

# Appendix A

## Useful Constants and Conversion Factors

$\mathfrak{R} = k_B N_A$	8.314472 J/mol K
$k_B$	$1.3806505 \times 10^{-23}$ J/K = $8.617339 \times 10^{-5}$ eV/K
$N_A$	$6.0221415 \times 10^{23}$
$V_{\text{molar}}$	22.4141 L/mol @ 273.15 K, 101,325 Pa
$M_{\text{air}}$	28.9644 gm/mol
$g$	9.80665 m/s <sup>2</sup>
$c = (\epsilon_o \mu_o)^{-1/2}$	$2.997925 \times 10^8$ m/s
$\epsilon_o$	$8.854187817620 \times 10^{-12}$ F m <sup>-1</sup>
$\mu_o$	$4\pi \times 10^{-7}$ H m <sup>-1</sup>
$h$	$6.626069 \times 10^{-27}$ J s = $4.135667 \times 10^{-15}$ eV s
$\sigma$	$5.6697 \times 10^{-8}$ W/m <sup>2</sup> -K <sup>4</sup> = $[k_B^4 \pi^2 / 60 h^3 c^2]$
1 psi	6894.8 Pa = 2.307 ft H <sub>2</sub> O (1 psf = 47.88 Pa)
1 torr	133.32 Pa (1" H <sub>2</sub> O = 249.1 Pa)
1 ft <sup>3</sup>	28.317 L
1 gal	3.785411784 L = 231 in. <sup>3</sup>
1 gpm	63.088 cm <sup>3</sup> /s (1 cfm = $4.72 \times 10^{-4}$ m <sup>3</sup> /s)
1 cal	4.184 J
1 W	3.413 BTU/h
1 ton	3517 W ( $\equiv$ 12,000 BTU/h)
1 hp	746 W

# Appendix B

## Resonator Quality Factor

*“A man with one watch knows the time; a man with two is never sure.”*

The quality factor ( $Q$ ) of a resonator is a dimensionless measure of the “sharpness” of a resonance. One of the greatest sources of its utility is that we have many equivalent ways of expressing the  $Q$ . This variety allows us to connect the most convenient experimental method to the parameter of interest and provides us with a “second watch” if we want to make a self-consistency check of our results, either theoretically or experimentally.

*Caution:* The results summarized below assume that the resonance under consideration is “isolated,” so there are no other resonances that might be sufficiently close in frequency that they would affect the amplitude or phase of the resonance being considered.

*Q-multiplier.* For a given force  $F$  or pressure  $p$ , the magnitude of the response at the resonance frequency of the  $i$ th mode,  $\omega_i$ ,  $i = 0, 1, 2, 3, \dots \infty$ , will be “amplified” by the quality factor  $Q_i$  of that mode:

$$Q_i = \left| \frac{p(\omega_i)}{p(\omega = 0)} \right| \tag{B.1}$$

*Energy storage-to-dissipation ratio.* The time-averaged power dissipated is written in terms of the energy stored and the average power dissipated  $\langle \Pi_{\text{dissipated}} \rangle$  follows:

$$Q = 2\pi \frac{E_{\text{stored}}}{E_{\text{dissipated/cycle}}} = \frac{\omega E_{\text{stored}}}{\langle \Pi_{\text{dissipated}} \rangle_t} \tag{B.2}$$

*Lumped element storage-to-loss ratio.* For a mass–spring system with natural frequency  $\omega_o$ , mass  $m$ , and stiffness  $s$ ; or a similar electrical circuit with inductance  $L$  and capacitance,  $C$ , or an acoustical compliance  $C$  and acoustical inertance  $L$ :

$$Q = \frac{\omega_o m}{R_m} = \frac{k}{\omega_o R_m} = \frac{1}{\omega_o R_{dc} C} = \frac{\omega_o L}{R_{dc}}$$

*Half-power bandwidth.* If the frequencies of the  $-3$  dB points are  $f_+$  and  $f_-$ , then the full  $-3$  dB bandwidth of the resonance,  $\Delta f = f_+ - f_-$ , is related to the quality factor,  $Q$ , by the resonance frequency,  $f_o = (f_+ f_-)^{1/2}$  written as follows:

$$Q = \frac{f_o}{f_+ - f_-} = \frac{\omega_o}{\omega_+ - \omega_-} \quad \text{where} \quad f_o = \sqrt{f_+ f_-} = \frac{\sqrt{\omega_+ \omega_-}}{2\pi} \quad (\text{B.3})$$

*Rate of phase change with frequency at resonance.* If the phase shift between force (or pressure) and velocity (or volume flow rate) is expressed as  $\phi$  in radians, or  $\theta$  in degrees, then:

$$Q = \frac{\omega_o}{2} \left. \frac{d\phi}{d\omega} \right|_{\omega_o} = \frac{f_o}{2} \left. \frac{d\phi}{df} \right|_{f_o} = f_o \frac{\pi}{360^\circ} \left. \frac{d\theta}{df} \right|_{f_o} = \frac{f_o}{114.6^\circ} \left. \frac{d\theta}{df} \right|_{f_o} \quad (\text{B.4})$$

*Free decay rate.* If the time required for the amplitude of the oscillations to decay to  $e^{-1} \cong 0.368$  of their value is  $\tau = \beta^{-1} = (2m)/R_m$ , then,

$$Q = \frac{1}{2} \omega_o \tau = \pi \tau f_o \quad (\text{B.5})$$

Similarly, the  $Q$  is expressed as  $2\pi$  times the number of cycles required for the **energy** to decay by  $e^{-1}$ , or  $\pi$  times the number of cycles required for the **amplitude** to decay by  $e^{-1}$ . More generally,

$$Q = \frac{\pi N}{\ln[x]} \quad (\text{B.6})$$

$N$  is the number of cycles for the amplitude to decay by a factor of  $x$ .

*Reflection coefficient.* In a standing-wave resonator, the standing wave can be represented as the superposition of a right- and left-going traveling waves. If the left-going wave is reflected with an amplitude that is  $R < 1$  times the right-going wave amplitude, the coefficient of the right-going wave would be given by the infinite geometric series  $1 + R + R^2 + R^3 + \dots$  and the left-going wave would have an amplitude that is  $R$  times that infinite sum. The resulting quality factor,  $Q_n$ , of the  $n$ th mode of the resonator can be expressed in terms of the reflection coefficient  $R$  and the mode number  $n$ :

$$Q_n = n\pi \frac{\sqrt{R}}{1 - R} \quad (\text{B.7})$$

*Pole-zero resonance fit.* Many modern spectrum analyzers allow a resonance to be fit by a pole-zero function. A single resonance will have two complex poles that are complex conjugates,  $a \pm jb$ . The resonance frequency is  $f = (a^2 + b^2)^{1/2} \cong b$ , if the damping is small ( $a \ll b$ ).

$$Q = \frac{-1}{2a} \sqrt{a^2 + b^2} \cong \frac{-b}{2a} \quad (\text{B.8})$$

*Loss tangent and damping factor.* In the characterization of elastomers used as vibration isolators, it is common to define a frequency dependent, complex elastic modulus  $E^*$ . The complex modulus has a real part  $E'$  and an imaginary part  $E''$  such that  $E^* = E' + jE'' \cong E(1 + j\delta)$ , where we choose to define a “loss tangent,”  $\tan \delta$ , that is the inverse of the quality factor.<sup>1</sup>

$$Q = \frac{1}{\tan \delta} = \frac{E'}{E''} = \frac{1}{2\zeta} \quad (\text{B.9})$$

The damping factor,  $\zeta$ , is the ratio of the mechanical resistance to the critical value of the mechanical resistance,  $R_m^{\text{crit}} = 2(km)^{1/2} = 2m\omega_o$ .<sup>2</sup>

---

<sup>1</sup>For example, see J.C. Snowdon, *Vibration and Shock in Damped Mechanical Systems* (Wiley, 1968).

