Y2 Statistical Physics & Entropy 2011/12 — Dr Neil Thomas

Lecture Outline

1. Statistical Physics. The isothermal atmosphere: Ideal-Gas Law $p = nkT$ and the Boltzmann factor $e^{-E/kT}$. Review of probability and statistics: molecular velocity and speed distributions. Collisions with the walls: Joule six-stream approximation and collision rate $\frac{1}{4}n\bar{v}$ per unit area. Intermolecular collisions: scattering cross-section σ, mean free-path $l = 1/n\sigma$, mean free-time τ, drift velocity $v = \mu F$ and mobility $\mu = \tau/m$. Diffusion: Fick's Law $J_x = -D\partial n/\partial x$, diffusion coefficient D and the Einstein Relation $D = \mu kT$. Brownian motion and the random walk. Binomial probability distribution. Poisson and Gaussian distributions.

2. Thermal Equilibrium. Microstates & macrostates. Order, disorder and the Boltzmann entropy $S = k\ln\Omega$ for a thermally isolated system. Equal *a priori* probabilities and maximum entropy. Zeroth Law of Thermodynamics. Thermodynamic temperature $T = (\partial U/\partial S)_V$. System in contact with a heat reservoir: the Boltzmann distribution and the partition function Z. Fluctuations. Two-level systems. Equipartition: classical and quantum harmonic oscillators. Black-body radiation and Johnson noise.

3. Thermodynamics. First Law: $\Delta U = \Delta Q + \Delta W$. Second Law: $\Delta S_{total} \geq 0$. Reversible and irreversible processes. Reversible heat $\Delta Q_{\text{rev}} = T\Delta S$. Latent heat. Clausius and Kelvin statements of the Second Law. Carnot cycle, heat engines and refrigerators. Functions of state. Infinitesimal changes: $dU = đQ + đW$ and $dU = TdS - pdV$. Entropy changes: heat capacity, compression/expansion of a gas, stretching a rubber band. Gibbs free-energy G: rubber elasticity, surface tension and phase equilibrium. Equilibrium conditions and availability A. Helmholtz free-energy F and enthalpy H. Maxwell relations. Joule-Kelvin effect. Third Law: $S \rightarrow 0$ as $T \rightarrow 0$. Adiabatic demagnetization.

4. Advanced Topics. Perpetual-motion machines and Maxwell's Demon. Entropy and information. Negative temperatures. Microscopic view of heat and work. Chemical potential and an introduction to Fermi-Dirac statistics (time permitting).

Textbooks

Feynman, R.P. 1963 *The Feynman Lectures on Physics*, Volume I, Chs. 39–46 (Addison-Wesley). Covers basic kinetic theory and Brownian motion for Section 1 of the course.
Mandl, F. 1971 *Statistical Physics* (Wiley). Treats statistical mechanics and thermodynamics for Sections 2-4.

Further Reading

Adkins, C.J. 1983 *Equilibrium Thermodynamics,* 3rd ed. (Cambridge). Introduction to classical thermodynamics.
Atkins, Peter 2007 *Four Laws that Drive the Universe* (Oxford University Press). Clear, concise overview.
Dill, K.A. & Bromberg, S. 2010 *Molecular Driving Forces* 2nd ed. (Garland Science). Modern text with many examples of statistical mechanics and thermodynamics.
Dugdale, J.S. 1966 *Entropy and Low Temperature Physics* (Hutchinson). Good overview of entropy.
Fermi, E. 1966 *Thermodynamics & Statistics* (University of Chicago). Lecture notes in Fermi's own hand.
Flowers, B.H. & Mendoza, E. 1970 *Properties of Matter* (Wiley). Good reference for kinetic theory.
Kittel, C. 1969 *Thermal Physics* (John Wiley). Elegant presentation starting from microscopic theory.
Leff, H.S. & Rex, A.F. 2003 *Maxwell's Demon* 2nd ed. (Institute of Physics). Stimulating discussion of Maxwell's Demon together with classic scientific papers.
Pippard, A.B. 1966 *Elements of Classical Thermodynamics* (Cambridge University Press). Concise and elegant treatment of classical thermodynamics from a purely macroscopic viewpoint.
Reif, F. 1965 *Fundamentals of Statistical & Thermal Physics* (McGraw-Hill). More advanced treatment.
Zemansky, M.W. 1968 *Heat & Thermodynamics*, 5th ed. (McGraw-Hill). Good for applications.

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