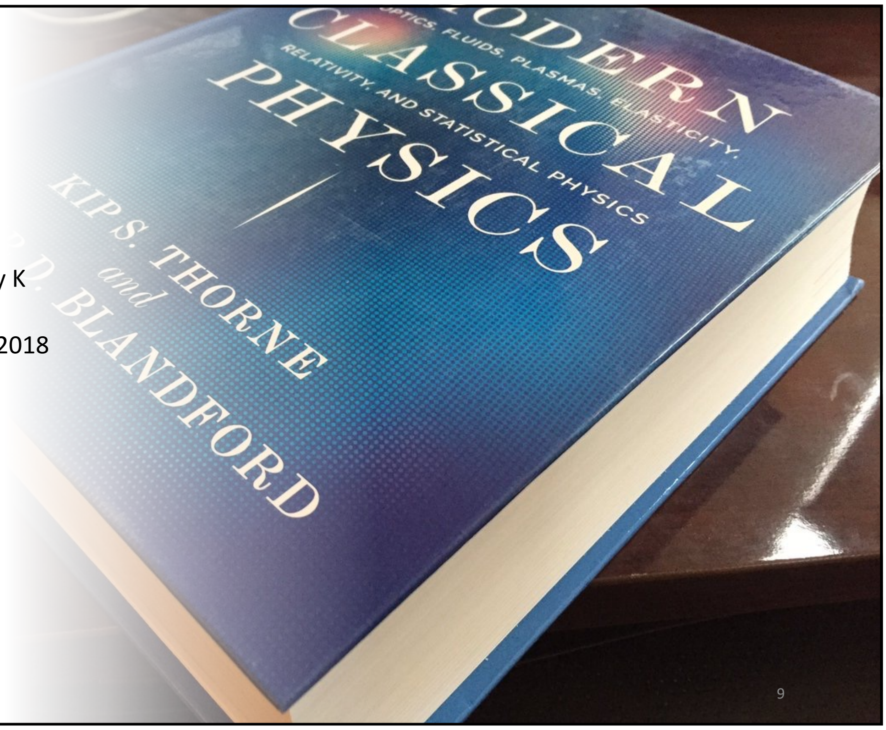
Bibliography (primary)

Modern Classical Physics, by K Thorne and R Blandford,

Princeton University Press, 2018 (Chapters 3, 4 and 6)



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Bibliography (secondary)

Newtonian kinetic theory is treated in many textbooks on statistical physics. At an elementary level, Kittel and Kroemer (1980, Chap. 14) is rather good. Texts at a more advanced level include Kardar (2007, Chap. 3), Reif (2008, Secs. 7.9–7.13 and Chaps. 12–14), and Reichl (2009, Chap. 11).

For a very advanced treatment with extensive applications to electrons and ions in plasmas, and electrons, phonons, and quasi-particles in liquids and solids, see Lifshitz and Pitaevskii (1981).

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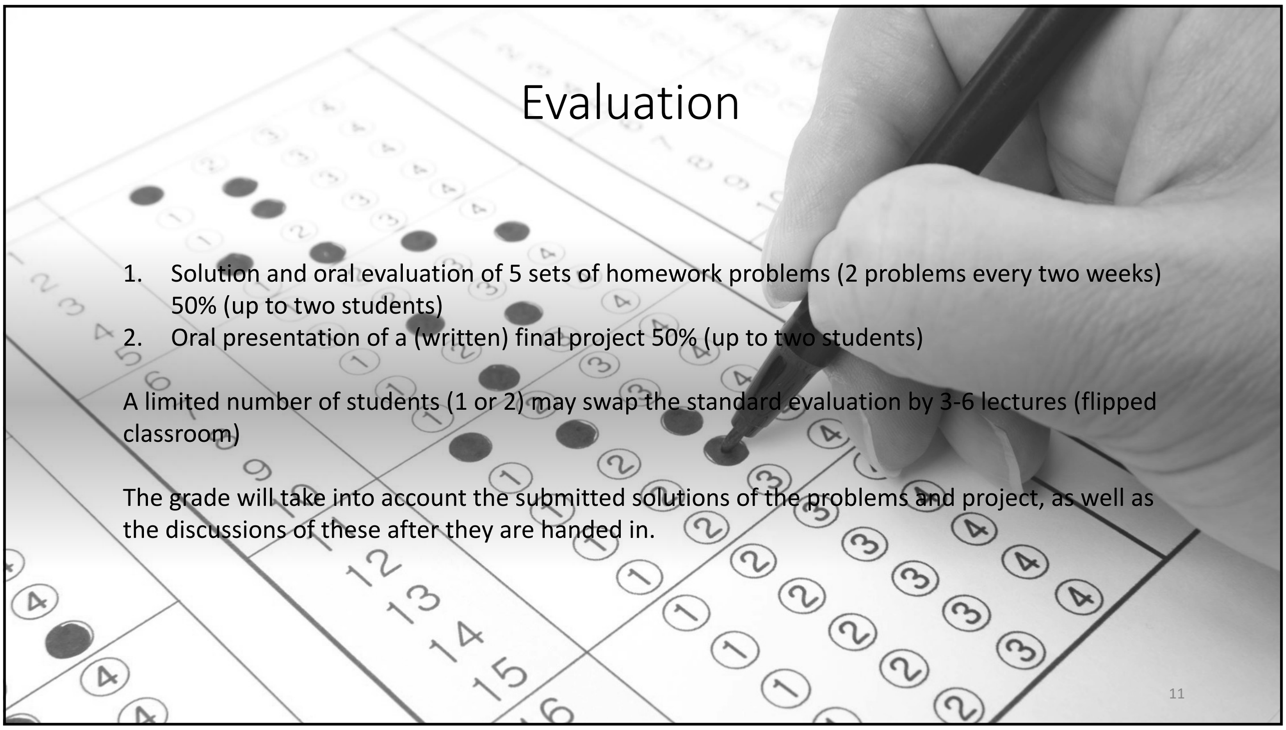

