

Index

- Absorbance 54–55
Absorptance, defined 54
Absorption *see also* Cross section, absorption
 tion
 by atmospheric gases 93
 classical versus quantum-mechanical 76–78
 by harmonic oscillator 72
 by particles 110–114
Absorption coefficient
 bulk 112, 159
 defined 51
 Einstein 86, 118
 of ice and liquid water, near-infrared 285
 and imaginary part of refractive index 159
 molecular 89
 of suspension of particles 111
Absorption cross section *see* Cross section
Absorption length
 defined 53
 of ice 53, 261, 280
 of liquid water 53, 261, 280
Absorption line *see also* Line shape and Line strength
 defined 72
Absorptivity
 average 20
 defined 14
 line 108
 of a pile of plates 247
Acoustic waves 142
Aerial perspective 403
Aerosol, defined 164
Airlight *see also* Skylight
 defined 400
 luminance of 416
 radiance of 401
Albedo 33
 Bond 237
 of Earth 33, 232
 for single scattering *see* Single-scattering albedo
Alexander's dark band 434
Amplitude modulation 161
Anticorona *see* Glory
Antisolar point 377, 431
Arago point 377
Asymmetry parameter
 general expression for 298
 in Henyey–Greenstein function 305
 of a plate 248
 in two-stream theory 256
 of a water droplet 269
Atmospheric optical phenomena *see* Meteorological optics
Atmospheric optics *see* Meteorological optics
Attenuation
 exponential 52
 nonexponential 63–65, 116
 in nonuniform medium 56
Attenuation coefficient 265
Average, concept of 17–20

Babinet point 377
Backscattering
 coherent 342
 radar *see* Cross section
Beer's law 53, 116, 122, *see also* Bouguer's law
Birefringence, linear 359
 of hailstones 362, 385

- induced 359
 - natural 359
 - and sun dogs 362
- Blackbody
 - defined 13
 - minimum temperature to be visible 38
- Blackbody radiation 12–14
 - history of 39
 - without a blackbody 15–17
- Blue moon and sun 174, 179
- Boltzmann factor 80
- Bond albedo *see* Albedo
- Bouguer's law 53, 115
- Brewster angle
 - defined 364
 - pseudo-Brewster angle 365
 - scattering interpretation of 366–367
- Brewster point 377
- Brewster's law 365, 386
- Brightness
 - defined 204, 206
 - dependence on angular size 194
 - of sky 399–406, 415
- Brightness temperature
 - of clear sky 26–27
 - of clouds 26–27
 - defined 21
 - of sky with zenith angle 58
 - of water, directional dependence 31
- Candela 200
- Carbon dioxide
 - absorption spectrum of 93
 - normal modes of 83, 101
- Carbon monoxide
 - absorption spectrum of 93, 99
 - rotational energy levels of 95
 - vibrational energy levels of 95
- Caustic 195, 430
- Chappuis bands 100, 411
- Chromaticity coordinates 218
- Chromaticity diagram 218, 219
- CIE 217, *see also* Colorimetry and Chromaticity diagram
- Cloud bow 435
- Clouds
 - brightness variation of 440–441
 - color of 259–261, 268–270, 442–444
 - composition of, determined remotely 116
 - emission by 26–29
 - irradiance profiles in 319
 - particle volume fraction of 268
- Coherence 136, 175
- Coherence length
 - lateral 137–139
 - of sunlight 139
- Collisional broadening 85, *see also* Line shape
- Color contrast, simultaneous 218
- Color names 214, 216, 228
- Color temperature
 - of blackbody 222
 - correlated 222
 - of daylight 21
 - defined 21
 - of incandescent lamp 21
 - of skylight 21
- Colorimetry 216–224
 - achromatic point 219
 - chromaticity coordinates 218
 - chromaticity diagram (CIE 1931) 219
 - chromaticity diagram (CIE 1976) 223–224
 - complementary colors 219
 - defined 216
 - nonspectral colors 219
 - purity 220
 - purple line 219
 - spectral colors 219
 - spectrum locus 219
 - tristimulus values 216–217
- Colors, complementary *see* Colorimetry
- Combinations, of fundamental frequencies 82, 100
- Complex variables 66–70
- Continuum absorption 90, 104, 118
- Contrast 196
 - between object and horizon sky 416
 - because of temperature differences 25
 - threshold 416
- Coordinate axes, transformation of 308–309
- Corona 260, 427–429
 - elliptical 429, 450
 - in the eye 449
 - from nonspherical particles 429, 449
 - theory of 427–429