<sup>2</sup>W.T. Thomson, *Theory of Vibration with Applications*, 2nd ed. (Prentice-Hall, 1981); ISBN 0-13-914523-0.

# Appendix C

## Bessel Functions of the First Kind

Bessel's equation:

$$x^2 \frac{d^2 J_m(x)}{dx^2} + x \frac{d J_m(x)}{dx} + (x^2 - m^2) J_m(x) = 0 \tag{C.1}$$

$$\frac{1}{x} \frac{d}{dx} \left( x \frac{d J_m(x)}{dx} \right) + \left( 1 - \frac{m^2}{x^2} \right) J_m(x) = 0 \tag{C.2}$$

Series expansions:

$$J_m(x) = \frac{1}{m!} \left( \frac{x}{2} \right)^m - \frac{1}{1!(m+1)!} \left( \frac{x}{2} \right)^{m+2} + \frac{1}{2!(m+2)!} \left( \frac{x}{2} \right)^{m+4} - \dots \tag{C.3}$$

$$J_0(x) = 1 - \frac{x^2}{2^2} + \frac{x^4}{2^2 \cdot 4^2} - \frac{x^6}{2^2 \cdot 4^2 \cdot 6^2} + \dots \tag{C.4}$$

$$J_1(x) = \frac{x}{2} - \frac{2x^3}{2 \cdot 4^2} + \frac{3x^5}{2 \cdot 4^2 \cdot 6^2} - \dots \tag{C.5}$$

$$J_2(x) = \frac{x^2}{2 \cdot 2^2} - \frac{x^4}{2 \cdot 3 \cdot 2^4} + \frac{x^6}{2 \cdot 3 \cdot 4 \cdot 2^6} - \dots \tag{C.6}$$

Asymptotic forms for large argument:

$$\lim_{x \rightarrow \infty} [J_1(x)] = \sqrt{\frac{2}{\pi x}} \cos \left( x - \frac{m\pi}{2} - \frac{\pi}{4} \right) \tag{C.7}$$

Addition theorem:

$$1 = J_0(x) + 2J_2(x) + 2J_4(x) + 2J_6(x) + \dots \tag{C.8}$$

Relationships to trigonometric functions:

$$\sin x = 2J_1(x) - 2J_3(x) + 2J_5(x) - 2J_7(x) + \cdots \quad (\text{C.9})$$

$$\cos x = J_0(x) - 2J_2(x) + 2J_4(x) - 2J_6(x) + \cdots \quad (\text{C.10})$$

$$\cos(x \cos \theta) = J_0(x) + 2 \sum_{k=1}^{\infty} (-1)^k J_{2k}(x) \cos(2k\theta) \quad (\text{C.11})$$

$$\cos(x \sin \theta) = J_0(x) + 2 \sum_{k=1}^{\infty} J_{2k}(x) \cos(2k\theta) \quad (\text{C.12})$$

$$\sin(x \sin \theta) = 2 \sum_{k=0}^{\infty} J_{2k+1}(x) \sin[(2k+1)\theta] \quad (\text{C.13})$$

$$\sin(x \cos \theta) = 2 \sum_{k=1}^{\infty} (-1)^k J_{2k+1}(x) \cos[(2k+1)\theta] \quad (\text{C.14})$$

Integral representations:

$$J_m(x) = \frac{(x/2)^m}{\sqrt{\pi} \Gamma(m+1/2)} \int_0^\pi \cos(x \cos \theta) d\theta \quad (\text{C.15})$$

$$J_0(x) = \frac{1}{\pi} \int_0^\pi \cos(x \sin \theta) d\theta = \frac{1}{\pi} \int_0^\pi \cos(x \cos \theta) d\theta \quad (\text{C.16})$$

$$J_m(x) = \frac{1}{\pi} \int_0^\pi \cos(x \sin \theta - m\theta) d\theta \quad (\text{C.17})$$

Recurrence relations:

$$J_{m-1}(x) + J_{m+1}(x) = \frac{2m}{x} J_m(x) \quad (\text{C.18})$$

$$J_{m-1}(x) - J_{m+1}(x) = 2 \frac{dJ_m(x)}{dx} \quad (\text{C.19})$$

$$\frac{dJ_m(x)}{dx} = J_{m-1}(x) - \frac{m}{x} J_m(x) \quad (\text{C.20})$$

$$\frac{dJ_m(x)}{dx} = -J_{m+1}(x) + \frac{m}{x}J_m(x) \quad ((C.21))$$

Derivatives:

$$\frac{dJ_m(x)}{dx} = \frac{1}{2}[J_{m-1}(x) - J_{m+1}(x)] \quad (C.22)$$

$$\frac{dJ_0(x)}{dx} = -J_1(x) \quad (C.23)$$

$$\frac{d}{dx}[x^m J_m(x)] = x^m J_{m-1}(x) \quad (C.24)$$

$$\frac{d}{dx}[x^{-m} J_m(x)] = -x^{-m} J_{m+1}(x) \quad (C.25)$$

Integrals:

$$\int J_1(x) dx = -J_0(x) \quad (C.26)$$

$$\int x J_0(x) dx = x J_1(x) \quad (C.27)$$

$$\int x^{p+1} J_p(x) dx = x^{p+1} J_{p+1}(x) \quad (C.28)$$

$$\int J_0^2(x) x dx = \frac{x^2}{2} [J_0^2(x) + J_1^2(x)] \quad (C.29)$$

$$\int J_m^2(x) x dx = \frac{x^2}{2} [J_m^2(x) - J_{m-1}(x)J_{m+1}(x)] \quad (C.30)$$

$$\int J_m(ax)J_m(bx)x dx = \frac{x}{a^2 - b^2} [bJ_m(ax)J_{m-1}(bx) - aJ_m(bx)J_{m-1}(ax)] \quad (C.31)$$

Roots of Bessel functions (15 digits)

The $n$ th roots of $J_m(x) = 0$					
$m \backslash n$	$n = 1$	$n = 2$	$n = 3$	$n = 4$	$n = 5$
$m = 0$	2.40482555769577	5.52007811028631	8.65372791291101	11.7915344390142	14.9309177084877
$m = 1$	3.83170597020751	7.01558666981561	10.1734681350627	13.3236919363142	16.4706300508776
$m = 2$	5.13562230184068	8.41724414039986	11.6198411721490	14.7959517823512	17.9598194949878
$m = 3$	6.38016189592398	9.76102312998166	13.0152007216984	16.2234661603187	19.4094152264350
$m = 4$	7.58834243450380	11.0647094885011	14.3725366716175	17.6159660498048	20.8269329569623
$m = 5$	8.77148381595995	12.3386041974669	15.7001740797116	18.9801338751799	22.2177998965612
$m = 6$	9.93610952421768	13.5892901705412	17.0038196678160	20.3207892135665	23.5860844355813
$m = 7$	11.0863700192450	14.8212687270131	18.2875828324817	21.6415410198484	24.9349278876730
$m = 8$	12.2250922640046	16.0377741908877	19.5545364309970	22.9451731318746	26.2668146411766
$m = 9$	13.3543004774353	17.2412203824891	20.8070477892641	24.2338852577505	27.5837489635730
$m = 10$	14.4755006865545	18.4334636669665	22.0469853646978	25.5094505541828	28.8873750635304

