

Index

Note: Page numbers with “f” denote figures; “t” tables.

A

Airy
 diffraction pattern, 555
 disk, 564
Absorption in air, 472
Absorption coefficients (room)
 Sabine, 470–472
 Eyring, 470–472
Acoustic, definition, 10
Acoustic compliance, 46, 87–88
Acoustic components, 119–128
Acoustic conductance, 88–89, 415
Acoustic generators, 89, 72
Acoustic impedance, 14
Acoustic inertance, *see* Mass
Acoustic mass, 86–87, 120–121
Acoustic materials, 46–47, 298, 302, 304–308
Acoustic resistance, 88, 125–128
Acoustic transformers, 131
Acoustical, definition, 10
Acoustical circuits, 84–94
Acoustical elements, 84–94
Acoustical holography, 627–628
Acoustical standards, 14
Acoustics
 in concert halls, 475–476
 in living rooms, 483–485
Adiabatic, definition, 6
Adiabatic alternations, 24
Admittances
 analogies, 68–71
 conversion to impedance analogies, 70–71
 definitions, 69
 mechanical, 69–84
Air, basics, 5–13
Air attenuation constant, 472
Air density, 13
Air losses, 472
Air speed, 5
Air-suspension loudspeakers, 291
Alignment tables for loudspeaker in
 bass-reflex enclosure, 335–339
 closed-box enclosure, 317–319
American Standards Assoc., 14
Analogies, 65–112
 admittance type, 69–71
 conversion of, 70–71
 impedance type, 66–69

 transformation, 70–71
 rotational, 93–94
Anechoic chamber, 139, 157, 246, 259, 436, 474
Area, effective, of diaphragm, 245, 260, 301
Attenuation of sound in air, 472
Auditoriums
 mean free path, 469
 reverberation time, 470–472
 sound absorption coefficients, 471
 sound decay rate, 470
 sound energy density, 14
 sound pressure levels, 16
Average room absorption coefficient, 471

B

Babinet-Bouwkamp principle, 579, 602–609
Baffle
 bass-reflex, 291–292, 329–358
 closed-box, 291, 295–329
 finite, 294
 infinite, 294
 open back, 295
 unbaffled, 292–294
Barometric pressure (atmospheric), 12
Bass quality
 explanation, 142
 pressure-gradient microphone, 202–205
 ribbon microphone, 225
Beam-forming, 4, 148–153
Beam width, 137, 255
Bends in horns, 435–438
Bessel functions, 48–49, 51, 57–58, 60–61
Boundary conditions, 33, 37, 137, 138, 181, 355, 418, 487–613
 Dirichlet, 562, 583
 Neumann, 554, 573, 583, 610
 slip, 179
Boundary integral method, 536–646
 case study, 548–551
Boundary layer thickness, 183–184
Boundary value method, 487–533
Bouwkamp impedance theorem, 165, 609, 612, 620, 622
Box
 bass-reflex, 292, 329–358
 closed, 291, 295–329
 open-back, 295
 transmission-line, 292, 358–373

C

Call loudspeaker, 135, 391–397

Capacitor microphones

- construction and properties, 216–225
- humidity effects, 216
- temperature effects, 216

Cardioid pattern, 206–208, 228–239

- hypercardioid, 230
- supercardioid, 230

Cellphone acoustics, 391–406

- call loudspeaker, 391–392
- diaphragm, 391
- dust screen, 126, 395
- electret microphone, 397–400
- low-pass filter, 394–395
- magnetic fields, 395
- MEMS microphone, 400–402
- sidetone, 405–406
- testing, 396–397, 402–405
- turbulence, 396
- wind noise, 396

Characteristic impedance, 14, 37, 38, 48

Charles-Boyle gas law, 24–25, 181

Closed-box baffle, 291, 295–298

Closed tube, 37–46

- see also* Tubes

Coefficients

- absorption, 471
- reflection, 38, 492–493, 497–499
- transmission, 437–438, 492–494, 497–499, 572

Coil, voice, 267–270

Combination microphones, 206–208, 228–239

Compliance

- acoustic, 87–88, 121–123, 128
- closed box, 295–322
- closed tube, 121–122
- drive unit, 243–244
- jug, 123–125
- mechanical, 72–74
- series, acoustic, 122

Components, acoustic, 119–198

Compressibility

- dynamic, 179, 185, 188

Condenser microphones, *see* capacitor Microphones

Cone, *see* Diaphragm

Conical horn, 421–422, 429–430

Connector, exponential, 133–136

Constants

- barometric pressure, 12
- characteristic impedance, 14, 34, 38, 48
- decay, room, 464