Evaluation

1. Solution and oral evaluation of 5 sets of homework problems (2 problems every two weeks) 50% (up to two students)
2. Oral presentation of a (written) final project 50% (up to two students)

A limited number of students (1 or 2) may swap the standard evaluation by 3-6 lectures (flipped classroom)

The grade will take into account the submitted solutions of the problems and project, as well as the discussions of these after they are handed in.

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The role of problems/exercises

PRACTICE. EXERCISES THAT GIVE PRACTICE AT MATHEMATICAL MANIPULATIONS (E.G., OF TENSORS).

DERIVATION. EXERCISES THAT FILL IN DETAILS OF ARGUMENTS OR DERIVATIONS WHICH ARE SKIPPED OVER IN THE TEXT.

EXAMPLE. EXERCISES THAT LEAD THE READER STEP BY STEP THROUGH THE DETAILS OF SOME IMPORTANT EXTENSION OR APPLICATION OF THE MATERIAL IN THE TEXT.

PROBLEM. EXERCISES WITH FEW IF ANY HINTS, IN WHICH THE TASK OF FIGURING OUT HOW TO SET THE CALCULATION UP AND GET STARTED ON IT OFTEN IS AS DIFFICULT AS DOING THE CALCULATION ITSELF.

CHALLENGE. AN ESPECIALLY DIFFICULT EXERCISE WHOSE SOLUTION MAY REQUIRE THAT ONE READ OTHER BOOKS OR ARTICLES AS A FOUNDATION FOR GETTING STARTED.