The $n$ th roots of $J_m(x) = 0$					
$m \backslash n$	$n = 1$	$n = 2$	$n = 3$	$n = 4$	$n = 5$
$m = 0$	3.83170597020751	7.01558666981561	10.1734681350627	13.3236919363142	16.4706300508776
$m = 1$	1.84118378134065	5.33144277352503	8.53631636634628	11.7060049025920	14.8635886339090
$m = 2$	3.05423692822714	6.70613319415845	9.96946782308759	13.1703708560161	16.3475223183217
$m = 3$	4.20118894121052	8.01523659837595	11.3459243107430	14.5858482861670	17.7887478660664
$m = 4$	5.31755312608399	9.28239628524161	12.6819084426388	15.9641070377315	19.1960288000489
$m = 5$	6.41561637570024	10.5198608737723	13.9871886301403	17.3128424878846	20.5755145213868
$m = 6$	7.50126614468414	11.7349359530427	15.2681814610978	18.6374430096662	21.9317150178022
$m = 7$	8.57783648971407	12.9323862370895	16.5293658843669	19.9418533665273	23.2680529264575
$m = 8$	9.64742165199721	14.1155189078946	17.7740123669152	21.2290626228531	24.5871974863176
$m = 9$	10.7114339706999	15.2867376673329	19.0045935379460	22.5013987267772	25.8912772768391
$m = 10$	11.7708766749555	16.4478527484865	20.223031416817	23.7607158603274	27.1820215271905



# Appendix D

## Trigonometric Functions

Euler's formula

$$e^{jx} = \cos x + j \sin x \tag{D.1}$$

$$\cos x = \frac{e^{jx} + e^{-jx}}{2} \quad \sin x = \frac{e^{jx} - e^{-jx}}{2j} \tag{D.2}$$

Addition and subtraction

$$\cos(\alpha \pm \beta) = \cos \alpha \cos \beta \mp \sin \alpha \sin \beta \quad \sin(\alpha \pm \beta) = \sin \alpha \cos \beta \pm \cos \alpha \sin \beta \tag{D.3}$$

$$\sin^2 \alpha + \cos^2 \alpha = 1 \tag{D.4}$$

$$\sin(\alpha \pm \beta) = \sin \alpha \cos \beta \pm \cos \alpha \sin \beta \tag{D.5}$$

$$\cos(\alpha + \beta) = \cos \alpha \cos \beta \mp \sin \alpha \sin \beta \tag{D.6}$$

$$\sin \alpha \pm \sin \beta = 2 \sin \left( \frac{\alpha \pm \beta}{2} \right) \cos \left( \frac{\alpha \mp \beta}{2} \right) \tag{D.7}$$

$$\cos \alpha + \cos \beta = 2 \cos \left( \frac{\alpha + \beta}{2} \right) \cos \left( \frac{\alpha - \beta}{2} \right) \tag{D.8}$$

$$\cos \alpha - \cos \beta = -2 \sin \left( \frac{\alpha + \beta}{2} \right) \sin \left( \frac{\alpha - \beta}{2} \right) \tag{D.9}$$

## Products and powers

$$\cos \alpha \cos \beta = \frac{1}{2}[\cos(\alpha - \beta) + \cos(\alpha + \beta)] \quad (\text{D.10})$$

$$\sin \alpha \sin \beta = -\frac{1}{2}[\cos(\alpha + \beta) - \cos(\alpha - \beta)] \quad (\text{D.11})$$

$$\sin \alpha \cos \beta = \frac{1}{2}[\sin(\alpha + \beta) + \sin(\alpha - \beta)] \quad (\text{D.12})$$

$$\sin^2 \alpha = \frac{1}{2}(1 - \cos 2\alpha) \quad (\text{D.13})$$

$$\sin^3 \alpha = \frac{1}{4}(3 \sin \alpha - \sin 3\alpha) \quad (\text{D.14})$$

$$\cos^2 \alpha = \frac{1}{2}(1 + \cos 2\alpha) \quad (\text{D.15})$$

$$\cos^3 \alpha = \frac{1}{4}(3 \cos \alpha + \cos 3\alpha) \quad (\text{D.16})$$

# Appendix E

## Hyperbolic Functions

$$e^x = \cosh x + j \sinh x \tag{E.1}$$

$$\cosh x = \frac{e^x + e^{-x}}{2} \quad \sinh x = \frac{e^x - e^{-x}}{2} \tag{E.2}$$

$$\tanh x = \frac{e^x - e^{-x}}{e^x + e^{-x}} = \frac{e^{2x} - 1}{e^{2x} + 1} \quad \coth x = \frac{1}{\tanh x} \tag{E.3}$$

### Series expansions

$$e^x = 1 + \frac{x}{1!} + \frac{x^2}{2!} + \frac{x^3}{3!} + \dots \tag{E.4}$$

$$\sinh x = x + \frac{x^3}{3!} + \frac{x^5}{5!} + \frac{x^7}{7!} + \dots \tag{E.5}$$

$$\cosh x = 1 + \frac{x^2}{2!} + \frac{x^4}{4!} + \frac{x^6}{6!} + \dots \tag{E.6}$$

$$\tanh x = x - \frac{x^3}{3} + \frac{2x^5}{15} - \frac{17x^7}{315} + \dots \quad \left(x^2 < \frac{\pi^2}{4}\right) \tag{E.7}$$

$$\sinh^{-1} x = x - \frac{x^3}{2 \cdot 3} + \frac{1 \cdot 3}{2 \cdot 4} \frac{x^5}{5} - \frac{1 \cdot 3 \cdot 5}{2 \cdot 4 \cdot 6} \frac{x^7}{7} + \dots \quad (x^2 < 1) \tag{E.8}$$

$$\cosh^{-1} x = \ln(2x) - \frac{1}{2} \frac{1}{2x^2} - \frac{1 \cdot 3}{2 \cdot 4} \frac{1}{4x^4} - \frac{1 \cdot 3 \cdot 5}{2 \cdot 4 \cdot 6} \frac{1}{6x^6} - \dots \quad (x^2 < 1) \tag{E.9}$$

$$\tanh^{-1} x = x + \frac{x^3}{3} + \frac{x^5}{5} + \frac{x^7}{7} + \dots \quad (x^2 < 1) \tag{E.10}$$