- density-of-air, 13
- drive unit, 252
- flare, 422–424
- Thiele-Small, 252
- reference quantities, 14–18
- speed of sound, 13

Continuity equation, 25

Conversion tables

- impedance-to-admittance analogies, 70–71, 104–106
- factors (Appendix III)
- units (Appendix III)

Coordinates

- cylindrical, 55–58
- oblate spheroidal, 418, 572, 582
- rectangular, 54–55
- spherical, 59–62

Coupler, *see* connector

Crossection shapes, horns, 438

Crossover networks, 373–387

Cut-off frequency of horn, 421–428

Cylindrical wave, 48–50

D

Decay curves, for sound in rooms, 464–466

Density, air

- definition, 13
- dynamic, 179, 185, 188
- formula, 13
- normal, 13
- variational, 13

Diameter, effective, of diaphragms, 300

Diaphragms

- behavior, 270–273
- diameter, effective, 300

Diffraction of plane wave

- through resilient screen, 607–609
- through rigid screen, 607

Diffuse sound field, 469

Dipole source, *see* Doublet

Dipole strength, 155

Direct sound, 472

Directivity, 162–163

Directivity characteristics,

- of loudspeakers, 274, 286
- of microphones, 204, 207, 228–231

Directivity factor, 162–163

Directivity index (DI)

- calculation, 163
- definition, 163
- of sources, 165–167

Directivity patterns, 144–145, 156, 157
 dipole point source (doublet), 156
 sphere (pulsating & oscillating), 160–161
 Distortion
 loudspeakers, 280–285
 horn, 407, 433–435
 large-amplitude waves, 433–435
 phase delay of crossover, 382–383
 transient, 277–282
 Doublet
 microphone, 202–205
 piston without baffle, 175–176
 simple, 153–157
 Dual diaphragm microphones, 231–239
 Dynamic compressibility, 179, 185, 188–189
 Dynamic density, 179, 185, 188–189
 Dynamic loudspeaker, *see* Direct-radiator Loudspeakers
 Dynamic microphone, 208–215

E

Early sound, 475–476
 Effective area of diaphragm, 245, 260, 301
 Effective diameter of diaphragm, 300
 Effective length of tube, 121–122
 Effective particle velocity, 13
 Effective sound pressure, 13
 Effective volume velocity, 13
 Efficiency
 loudspeakers, 257
 horn, 410–412
 Electrodynamic loudspeakers, 241–288
 advantages, 242
 baffle
 finite, 294
 infinite, 294
 bass-reflex, 292, 329–358
 closed-box, 291, 295–328
 constants, 244
 construction, 242–244
 design factors, 263–270
 diaphragm, 270–273
 directivity, 273–275, 286
 dual concentric, 388
 efficiency, 257–259
 element values, 252
 impedance, input, 256–257
 metals, 268
 non-linearity, 282–287
 power output, 251
 response, 253–256
 Thiele-Small parameters, 252, 259–262

 transfer function, 275–277
 transient, 277–282
 transmission-line enclosures, 292, 358–373
 unbaffled, 292–294
 voice-coil velocity, 246–250
 Electromagnetic transducers, 94–96, 109–112
 Electromagnetic microphones, 208–215
 Electrostatic transducers, 96–101, 112–115
 Electrostatic microphones, *see* Capacitor Microphones
 Electret microphone, 397–400
 Elements of circuits
 acoustical, 84–89
 compliance, acoustic, 87
 compliance, mechanical, 72–74
 general, 65–66
 generator, mechanical, 75–76
 generator, acoustic, 89–93
 mass, acoustic, 86–87, 120–121
 mass, mechanical, 71–72
 mechanical, 71–76
 resistance, acoustic, 88–89
 resistance, mechanical, 74–75
 transformers, acoustic, 131–135
 transformers, mechanical, 76–79
 Enclosures
 bass-reflex, 292, 329–358
 closed-box, 291, 295–329
 transmission-line, 292, 358–373
 End corrections, tubes, 121
 Energy density, definition, 14–15
 Energy flux, *see* Intensity
 Equivalent suspension volume, 252, 260–262, 300
 Exponential, horn, 408, 422–425, 430–431, 432
 Exponential connector, 133–134
 Eyring, equation, 470–471

F

Far field, 157
 Ferrofluid, 285
 Field matching, 520, 526
 Field, sound
 diffuse, 469
 direct, 472
 far, 157
 free, 34
 near, 157
 reverberant, 476–477
 Filters, electrical, 373–387
 Flare constant, 422–424
 Flow resistance, 46, 304
 Fluctuations of sound, in room, 464–466