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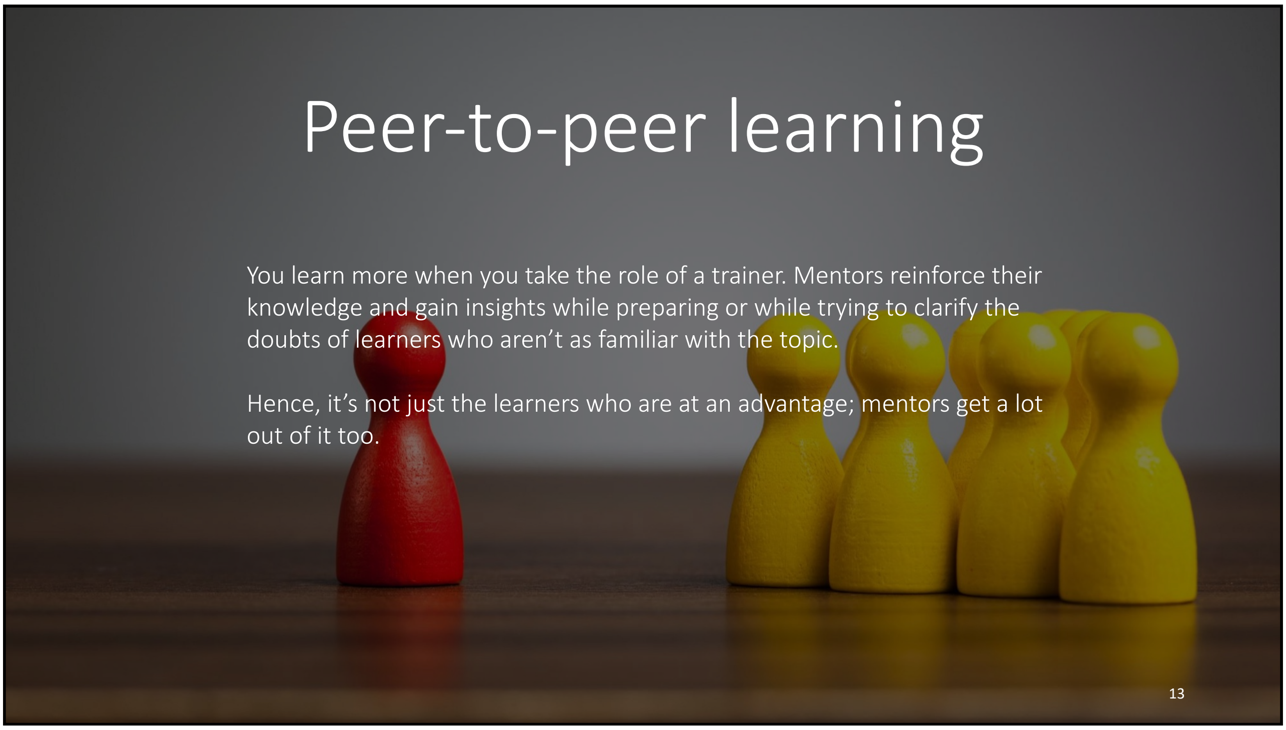
Peer-to-peer learning
You learn more when you take the role of a trainer. Mentors reinforce their knowledge and gain insights while preparing or while trying to clarify the doubts of learners who aren't as familiar with the topic.
Hence, it's not just the learners who are at an advantage; mentors get a lot out of it too.
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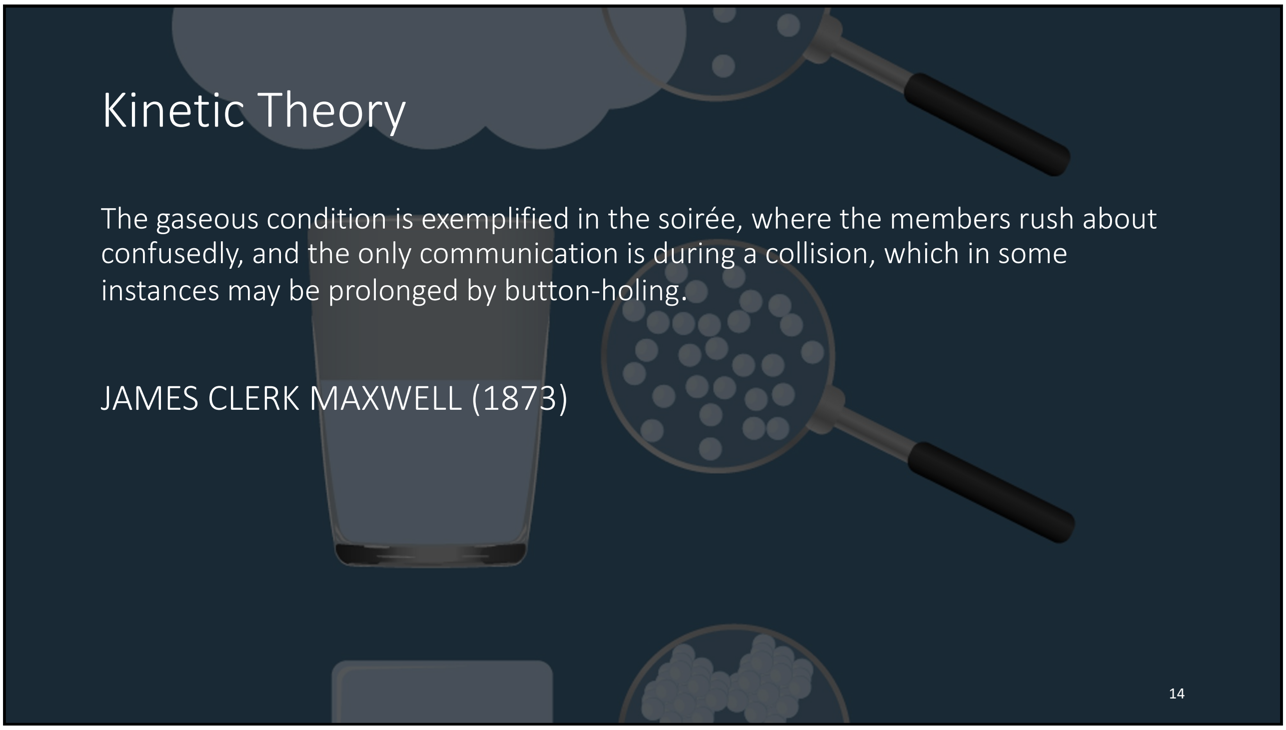
Kinetic Theory
The gaseous condition is exemplified in the soirée, where the members rush about confusedly, and the only communication is during a collision, which in some instances may be prolonged by button-holing.
JAMES CLERK MAXWELL (1873)
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