### Addition and subtraction

$$\cosh^2\alpha - \sinh^2\alpha = 1 \quad (\text{E.11})$$

$$\sinh(\alpha \pm \beta) = \sinh\alpha\cosh\beta \pm \cosh\alpha\sinh\beta \quad (\text{E.12})$$

$$\cosh(\alpha \pm \beta) = \cosh\alpha\cosh\beta \pm \sinh\alpha\sinh\beta \quad (\text{E.13})$$

$$\tanh(\alpha \pm \beta) = \frac{1 + \tanh\alpha\tanh\beta}{\tanh\alpha + \tanh\beta} = \frac{\sinh 2\alpha \pm \sinh 2\beta}{\cosh 2\alpha + \cosh 2\beta} \quad (\text{E.14})$$

$$\sinh\alpha \pm \sinh\beta = 2\sinh\left(\frac{\alpha \pm \beta}{2}\right)\cosh\left(\frac{\alpha \mp \beta}{2}\right) \quad (\text{E.15})$$

$$\cosh\alpha + \cosh\beta = 2\cosh\left(\frac{\alpha + \beta}{2}\right)\cosh\left(\frac{\alpha - \beta}{2}\right) \quad (\text{E.16})$$

$$\cosh\alpha - \cosh\beta = 2\sinh\left(\frac{\alpha + \beta}{2}\right)\sinh\left(\frac{\alpha - \beta}{2}\right) \quad (\text{E.17})$$

### Products and powers

$$\sinh\alpha\sinh\beta = \frac{1}{2}[\cosh(\alpha + \beta) - \cosh(\alpha - \beta)] \quad (\text{E.18})$$

$$\cosh\alpha\cosh\beta = \frac{1}{2}[\cosh(\alpha + \beta) + \cosh(\alpha - \beta)] \quad (\text{E.19})$$

$$\sinh\alpha\cosh\beta = \frac{1}{2}[\sinh(\alpha + \beta) + \sinh(\alpha - \beta)] \quad (\text{E.20})$$

$$\sinh 2\alpha = 2\sinh\alpha\cosh\alpha \quad (\text{E.21})$$

$$\sinh 3\alpha = 3\sinh\alpha + 4\sinh^3\alpha \quad (\text{E.22})$$

$$\cosh 2\alpha = 2\cosh^2\alpha - 1 \quad (\text{E.23})$$

$$\cosh 3\alpha = 4\cosh^3\alpha - 3\cosh\alpha \quad (\text{E.24})$$

$$\sinh^2\alpha = \frac{1}{2}(\cosh 2\alpha - 1) \quad (\text{E.25})$$

$$\sinh^3\alpha = \frac{1}{4}(\sinh 3\alpha - 3\sinh\alpha) \quad (\text{E.26})$$

$$\cosh^2\alpha = \frac{1}{2}(\cosh 2\alpha + 1) \quad (\text{E.27})$$

$$\cosh^3 \alpha = \frac{1}{4}(\cosh 3\alpha + 3\cosh \alpha) \quad (\text{E.28})$$

Functions of complex arguments

$$\begin{aligned} \sin jx &= \cosh x & \sinh jx &= j \sin x \\ \sin x &= -j \sinh jx & \sinh x &= -j \sin jx \end{aligned} \quad (\text{E.29})$$

$$\begin{aligned} \cos jx &= \cosh x & \cosh jx &= \cos x \\ \cos x &= \cosh jx & \cosh x &= \cos jx \end{aligned} \quad (\text{E.30})$$

$$\begin{aligned} \tan jx &= -j \tanh jx & \tanh jx &= -j \tan jx \end{aligned} \quad (\text{E.31})$$

# Index

## A

Accelerometer, 27, 41, 94, 121, 221–224, 228, 676  
Acoustic admittance, 577–579  
Acoustical compliance, 424, 427–435, 441–443, 447, 480, 485, 486, 506  
Acoustical impedance, 433, 434, 441, 447, 485, 569, 575–577, 579, 581, 591, 596, 671, 711  
Acoustical inertance, 424, 427, 428, 441–443, 447, 485, 486  
Acoustical network, 424, 442–444, 451, 453, 454, 486, 577, 663, 669  
Acoustic approximation, 426, 439, 452, 486  
Acoustic intensity, 534, 547, 550, 591, 646, 659, 729  
Acoustic levitation, 853–854, 861, 866  
Acoustic Mach number, 426, 486, 814, 819, 826  
Acoustic transfer impedance, 545, 559–562, 564, 566–568, 591, 596, 598, 637, 638, 640, 641, 645–646, 653, 681, 692, 695, 706  
Adiabatic, 6, 84, 213, 356–358, 402, 419, 425, 504, 534, 537, 541, 557, 584, 594, 596, 607, 638, 717, 780, 814  
Adiabatic compressibility, 541, 591  
Adiabatic equation of state, 405–407, 419, 435, 542, 782  
Adiabatic gas law, 6, 362, 363, 379, 405, 419, 432, 435, 442, 534, 596, 638–640, 645, 648, 650, 708, 844, 846  
Adiabatic invariance, 84–86, 356–358, 717, 750, 765, 855–861, 865, 869

Adiabatic sound speed, 433, 434, 509, 541, 542, 594, 788  
Amplitude reflection coefficient, 578, 579, 610, 616  
Amplitude transmission coefficient, 578, 579  
Angle of intromission, 617, 618, 630  
Angular frequency, 71, 138, 164, 192, 207, 252, 409, 447, 465, 540, 772, 782  
Anti-nodes, 165, 204, 283, 290, 446, 556, 558, 656, 662, 847  
Anti-reflective coating, 611, 630  
Anti-symmetric mode, 124–126, 132, 138, 148, 226  
Argand plane, 22–23, 58  
Array gain, 700, 706  
Association–dissociation reactions, 793, 800, 804  
Atmospheric lapse rate, 436, 486  
Auxetic materials, 219, 272  
Avogadro's number, 287, 400, 419, 427, 522  
Axial mode, 724, 736, 743, 744, 765

## B

Baffled source, 659, 706  
Ballistic propagation, 509, 529  
Basis functions, 16, 127, 138, 180, 181, 762, 763  
Bass-reflex loudspeaker enclosure, 448, 453, 477–486, 680, 869  
Beam steering, 687–690, 706  
Beating, 129–131, 138, 167, 840  
Bending moment, 229–231, 238, 272, 293  
Bernoulli pressure, 439, 846–849, 851, 865, 866