Flux density
 definition, 244
 typical, for loudspeakers, 264–267
 Force equation, 38
 Fourier law, 181
 Fourier series, 11, 31
 Fourier transform, 153, 279, 464, 542–543, 614–618, 627–628
 Forward traveling wave, 32–47
 Fraunhofer
 diffraction pattern, 555
 diffraction zone, 558
 Fresnel region, 558
 Friction, in air, 472

G

Gas
 adiabatic, 6
 isothermal, 6
 law, 24–25, 181
 Generators
 acoustic, 89–90
 constant force, 75–76
 constant pressure, 89–90
 constant velocity, 75
 loudspeakers, *see* Direct radiator Loudspeakers
 mechanical, 75–76
 piezo-electric, 96–101
 Gradient microphones
 general, 202–205, 225–228
 ribbon, 225–228
 Gram-molecular weight, 24
 Green's function, 536–539, 541–548
 Green's theorem, 540

H

Handsfree loudspeaker, 391–392
 Harmonic distortion
 in horns, 407, 433–435
 in loudspeakers, 281–285
 in large-amplitude waves, 433–435
 Helmholtz resonator, 92–93, 394–395
 Helmholtz wave equation
 cylindrical coordinates, 55–58
 infinite lossy tube, 184–185
 inhomogeneous, 539
 plane wave, 32–33
 rectangular coordinates, 54–55
 spherical coordinates, 59–62
 History, 1–5
 Horn drive units,
 circuit for, 408–410

efficiency, 410–412
 response, 412–415
 Horn loudspeakers, 407–448
 Horns
 advantages, 407
 bends, 435–438
 circuit for, 408–410
 conductance, 415
 conical, 421–422, 429–431
 cross-section shapes, 438
 cutoff frequency, 421–425
 disadvantages, 408
 distortion
 non-linear, 433–435
 drive unit, 407
 exponential, 408, 422–425, 430–431, 432
 frequency response, 412–415
 finite, 428–435
 flare constant, 422–424
 folded, 436–438
 high-frequency, 412, 415, 419
 hyperbolic, 425–428, 430, 431
 impedance, 407, 414, 421–428, 430, 432
 Klipsch, 441–442
 low-frequency, 413–415
 materials, 438–439
 mid-frequency, 412
 mouth, 419
 parabolic, 419–421, 429, 430
 Humidity, effects, 472
 Huygens-Fresnel principle, 536

I

Impedances
 analogies, 68
 characteristic, 14, 34, 38, 48
 closed box, 302–309
 definitions, 14
 horn, *see* Horns
 loudspeaker, 256–257
 mechanical, 14, 69–71
 perforated sheet, 130
 screens, 126
 specific, 14
 tubes, 126–127, 129, 178–198
 Inertance, *see* Mass
 Infinite baffle, 121, 165–166, 170, 243, 294, 520, 526, 553–627
 Intensity
 definition, 14–15
 level, 15
 Isothermal, definition, 6

J

Jug, 123

K

King integral, 553, 560, 566, 573, 584
 Kirchhoff-Helmholtz boundary integral, 539–541
 Klipsch horn, 441–442
 Knudsen number, 127

L

Laplace operator
 cylindrical coordinates, 56
 Green's theorem, 540
 rectangular coordinates, 54
 spherical coordinates, 59
 Laplace transform, 275–280, 464
 Large amplitude waves, 433–435
 Least-mean-squares method, 148–153, 586
 Legendre function, 62
 Levels, 15–18
 Levers, 76–79
 Linings, baffle box, 291–292, 302–308
 Losses, air, 472
 Loudness
 concert hall, 482
 listening room, 483–484
 Loudspeakers
 bass-reflex enclosed, 329–358
 box enclosed, 295–321
 direct radiator, *see* Electrodynamic loudspeakers
 dual concentric, 388
 electrodynamic, 241–288
 magnet size, 264–267
 transmission line enclosures, 292, 358–373
 wave, 358–365

M

Magnetic fields, 395
 Magnet size, 264–267
 Mass
 acoustic, 120–121
 diaphragm, 244–252
 mechanical, 71–72
 voice-coil, 267–270
 Matrices
 ...transmission parameter, 108–114, 187
 ...z-parameter, 99, 111–115, 186, 219, 352–358
 Materials, sound absorbent, 304–309
 Mean free path
 of air molecules, 5, 127, 179, 182
 of waves, 469

