5.6 Fluctuations and noise

Thermodynamic fluctuations[a]

Fluctuation probability	$\mathrm{pr}(x) \propto \exp[S(x)/k]$	(5.130)	pr	probability density
	$\propto \exp\left[\frac{-A(x)}{kT}\right]$	(5.131)	x	unconstrained variable
			S	entropy
			A	availability
General variance	$\mathrm{var}[x] = kT\left[\frac{\partial^2 A(x)}{\partial x^2}\right]^{-1}$	(5.132)	$\mathrm{var}[\cdot]$	mean square deviation
			k	Boltzmann constant
			T	temperature
Temperature fluctuations	$\mathrm{var}[T] = kT\left.\frac{\partial T}{\partial S}\right\|_V = \frac{kT^2}{C_V}$	(5.133)	V	volume
			C_V	heat capacity, V constant
Volume fluctuations	$\mathrm{var}[V] = -kT\left.\frac{\partial V}{\partial p}\right\|_T = \kappa_T VkT$	(5.134)	p	pressure
			κ_T	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)	w	exchangeable noise power
	$= kT_\mathrm{N}\,\mathrm{d}\nu$	(5.139)	k	Boltzmann constant
	$\simeq kT\,\mathrm{d}\nu \qquad (h\nu \ll kT)$	(5.140)	T	temperature
			T_N	noise temperature
			$\beta\epsilon$	$= h\nu/(kT)$
			ν	frequency
			h	Planck constant
Johnson (thermal) noise voltage[a]	$v_\mathrm{rms} = (4kT_\mathrm{N}R\Delta\nu)^{1/2}$	(5.141)	v_rms	rms noise voltage
			R	resistance
			$\Delta\nu$	bandwidth
Shot noise (electrical)	$I_\mathrm{rms} = (2eI_0\Delta\nu)^{1/2}$	(5.142)	I_rms	rms noise current
			$-e$	electronic charge
			I_0	mean current
Noise figure[b]	$f_\mathrm{dB} = 10\log_{10}\left(1+\frac{T_\mathrm{N}}{T_0}\right)$	(5.143)	f_dB	noise figure (decibels)
			T_0	ambient temperature (usually taken as 290 K)
Relative power	$G = 10\log_{10}\left(\frac{P_2}{P_1}\right)$	(5.144)	G	decibel gain of P_2 over P_1
			P_1, P_2	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."