- Bessel functions, 177, 179, 201, 202, 351, 352, 354, 356, 358, 359, 361, 364, 367, 381–383, 385, 389, 465, 519, 646, 647, 691, 694, 696, 700, 738, 739, 741, 743, 763, 830, 831
- Bipole, 652–656, 660, 661, 663, 706, 709
- Boltzmann factor, 410, 419
- Boltzmann's constant, 91, 92, 399, 419, 526, 542, 755
- Broadside direction, 653, 706
- Bulk modulus, 213–216, 219, 220, 258, 272, 326, 541, 591, 594, 595, 607, 678, 682, 786
- Bulk viscosity, 412, 415, 417, 496, 548, 793, 804, 807, 808, 832
- C**
- Capacitive reactance, 434, 486
- Cavitation effects, 607, 630
- Celerity, 136, 138, 426
- Characteristic equation, 125, 129, 138, 327
- Characteristic impedance, 192, 194, 203, 204, 433, 545, 591, 642, 706
- Chromatic scale, 169, 204
- Coherent sound sources, 552, 591
- Collision time, 783, 790, 804
- Compact source, 586, 636–638, 641, 652, 654, 659–673, 675, 684, 685, 706, 771
- Compactness criterion, 360, 366, 385, 637, 643, 665, 706
- Complex conjugate, 24–26, 58, 580
- Complex exponential, 22–25, 58, 71, 73, 74, 87, 163, 193, 295, 427, 497, 670, 694, 719, 737, 745
- Condenser microphone, 362, 368–380, 384, 385, 388, 389, 529, 596, 597
- Confounding variables, 49, 58
- Conservation equation, 396, 402, 413, 418, 424, 425, 537, 547, 550, 556, 726, 784, 785, 793, 832, 845, 846
- Conservation laws, 401, 418, 419, 832
- Conservation of mass, 401, 413, 419, 428, 437
- Consonance and dissonance, 167, 168, 170, 202, 204
- Continuity equation, 396, 413, 415, 419, 424, 425, 427–435, 443, 452, 485, 497, 534, 537–540, 546, 547, 584–586, 592, 782, 790, 814, 815, 818, 832
- Convective non-linearity, 815, 820, 866
- Correlated/uncorrelated errors, 43, 58
- Correlation coefficient, 47–51, 58, 112, 113
- Covariance, 43–44, 58
- Critical angle, 503, 612, 614, 615, 617, 618, 630
- Critical damping, 89–90, 138, 264
- Critical distance, 731–734, 765, 767, 773
- Cut-off frequency, 54, 55, 106, 503, 585, 586, 588, 599, 758, 760–763, 765, 771, 775, 841, 842
- D**
- $d^2$ Alembertian operator, 156, 204
- Dashpot, 87, 117, 118, 138, 146, 159, 194, 220, 245–250, 252, 257, 264, 265, 271, 403, 421
- Decibel, 34, 102–104, 138, 265, 535, 548–552, 630, 700
- Degenerate modes, 341, 343, 385, 717, 721, 722, 747, 748, 765, 768
- Density of modes, 344–348, 387, 717, 723–726, 732, 733, 765, 773
- De-tuning/de-phasing instability, 862, 863, 866
- Differential, 58
- Differential scattering cross-section, 677, 706
- Diffuse sound field, 725–727, 731–733, 765, 767
- Diffusion constant, 511, 529, 789
- Dilatational modulus, 216, 217, 220, 258, 272, 284, 780, 785, 840
- Dimensional homogeneity, 27–29, 34, 35, 58, 88, 213
- Dimensionless groups, 28, 30, 31, 33, 34, 58, 88
- Dipole, 60, 145, 360, 660, 662–669, 671–678, 700, 706, 709, 713
- Dipole strength, 665, 674, 675, 678, 706
- Directionality factor, 655, 661, 698
- Directivity, 116, 689, 690, 696–700, 706
- Directivity index (DI), 696, 700, 706, 807
- Dispersion, 294–297, 331, 461, 682, 684, 758, 765, 782, 794–797, 836, 839
- Dispersion relation, 296, 297, 327, 540–544, 585, 591, 782, 816
- Dynamic (or absolute) viscosity, 511
- Dynamic modulus, 260, 261, 272
- Dynamic range, 312, 549
- Dynamical equation, 71, 133, 138, 156, 244, 396
- E**
- Effective bandwidth, 95, 138
- Effective mass, 141, 272, 331, 389, 487, 643, 644, 648, 667, 684, 706, 711, 713

- Eigenvalues, 720, 765  
 Electret microphone, 369, 376–380, 385, 549, 560, 566, 870  
 Electromagnetic cross-talk, 312, 313, 331  
 Electrostatic potential energy, 374, 385, 424  
 End-fire array, 688, 689, 706, 835–839, 865  
 End-fire direction, 653, 706  
 End-to-end calibration, 41, 58  
 Energy balance equation, 725, 728, 765  
 Enthalpy, 396, 547, 786, 851, 852, 866  
 Enthalpy function, 786, 804  
 Entrance length, 513, 529  
 Entropy, 7, 92, 402, 403, 412, 416–417, 419, 424, 425, 497, 498, 501, 507, 508, 537, 644, 781, 784, 785, 790, 793, 825, 827, 832, 833  
 Equal-loudness contours, 550, 552, 807  
 Equal temperament, 166, 168, 170, 204, 330  
 Equation of state, 71, 138, 154, 156, 171, 201, 212, 280, 396, 401, 405–407, 417–418, 432, 435, 534, 537, 542, 546, 584, 587, 780, 782, 783, 785, 790–793, 814, 817, 819, 820, 824, 827, 832, 833  
 Equipartition theorem, 91, 93, 104, 137, 138, 273, 399, 404, 407–409, 412, 419, 521, 548, 726, 733  
 Equivalent noise bandwidth, 94, 104, 138, 320  
 Ergodic hypothesis, 37, 58  
 Euler equation, 413–415, 419, 424, 425, 428, 435, 437–443, 485, 497, 534, 537–540, 545–547, 584, 587, 591, 592, 604, 607, 615, 641, 642, 644, 656, 665, 666, 671, 675, 719, 736, 738, 745, 755, 786, 814, 816, 818, 819, 846, 851  
 Euler force, 238, 272  
 Euler's identity, 21, 58  
 Eulerian co-ordinate system, 413, 415, 416, 427, 428, 486  
 Eulerian volume, 428, 429, 440, 486  
 Evanescent waves, 503, 529, 783  
 Event horizon, 638–640, 706  
 Extensive variables, 400, 419
- F**
- Faraday's Law of induction, 112, 138  
 Far field, 637, 645, 646, 655, 664, 665, 668, 677, 679, 685, 691–693, 695, 697, 698, 702–704, 706, 709, 713  
 Fermat's Principle, 611–618, 630  
 Ferroelectric ceramic, 222, 223, 272
- First Law of Thermodynamics, 402, 419  
 Fixed boundary, 156, 159, 160, 195, 196, 204, 330, 348, 358, 359, 361, 565  
 Flare constant, 585, 587, 591, 599, 758  
 Fletcher–Munson curves, 550, 552, 591  
 Flexural rigidity, 131, 154, 294, 325, 328–331, 336, 337, 362, 384  
 Fluid particle/parcel, 427, 440  
 Fourier Diffusion Equation, 497, 500, 529  
 Fourier synthesis, 15–18, 58, 64, 98  
 Fourier's theorem, 280, 426, 486  
 Free boundary, 159, 161, 162, 194, 204, 283, 298, 322, 331, 336, 405  
 Free decay frequency, 88–89, 114, 138  
 Frequency, 13, 70, 162, 222, 409, 424, 495, 535, 536, 540, 541, 544, 551–554, 557, 562, 564, 566–568, 570–574, 579–581, 585, 586, 588, 592, 594, 596, 598, 599, 604, 636, 721, 780, 819  
 Fundamental frequency, 16, 165, 174, 180, 203, 204, 388, 389, 460, 773, 803, 827, 855, 867  
 The Fundamental Theorem of Calculus, 5, 6, 9, 58, 406
- G**
- Gas stiffness, 115, 363–365, 368, 384, 385, 388, 442, 534, 571, 572, 574, 648, 651, 856  
 Generalized susceptibility, 245, 272  
 Geometric resonance, 834, 836, 866  
 Geophone, 27, 120–122, 138, 676  
 Gol'dberg number, 824–826, 836, 866, 867  
 Grazing angle, 623, 624, 630, 632  
 $\Pi$ -Groups, 35  
 Grüneisen parameter, 817–820, 822, 826, 834, 866
- H**
- Harmonic analysis, 280, 330–331, 425, 431, 435, 439, 486, 502, 540  
 Harmonic generation, 58, 829–831, 865  
 Harmonic series, 165, 167, 168, 184, 186, 204, 283, 284, 461, 570  
 Heat capacity at constant pressure, 406, 419, 787  
 Heat capacity at constant volume, 403, 408, 411, 419  
 Helmholtz equation, 295, 339, 385, 587, 718, 719, 734, 736, 749