MEMS microphone, 400–402
 Mechanical circuits, 69–84
 Mechanical compliance, 72–74
 Mechanical elements, 71–77
 Mechanical generators, 75–76
 Mechanical impedance, 14, 69
 Mechanical mass, 71–72
 Mechanical resistance, 74–75
 Mechano-acoustic transducers, 101–102
 Metals

 density, 268
 resistivity, 268

Microphones, 199–240

 bass quality, 204, 225
 capacitor, *see* Capacitor microphones
 cardioid, 206–208, 228–239
 combination, 206–208, 228–239
 directivity, 204–205, 208, 228–231
 dual diaphragm, 231–239
 electret, 397–400
 electrostatic, *see* Capacitor microphones
 gradient, 202–205, 225–228
 MEMS, 400–402
 moving coil, 208–215
 piezoelectric, 96–97
 pressure, 200–201, 208–225
 pressure gradient, 202–205, 225–228
 ribbon, *see* Ribbon microphones
 summary, 199–200

Mutual impedance of

 bend in horn, 453–438
 pistons in closed box with or without lining, 352–358
 pistons in infinite baffle, 408, 621–627

N

Navier-Stokes equation, 178, 180
 Near field, 157
 Networks, 373–387
 Non-linear distortion
 in horns, 407, 433–435
 in loudspeakers, 282–285
 in large-amplitude waves, 433–435
 Normal frequencies, 450–458
 Normal frequency diagram, 468
 Normal modes of vibration, 450–458
 Norton's theorem, 246, 652

O

Optimum reverberation time, 473
 Orchestra power levels, 477–478
 Orthogonality, 356, 499–500
 Oscillating sphere, 157–162

P

- Parabolic horn, 419–421, 429, 430
- Perforated sheet, 130
- Piezoelectric transducer, 96–101, 116–118
- Pipes, junctions, 131–135
- Piston
 - directivity, 165–166
 - in infinite baffle, 165–166, 170–174
 - one-sided (closed-back), 165–166, 176–178
 - without baffle, 165–166, 175–176
- Plane waves
 - free progressive, impedance, particle velocity, pressure, 32–34
 - impedance terminated tube, 37–40
 - reflection from plane, 137–139
 - rigidly closed tube, 40–46
- Point source
 - dipole (doublet), 153–157
 - monopole (simple), 142
- Poiseuille flow, 193
- Polar diagram, *see* Directivity patterns
- Port
 - constants, 332–334
 - definition, 329
 - performance, 342–343
- Power
 - Level, band, spectrum, 15–18
- Prandtl number, 181
- Pressure
 - ambient (atmosphere), 13
 - microphones, 200–201, 208–225
 - gradient, 202–205, 225–228
 - reference, 16
- Pressure level, 16
- Pressure spectrum level, 18
- Product theorem, 618
- Propagation
 - general, 29–54
 - through gas, 7–9
 - speed in air, 13
 - in diaphragms, 270–273
 - in porous materials, 304–306
- Pulsating sphere, 139–142

Q**Q**

- of loudspeakers, 243, 248, 301, 343
- of perforated sheet, 130

R

- Radiation
 - from convex dome in infinite baffle, 520–526

- from concave dome in infinite baffle, 526–533
- from dipole point source (doublet), 153–157
- from free piston without baffle, 175–176, 582–596
- from infinite cylinder or line source, 487–489
- from infinite strip in infinite baffle, 610–613
- from monopole point source (simple), 142
- from linear array (beam-forming), 145–153
- from loudspeaker, 273–275, 287
- from one-sided piston (closed-back), 176–178, 597–602
- from oscillating sphere, 157–162, 169–170
- from piston in infinite baffle, 170–174, 553–562
- from piston in finite circular open baffle, 582–596
- from piston in finite circular closed baffle, 597–602
- from piston in a sphere, 515–520
- from pulsating sphere, 139–142, 167
- from point source on sphere, 499–503
- from rectangular cap in a sphere, 509–515
- from rectangular piston in infinite baffle, 618–621
- from resilient disk without baffle, 562–572
- from resilient disk in infinite baffle, 572–582
- from spherical cap in a sphere, 503–509
- impedances of pistons, 167–178
- impedance between pistons in infinite baffle, 621–627

