Complementary Statistical Physics

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Aim:

The aim of the curricular unit is to introduce students to the basic principles and methods of nonequilibrium statistical mechanics and to develop the theoretical and problem-solving skills needed to analyse systems that evolve in time. Topics include stochastic motion, kinetic and transport processes, relaxation and fluctuations, with applications ranging from gases and plasmas to structure formation in astrophysics.

1. **Brownian motion**
   - 1.1 Length and time scales and elements of Einstein's theory
   - 1.2 The Langevin equation
   - 1.3 The Chapman–Kolmogorov-Smoluchowski equation
   - 1.4 The Fokker-Planck equation
   - 1.5 Random walks

2. **Kinetic equations in statistical mechanics**
   - 2.1 N-particle microstates and their time evolution
   - 2.2 General structure of a kinetic equation for the one-particle distribution function
   - 2.3 BBGKY hierarchy
   - 2.4 The Boltzmann kinetic equation
   - 2.5 The Boltzmann H-theorem
   - 2.6 Kinetic theory of plasma and the Vlasov equation
   - 2.7 The Pauli master equation
   - 2.8 Applications: isotropic distribution functions; equations of state; transport coefficients

3. **Random processes**
   - 3.1 Random variables and random processes
   - 3.2 Probability distributions
   - 3.3 Ergodicity of a stochastic process
   - 3.4 A stationary Markov process
   - 3.5 A stationary Gaussian process
   - 3.6 Spectral representation of stochastic processes and autocorrelation functions
   - 3.7 The master equation
   - 3.8 Examples: Light spectra and noise in a gravitational wave detector; filters.

4. **Fluctuation-dissipation theorem**
   - 4.1 Elementary version
   - 4.2 Langevin equation
   - 4.3 Johnson noise in a resistor
   - 4.4 Relaxation time for Brownian Motion
   - 4.5 Generalized version of the fluctuation-dissipation theorem
   - 4.6 Examples: Thermal noise in a laser beam's measurement of mirror motions; standard quantum limit for measurement accuracy

5. **Statistical mechanics in the presence of gravity**
   - 5.1 Galaxies
   - 5.2 Black holes
   - 5.3 Structure formation in the expanding universe

6. **Aggregation and fragmentation kinetics**
   - 6.1 Cluster-size distributions and master equations
   - 6.2 Aggregation processes
   - 6.3 Fragmentation processes
   - 6.4 Astrophysical applications: dust growth, planetesimal formation and collisional evolution of asteroid populations

7. **Entropy and information**
   - 7.1 Information content
   - 7.2 Some properties of information
   - 7.3 Information in communication theory
   - 7.4 Examples: Information gained when measuring the state of a system in a microcanonical ensemble; capacity of communication channels

Books:

MAIN: Kip S. Thorne and Roger D. Blandford, *Statistical Physics: Volume 1 of Modern Classical Physics*. Princton University Press (2021).

ADDITIONAL:

B. Bagchi, *Nonequilibrium Statistical Mechanics: An Introduction with Applications*. Taylor & Francis Group, LLC (2024).

N. G. Van Kampen, Stochastic Processes in Physics and Chemistry. Amsterdam: Elsevier (1992).