- Helmholtz resonator, 105, 186, 244, 368, 424, 442–448, 450–455, 462, 463, 465, 467, 474–480, 482, 484–486, 490–492, 495, 506, 515–520, 528, 534, 545, 556, 557, 559, 568, 577, 579–581, 635, 649, 650, 663, 664, 702, 780, 848, 849
- Homogeneous, 20, 27, 28, 31, 35, 71, 88, 98, 99, 108, 156, 160, 201, 213, 214, 220, 294, 363, 364, 366, 401, 412, 413, 418, 429, 537, 538, 548, 587, 641, 719, 731, 738, 779, 781, 782, 784, 788, 790, 794, 832, 833
- Homogeneous fluid, 419, 779, 784, 788, 832
- Hooke's law, 7–12, 14, 27, 28, 58, 71, 78, 79, 82, 100, 131, 132, 172, 212, 213, 219–221, 241, 244, 246, 247, 252–254, 268, 280, 331, 396, 435, 648, 862
- Hydrodynamic mass, 140, 487, 644, 647, 648, 659, 667, 680, 700–702, 706, 708, 712
- Hydrostatic strain, 784, 804
- I**
- Ideal Gas Law, 6, 384, 395–421, 432, 436, 521, 522, 542
- Impedance matching layer, 611, 630
- Impedance transformer, 197, 204, 222
- Inductive reactance, 441, 486
- Inert gas, 60, 145, 398, 399, 408, 411, 419, 490, 524, 527, 528, 790, 793, 819
- Inertia coefficient, 173, 176, 179, 204, 329
- Inhomogeneous differential equation, 385, 843
- Input mechanical impedance, 193, 194, 204, 249, 253
- Instantaneous value, 426, 486, 529
- Integration by parts, 2, 5, 58, 254
- Intensive variables, 400, 419
- Intermodulation distortion, 814, 835–839, 866
- Internal energy, 245, 403, 404, 786, 851, 866
- Interval, 108, 159, 160, 165–170, 204, 330, 336, 344, 347, 355, 384, 385, 429, 549, 553, 554, 638, 640, 672, 692, 711, 761, 826
- Isobaric heat capacity, 404, 407, 408, 417, 419, 526
- Isochoric heat capacity, 403–405, 408, 417, 419
- Isochronism, 13, 58
- Isothermal equation of state, 405, 419
- Isotropic, 58, 214–221, 258, 268, 270, 300, 312, 400, 401, 412, 413, 418, 537, 546, 642, 652, 679, 731, 780, 781, 790, 840
- Isotropic fluid, 418, 419, 486, 652
- J**
- Joining conditions, 443, 486
- Joule heating, 194, 498, 516, 529, 575
- K**
- Kinematic viscosity, 511, 514, 529, 789
- Kinetic theory, 92, 398, 401, 521–528, 727, 783, 790, 804, 847
- Kinetic theory of gases, 92, 398, 419, 783, 804, 847
- Kramers–Kronig relations, 245, 254–257, 272, 320, 780, 794, 795, 804
- Kronecker delta, 17, 58
- $k$ -space, 345, 346, 385, 724, 743, 765
- Kundt's tube, 847, 866
- L**
- Laboratory frame of reference, 395, 396, 427, 428, 486, 847
- Lagrangian description, 428, 486
- Laplace's formula, 647, 706
- Laplacian operator, 338, 348, 385, 414, 497, 641, 718, 735
- Le Châtelier's Principle, 793, 804
- Least-squares fit, 49–56, 58, 113, 114, 137, 347, 421, 805
- Legendre transformation, 786, 804
- Lenz's Law, 112, 138
- Level repulsion, 129–131, 138, 485, 571, 574
- Linear relationship, 11, 45, 49, 50, 58, 113, 212
- Linear response theory, 245, 251, 254, 272
- Linearized continuity equation, 430, 433, 435, 537–540, 591, 592, 814
- Linearized Euler equation, 435, 437, 440, 441, 443, 538–540, 584, 591, 592, 642, 675, 736, 738
- Logarithmic decrement, 88, 89, 138
- Logarithmic differentiation, 2, 6–7, 44, 58, 59, 84, 213, 215, 281, 362, 369, 371, 406, 419, 435, 542, 640, 816
- Loss factor/damping factor, 253, 272
- Loss modulus, 260, 261, 272
- Lumped element, 74–77, 86, 184, 188, 203, 388, 389, 424–492, 495, 528, 534–536, 559, 579, 603, 638, 640, 647, 780, 844
- M**
- Macroscopic variables, 401, 419
- Mass-controlled regime, 118, 120, 138, 700
- Master curve, 261, 321, 331

- Maxwell model, 248–251, 253, 272, 780  
 Maxwell relations, 787, 804  
 Mean field approximation, 682, 683, 706  
 Mean free path, 374, 521–522, 524, 525, 528, 529, 783, 789, 791, 802, 804  
 Mean value, 37, 38, 93, 425, 426, 432, 434, 439, 486  
 Mechanical impedance, 70, 98–100, 104, 108, 118, 137, 138, 185, 192–194, 196–198, 203, 249, 252, 280, 433, 479, 545, 570, 571, 573, 591, 643, 667, 681, 700  
 Mechanical reactance, 99, 138  
 Mechanical resistance, 15, 29, 70, 87–88, 94, 95, 99, 102, 103, 113–115, 117, 119, 121, 137, 138, 140, 146, 149, 151, 192–194, 200, 246, 252, 264, 265, 389, 425, 483, 530, 569, 572, 576, 712, 779, 780, 862, 863  
 Method of images, 162, 204, 656–660  
 Minor lobe, 695, 706  
 Modal density, 344, 348, 385, 733, 742–744  
 Mode splitting, 343, 385, 747–749, 767  
 Modified Bessel functions, 381–383  
 Modulus of unilateral compression, 216–217, 219, 220, 258, 259, 272, 284, 780, 785, 840  
 Monopole, 636, 637, 642–647, 652–663, 665–667, 669, 673, 674, 676, 687, 688, 695, 698, 706, 731
- N**
- Natural frequency, 29, 70, 80, 81, 83–85, 89, 98, 99, 106, 108, 109, 112, 119, 121, 122, 130, 138–140, 142, 146, 171, 186, 187, 222, 235, 257, 258, 264, 266, 267, 273, 274, 276, 530, 556, 664, 680, 713, 733, 745, 863, 864  
 Navier–Stokes Equation, 32, 295, 415, 417, 419, 424, 425, 435, 452, 497, 510, 511, 514, 644, 780–782, 789  
 Nearest-neighbor interactions, 133, 138  
 Near field, 645, 701–706  
 Neumann functions, 353, 359, 364, 381, 382, 385, 694, 738, 739  
 Neutral equilibrium, 8, 58  
 Neutral plane, 229, 230, 272, 380  
 Newton’s Law of Cooling, 499–510, 524, 529  
 Newtonian fluids, 510, 511, 529  
 Nodes, 165, 177, 182, 183, 188, 189, 197, 199, 204, 207, 208, 225, 227, 304, 341, 343, 387, 535, 582, 656, 662, 723, 741, 748, 846, 853, 855, 856, 858, 861, 862
- Nondimensional frequency, 780, 794–796, 804  
 Non-linear effect, 426, 432  
 Non reflecting termination, 194, 204  
 Non-slip boundary condition, 510, 512, 513, 515, 529  
 Normal coordinates, 126–127, 138  
 Normal mode frequencies, 86, 123–125, 134, 136, 138, 147, 148, 162, 165, 166, 168, 173–179, 184–186, 188, 201–203, 206, 208, 226–228, 243, 262, 271, 272, 284, 286, 299, 300, 302, 304, 306, 318, 322, 331, 339, 341, 342, 352, 354–356, 358–360, 362–366, 368, 381, 383, 385, 389, 475, 476, 484, 555, 740, 750, 751, 753, 855, 856, 858  
 Normal modes, 86, 162–170, 225, 300, 336, 469, 475–477, 484, 555, 660, 717, 855
- O**
- Oblique mode, 765  
 Ohm’s law, 27, 498–499, 510, 515, 529  
 Open-circuit microphone sensitivity, 372, 385, 598, 599  
 Order expansion, 827–829, 866  
 Orthogonal functions, 16, 58  
 Oscillatory plug flow, 529  
 Over damped, 138  
 Overtones, 165, 167, 204, 303, 328, 330, 461, 733
- P**
- Particular solution, 364, 366, 385  
 Pascal’s law, 214, 400, 419, 443  
 Paschen’s law, 374, 385  
 Period, 14, 71, 154, 261, 288, 341, 403, 426, 508, 541, 554, 620, 639, 737, 784, 825  
 Periodic boundary conditions, 350, 381, 385, 737, 765  
 Permittivity of free space, 144, 146, 369, 385  
 Phase-locked loop, 104–107, 138, 318, 562  
 Phase matching, 834–836, 840, 866  
 Phase speed, 48, 54, 55, 282, 295, 300, 302, 305, 327, 331, 540–544, 584, 759–762, 770–772, 816, 834, 840, 841  
 Phasor notation, 23, 58  
 Piecewise-linear approximation, 619, 620, 624, 628, 630  
 Planck distribution, 410, 419  
 Planck’s constant, 84, 409–411, 419, 564  
 Point particles, 398, 399, 401, 408, 410, 419, 521, 818