Rate of sound decay, 470

Rayl, 14

Rayleigh distance, 558

Rayleigh integrals, 536–539

Reactance, *see* Impedance

Reciprocity, 186, 499, 539

Reference

- intensity, 16

- power, 17

Reflection

- diffuse, 137, 464

- point source from plane, 551–553

- plane wave from plane, 137–139

- plane wave from plane resilient object, 606–607

- plane wave from plane rigid object, 604–606

- specular, 137, 464

Relative humidity, *see* Humidity

Resistance

- acoustic, 88–89, 125–130

- flow, 46, 304

- frictional, 74

- lossy tube, 191

- mechanical, 74

- radiation, oscillating sphere, 161–162

- radiation, pulsating sphere, 141

- radiation, pistons, 167–178

screens, 126
 viscous, 74
 voice-coil, 267
 Resistivity
 metals, 268
 wire, 267
 Resonance curve, 463–464
 Resonator, Helmholtz, 92–93, 394–395
 Response of microphone, 215, 223, 234–236
 Response of loudspeaker
 in bass-reflex enclosure, 335–340
 in closed-box enclosure, 317–319
 in infinite baffle, 246–256
 Reverberant sound, 470–477
 definition, 470
 enclosures, 470–472
 equations
 Eyring, 470–472
 Sabine, 471–472
 living rooms, 483
 optimum, 473
 Reynolds number, 396
 Ribbon microphones, 225–228

S

Sabine, 1, 471–472
 Scattering
 plane wave from sphere, 489–494
 point source from sphere, 494–499
 Sheets, perforated, 130
 Side lobe, 145, 153
 Simple source, 142
 Slip (boundary), 127, 179–184, 236, 350
 Slit, impedance, 127–128
 Sound
 definition, 5–7
 diffuse field, 405, 469, 483
 direct, 472
 energy density, 14–15
 intensity, 14–15
 pressure, 14, 15–16, 47
 reverberant, 470–477
 speed, 13
 velocity, 13, 47–48
 weighting curves, 18
 Sound absorption, in air, 472
 Sound energy, density, 14–15
 Sound levels
 for speech, 477–479
 for music, 477–479
 Sound strength, G, 473–475
 Sources

 dipole point source (doublet), 153–157
 free piston without baffle, 175–176, 582–596
 linear array (beam-forming), 145–153
 monopole point source (simple), 142
 one-sided piston (closed-back), 176–178, 597–602
 piston in infinite baffle, 170–174, 553–562
 pulsating sphere, 139–142, 167
 rooms, inside, 477–479
 spherical, *see* Spherical sources
 two (simple) point sources in phase, 143–145
 Specific acoustic impedance
 definition, 14
 cylindrical wave, 49–50
 plane wave, 34
 spherical wave, 52–53
 Specific heat, of air, 6
 Spherical wave, 51–53
 Squawker, 373
 Standing wave, 41, 46, 58, 121, 306, 335, 359, 438, 450
 Standing wave ratio, 38
 Superposition, 78
 of waves, 469
 of fields, 490, 495, 506, 536, 549, 551, 597
 State variable analysis, 634–638
 Stationary wave, 41, 450
 Stiffness (reciprocal of compliance), *see* compliance
 Suspension resonance frequency, 252, 260–261, 300
 Symbols, meaning of, 67, 68

T

Terminology, 10–18
 Thermal conductivity, 181
 Thermal diffusion wave, 24
 Thermal and viscous losses, 178–198
 Thévenin's theorem, 106–107
 Thiele-Small
 parameters, 252, 300–301, 411–412
 measurement, 259–262
 Time reversal, 629–630
 Transducers, 97–102
 Transformers, acoustic, 131–135
 Transient behavior,
 loudspeakers, 277–282
 rooms, 464–466
 Transmission line loudspeaker enclosure, 292,
 358–373
 Tubes
 closed, 37–46
 filled with absorbent material, 46–47
 intermediate diameter, 129
 lossy, 178–198
 piston in end of, 37

Tubes (*Continued*)

- rigidly closed, 40–46
- specific acoustic impedance, 46
- small diameter, 126–127
- termination impedances, 38, 39

Turbulence, 396

Tweeter, 373–387

U

Units, mks, SI, 12

V

Viscosity of air, 127, 129, 180, 236

Viscous and thermal losses, 178–198

Voice-coil

- design, 267–270
- velocity, 246–250

Volume velocity, 13

W

Waves

- backward traveling, 32–33
- cylindrical, 48–50

evanescent, 58, 628

forward traveling, 32–33

free progressive, 47–48

plane, 137–139

spherical, 51–54

standing, stationary, 39–46

Wave equation, 27–29

see also Helmholtz wave equation

Wave number, 32, 47, 185

Wavelength, 9

Webster's equation, 29

Weighting curves, 18

Wind noise, 396

Woofers, 373–387

Y

Young's modulus, cone, 285