5.6 Fluctuations and noise

Thermodynamic fluctuations[a]

Fluctuation probability	$\mathrm{pr}(x) \propto \exp[S(x)/k]$ (5.130) $\propto \exp\left[\frac{-A(x)}{kT}\right]$ (5.131)	pr x S A	probability density unconstrained variable entropy availability
General variance	$\mathrm{var}[x] = kT\left[\frac{\partial^2 A(x)}{\partial x^2}\right]^{-1}$ (5.132)	$\mathrm{var}[\cdot]$ k T	mean square deviation Boltzmann constant temperature
Temperature fluctuations	$\mathrm{var}[T] = kT\left.\frac{\partial T}{\partial S}\right\|_V = \frac{kT^2}{C_V}$ (5.133)	V C_V	volume heat capacity, V constant
Volume fluctuations	$\mathrm{var}[V] = -kT\left.\frac{\partial V}{\partial p}\right\|_T = \kappa_T V kT$ (5.134)	p κ_T	pressure isothermal compressibility
Entropy fluctuations	$\mathrm{var}[S] = kT\left.\frac{\partial S}{\partial T}\right\|_p = kC_p$ (5.135)	C_p	heat capacity, p constant
Pressure fluctuations	$\mathrm{var}[p] = -kT\left.\frac{\partial p}{\partial V}\right\|_S = \frac{K_S kT}{V}$ (5.136)	K_S	adiabatic bulk modulus
Density fluctuations	$\mathrm{var}[n] = \frac{n^2}{V^2}\mathrm{var}[V] = \frac{n^2}{V}\kappa_T kT$ (5.137)	n	number density

[a]In part of a large system, whose mean temperature is fixed. Quantum effects are assumed negligible.

Noise

Nyquist's noise theorem	$\mathrm{d}w = kT \cdot \beta\epsilon(\mathrm{e}^{\beta\epsilon} - 1)^{-1}\,d\nu$ (5.138) $= kT_{\mathrm{N}}\,\mathrm{d}\nu$ (5.139) $\simeq kT\,\mathrm{d}\nu \quad (h\nu \ll kT)$ (5.140)	w k T T_{N} $\beta\epsilon$ ν h	exchangeable noise power Boltzmann constant temperature noise temperature $= h\nu/(kT)$ frequency Planck constant
Johnson (thermal) noise voltage[a]	$v_{\mathrm{rms}} = (4kT_{\mathrm{N}}R\Delta\nu)^{1/2}$ (5.141)	v_{rms} R $\Delta\nu$	rms noise voltage resistance bandwidth
Shot noise (electrical)	$I_{\mathrm{rms}} = (2eI_0\Delta\nu)^{1/2}$ (5.142)	I_{rms} $-e$ I_0	rms noise current electronic charge mean current
Noise figure[b]	$f_{\mathrm{dB}} = 10\log_{10}\left(1 + \frac{T_{\mathrm{N}}}{T_0}\right)$ (5.143)	f_{dB} T_0	noise figure (decibels) ambient temperature (usually taken as 290 K)
Relative power	$G = 10\log_{10}\left(\frac{P_2}{P_1}\right)$ (5.144)	G P_1, P_2	decibel gain of P_2 over P_1 power levels

[a]Thermal voltage over an open-circuit resistance.
[b]Noise figure can also be defined as $f = 1 + T_{\mathrm{N}}/T_0$, when it is also called "noise factor."