Point-mass, 70, 131, 138, 176–177, 409  
 Poiseuille's formula, 513, 529  
 Poisson's ratio, 213–220, 242, 258, 268,  
 272, 274, 281, 282, 284, 285, 332,  
 380, 840, 841  
 Polar moment of inertia, 291, 292  
 Polarizing voltage, 370, 373–376, 385  
 Polyatomic molecules, 409, 419, 525, 791  
 Polytropic coefficient, 6, 362, 365, 385, 406,  
 412, 418, 421, 542, 543, 568, 789, 821  
 Potential energy, 7–10, 12, 13, 42, 58, 59,  
 78–80, 82, 86, 91, 94, 97, 137, 141,  
 144, 171–173, 179, 183, 233, 248,  
 250, 276, 289, 290, 329, 374, 389,  
 409, 424, 498, 534, 547, 556, 560,  
 591, 592, 650, 726, 748, 764, 846,  
 856, 857  
 Prandtl number, 454, 526–529, 543, 789  
 Precision, 35–45, 58, 279, 288, 313, 325,  
 403, 421, 568, 597, 753, 754  
 Pressure gradient microphone, 669–672, 706  
 Pressure reflection coefficient, 608, 610, 630  
 Pressure release boundary, 609, 630  
 Pressure transmission coefficient, 609, 630  
 Principle of reciprocity, 562–564  
 The Principle of superposition, 15, 58, 214,  
 647, 652  
 Product rule, 58, 641, 642, 786, 851  
 Proof mass, 222, 272, 276  
 Pump waves, 806, 835–840, 866  
 Pure tone, 295, 331, 593, 799, 806, 827  
 Pythagorean scale, 169, 170, 204

## Q

Quadratic degree-of-freedom, 399, 419  
 Quadrature output, 320, 331  
 Quality factor, 30, 70, 88–89, 103, 105, 107,  
 109, 118, 119, 138, 139, 284, 290, 313,  
 320, 389, 424, 463, 465, 469, 473, 482,  
 489, 491, 517–520, 531, 544, 556–560,  
 566, 568, 569, 649–651, 680, 682, 723,  
 731, 753, 780, 862  
 Quasi-static approximation, 74, 81, 138, 244

## R

Radian frequency, 29, 71, 138, 163, 173, 176,  
 189, 193, 205, 253, 557, 772  
 Radiation mass, 226, 228, 272, 448, 711  
 Radiation pressure, 751, 846, 851–852, 857,  
 862, 866  
 Radiation reactance, 245, 644, 706

Radiation resistance, 193, 194, 204, 245,  
 644, 646, 667, 700, 706, 712  
 Radius-of-gyration, 229–231, 242, 272, 293,  
 294, 300, 849  
 Random errors, 36–38, 40, 58, 317  
 Ray tracing, 451, 619, 630  
 Rayl, 545, 591  
 Rayleigh resolution criterion, 637, 696–698,  
 706, 802  
 Rayleigh scattering, 677, 706  
 Rayleigh's method, 80–81, 138, 142, 171,  
 173, 174, 176–179, 201, 206, 207,  
 272, 313, 316, 329, 343, 748, 856  
 Reciprocal space, 345, 385  
 Reciprocity calibration, 562, 564–568, 591,  
 596–599, 659  
 Reduced frequency, 321, 322, 331  
 Reduced mass, 521  
 Reference intensity level, 550, 591  
 Reference sound pressure level, 551, 591  
 Refraction, 603, 616, 618, 621–623, 630,  
 632, 657, 802  
 Relative uncertainty, 36–38, 40, 44, 47, 52,  
 53, 58, 113–115, 312, 313, 317, 332,  
 421, 451, 491  
 Relaxation time, 245–249, 251, 255, 259, 263,  
 266, 271, 272, 321, 412, 415, 530, 651,  
 780, 783, 791, 793–800, 804, 863  
 Residual, 43, 45, 46, 51, 56–58, 549  
 Resistance-controlled regime, 99, 138  
 Resonance, 70, 186, 224, 367, 368, 370, 371,  
 378, 389, 424, 447–450, 460, 461,  
 463–465, 468, 470, 473–475, 477, 478,  
 480–485, 488–491, 495, 536, 571, 574,  
 588, 647, 731, 780, 834–835  
 Resonant mode conversion, 566, 839–843, 866  
 Resonant Ultrasound Spectroscopy, 322–325,  
 331  
 Reversible transducer, 115, 138, 564–566,  
 597, 598, 850  
 Ribbon microphone, 671, 706  
 Ring down, 108, 138

## S

Scale of just intonation, 168, 169, 204  
 Schroeder frequency, 731–734, 765, 766, 773  
 Second Law of Thermodynamics, 402, 419  
 Second order correction, 4, 58, 828  
 Second sound, 822, 823, 841–843, 850, 866  
 Second viscosity, 412, 548, 793, 804  
 Secular equation, 125, 138, 782  
 Seismic mass, 222, 223, 272

- Seismometer, 27, 120, 138
- Self-interaction, 814, 835, 866
- Semi-infinite half-space, 695, 699, 706
- Separation condition, 339, 385, 719, 757
- Separation of variables, 297, 327, 330, 331, 339, 358, 718–725, 735
- Shaded array, 690, 706
- Shape factor, 259, 272
- Shear (or dynamic or absolute) viscosity, 511, 529
- Shear strain, 218, 258, 784, 804
- Shear viscosity, 32, 414, 415, 417, 419, 424, 454, 497, 510, 516, 521, 525, 529, 530, 548, 780, 785, 786, 789, 790, 793, 799, 804, 826
- Shock inception distance, 817, 819, 824, 825, 829, 830, 838, 866, 867
- SI System of units, 27, 28, 58
- Similitude, 28–35, 58, 63, 74, 77, 88, 186, 244, 246, 247, 592, 780
- Single relaxation time model, 245, 254, 255, 266, 271, 272
- Slenderness ratio, 237, 272
- Snell's law, 611–618, 623–626, 628, 630
- SOFAR channel, 627, 630, 807
- Solid angle, 523, 582, 677, 679, 696–698, 706
- Sound channel, 620, 623–630, 807
- Sound level meter, 370, 553, 597–599
- Source strength, 561, 565, 566, 644–647, 650, 653–656, 659, 661–663, 665, 673, 675, 679, 684, 687, 690, 691, 698, 706, 709
- Spatial attenuation coefficient, 764, 782–784, 786, 797, 804, 806, 836
- Speaking length (for piano strings), 330, 331
- Specific acoustic impedance, 545–546, 550, 591, 606–611, 616, 618, 630, 642–644, 646, 659, 706
- Specific heat ratio, 406, 419, 794
- Specular reflection, 613, 630
- Stability coefficient, 173, 175, 176, 179, 204, 329
- Stable equilibrium, 2, 3, 7–12, 14, 58, 793
- Standard deviation, 36–40, 44, 45, 51, 58, 113, 304, 312, 317
- Standard linear viscoelasticity model, 272
- Standing waves, 105, 162–172, 184, 186–189, 191, 192, 200, 204–206, 272, 282–284, 288, 289, 291, 298–300, 302, 304, 318, 320, 330, 427, 439, 446, 447, 453, 458, 469, 489, 490, 505, 514, 535, 540, 554–559, 565, 570–574, 582, 588, 592, 597, 598, 684, 720, 733, 740, 747, 748, 753, 755, 761, 846, 847, 850, 852–856, 858, 862–864, 868, 869
- Statistical fluctuations, 36, 37, 47, 58
- Steradian, 677, 697, 706
- Stiffness matrix, 268–270, 272
- Stiffness-controlled regime, 121, 138
- Storage modulus, 260, 272
- Strain, 27, 212, 213, 215, 217, 219, 229–232, 234, 244, 251–253, 269, 272, 274, 275, 280–282, 285, 289, 290, 510
- Streaming, 432, 583, 865
- Stress, 27, 212–214, 217–219, 221, 224, 229–231, 234, 236, 240, 241, 244, 252, 253, 258, 259, 268, 269, 272, 274, 280, 285, 294, 313, 348, 398, 415, 417, 507, 510, 515, 530, 554, 651, 718, 784, 790
- Structural relaxation, 799, 804
- Symmetric mode, 123, 125–127, 132, 138
- Systematic (bias) errors, 36, 58
- T**
- Tangential mode, 724, 765
- Taylor series expansion, 3, 8, 9, 12, 20, 21, 58, 59, 105, 109, 171, 187, 191, 201, 280, 328, 331, 501, 695, 815
- Temporal attenuation coefficient, 782, 784, 786, 804
- Test mass, 222–224, 272
- Thermal conductivity, 27, 35, 223, 416, 419, 424, 451, 454, 457, 496, 497, 499–509, 517, 521–526, 528, 529, 543, 548, 596, 780, 782, 784, 786, 799, 804, 826, 832
- Thermal diffusivity, 501, 511, 514, 529
- Thermal penetration depth, 454, 505, 506, 508, 513, 517, 520, 528, 529, 558, 568, 596, 606, 651
- Thermal relaxation, 464, 465, 467, 468, 517, 557–559, 606, 649–651, 754, 780, 804
- Thermal velocity, 521, 523, 529, 789
- Thermometric conductivity, 501, 529
- Thermoviscous boundary layer, 424, 448, 517, 556, 758, 765, 779, 780, 804
- Thermoviscous losses, 475, 764, 765, 788, 789, 826
- Time reversal invariance, 496–498, 529
- Tonpiltz transducer, 225, 226, 272, 522, 702
- Torsional rigidity, 292, 331
- Total internal reflection, 612, 614–618, 630
- Total scattering cross-section, 678, 679, 681, 706
- Trace wavelength, 612, 613, 630
- Transcendental equation, 185, 189, 191, 198, 204, 208, 286, 299, 302, 313, 328, 365, 570, 571, 745, 755
- Transmissibility, 117–120, 138, 142, 262–268

Transverse wave speed, 204, 208, 387–389  
 Traveling wave, 156, 165, 204, 282, 283, 295,  
 297, 327, 342, 427, 431, 432, 453, 458,  
 497, 540, 546, 577, 578, 591, 605, 638,  
 640, 747, 748, 761, 765, 782, 816, 828,  
 834, 852  
 Two-fold degeneracy, 740, 747, 765

**U**

Under damped, 138  
 Universal Gas Constant, 6, 400, 408, 419,  
 542, 755, 756, 773, 788, 825  
 Unstable equilibrium, 8, 9, 11, 58

**V**

Velocity potential, 851, 866  
 Vibrating reed electrometer, 378, 385  
 Vibration isolator, 118, 120, 138, 142, 221,  
 249, 258, 259, 262–268, 271, 274,  
 275, 435  
 Vibrational relaxation time, 796  
 Virial expansion, 819–821, 823, 824, 866  
 Virial theorem, 79–80, 137, 138, 172, 726  
 Viscoelasticity, 244–257, 780, 804  
 Viscous drag, 42, 87, 515–517, 530, 780,  
 804, 862  
 Viscous penetration depth, 454, 514, 515,  
 518, 519, 528–531, 554, 557  
 Viscous stress tensor, 416, 417, 419  
 Void fraction, 396, 401, 683, 706

Voigt notation, 269, 272  
 Volume velocity, 200, 360, 430, 433–435,  
 441–443, 446, 447, 457–467, 470,  
 476–482, 512, 534, 545, 546, 559,  
 560, 569, 573–580, 582, 584–586,  
 589, 590, 596, 636, 722, 868  
 Volumetric strain, 215, 272

**W**

Wakeland number, 591  
 Wave equation, 156, 157, 162, 163, 178,  
 192, 193, 197, 201, 202, 204, 279,  
 282, 292, 294, 301, 322, 330, 338,  
 339, 348–353, 380, 534, 537–540,  
 555, 556, 587, 591, 603, 640, 641,  
 646, 717, 833–834, 842, 843  
 Wavenumber, 162–165, 185, 191–193,  
 202–205, 283, 286, 295, 297, 299–302,  
 328, 345, 354, 364–366, 381, 497, 502,  
 503, 509, 514, 528, 540, 541, 555, 570,  
 585, 610, 613, 665, 711, 724, 757, 758,  
 760, 762, 765, 780, 782, 783, 840  
 Wavenumber space, 724, 765

**Y**

Young's modulus, 142, 213, 214, 217,  
 218, 220, 223, 226, 230, 258, 260,  
 272–274, 276, 280, 281, 284, 285,  
 294, 300, 312, 318, 330, 332, 333,  
 380, 389, 595, 840