- Critical angle 210, 390
 and sun dogs 439
 Critical opalescence 153
 Cross section
 absorption, of atmospheric molecules 93
 absorption, of a molecule 61
 absorption, of a particle 110
 absorption, of a water droplet over six decades 170
 absorption, of a water molecule 65
 and emissivity 65
 extinction, defined 155
 extinction, of a large particle 169
 extinction, of a sphere 166
 and molecular absorption coefficient 62, 89
 radar backscattering 168
 scattering, differential 155
 scattering, of a molecule 129
 scattering, of a molecule, and polarizability 418
 scattering, of a sphere 166
 scattering, of a water droplet over six decades 170
 scattering, total 155
 volumetric absorption, defined 111
 volumetric absorption, of a particle, approximate 121
 volumetric absorption, of a slab 112
 volumetric absorption, of a water droplet 114
 volumetric scattering, defined 156
 volumetric scattering, of a water droplet 173
 wavelength dependence of 173
 Crowding 272
 Daylight 21, 405, 447
 Degree of polarization *see* Polarization
 Detailed balance, principle of 14, 40
 Dichroism
 circular 351
 linear 350
 Diffraction
 many meanings of 126
 two-slit pattern 137–138
 Diffuse radiation 261–263
 Diffusion coefficient 297–298
 Diffusion equation 297
 Diffusion length
 of cloud 299
 defined 297
 Diffusion theory 297–299
 boundary conditions for 299
 Dipole
 electric 73
 induced 73
 magnetic 374
 permanent 73
 scattering by 127–129
 Dipole moment
 electric 73
 magnetic 374
 magnetic, of oxygen 100
 Directional derivative 292–293
 Discrete ordinates 296, 336
 Dispersion
 anomalous 162
 normal 162
 of polarization 378–379
 Distribution function
 change of variable of 8
 defined 5
 distinction between point function 12
 Dominant wavelength
 of blue sky 221
 defined 218
 Doppler broadening of spectral lines 85, 102–103
 Doppler effect 143–145, 176
 Doppler shift
 blue shift 145
 longitudinal 145
 red shift 145
 transverse 145
 Doubling, method of 246, 279
 Earthshine 232
 Efficiency *see* Efficiency factor *also* Cross section
 Efficiency factor 111, 156
 e-folding length 53
 Einstein absorption coefficient *see* Absorption coefficient
 Einstein induced emission coefficient 86, 118
 Einstein spontaneous emission coefficient 86, 118

- Electric field 227
- Electromagnetic radiation *see also* Black-body radiation and Solar spectrum
 - terminology for spectral regions 22
 - wave versus particle description 1–4
- Ellipsometric parameters 346
- Ellipticity of vibration ellipse 346
- Emission
 - by clouds 26–29
 - induced 84
 - by negligibly scattering medium 310
 - spontaneous 84
 - stimulated 84
 - in two-stream theory 277–279
- Emissivity
 - and absorptivity 14
 - average 20
 - and cross sections 65
 - defined 14
 - directional 29–31, 57, 238
 - directional, of atmosphere 57
 - directional, of liquid water 29
 - and global warming 31–35
 - greater than one 13, 111
 - hemispherical 237
 - of liquid water, normal 28
 - normal 26
 - of moist air, normal 28
 - polarization dependence of 366, 386
 - of a sphere 111
- Emittance 13, 40
- Energy balance *see* Global warming
- Energy levels 78, *see also* Carbon monoxide
 - electronic 78, 80
 - excited states 79
 - ground state 79
 - lifetime of 79
 - multiplicity of 95, 96
 - populations of 96–98
 - probability of occupancy 80, 87, 95, 98
 - rigid rotator 83
 - rotational 78, 80, 83
 - vibrational 78, 80
 - of water, vibrational 81
- Entropy, of radiation 384, 394
- Equilibrium radiation *see* Blackbody radiation
- Extinction coefficient 156
- Extinction cross section *see* Cross section
- Extinction paradox 169
- Far field 371
- Fermat's principle 420
- Fick's law 297
- Field, defined 189
- Fluorescence
 - defined 41
 - of orange vests 201–202
 - of paper 203–204
- Flux 206, *see also* Irradiance
- Flux density 206, *see also* Irradiance
- Flux divergence
 - computation of by Monte Carlo method 312–313
 - defined 59, 212
 - of solar radiation in clear atmosphere 328
 - of terrestrial radiation in clear atmosphere 328
- Fog bow 435
- Fraunhofer theory 427
- Frequency
 - beat 142
 - carrier 142
 - circular 2
 - plasma 155
 - resonant 72
 - unit of 2
- Frequency modulation 161
- Fresnel coefficients
 - for reflection 364
 - for transmission 366
- Geometrical optics 3, 429
- Global warming 31–35
- Glory 436–437, 450
- Green flash 425–426, 449
 - demonstration of 449
 - role of physiology in 426, 449
- Green rim of sun 426
- Green thunderstorms 441–445, 451
- Greenhouse effect 37
- Group velocity 162–163, 178
- Halo
 - 22° 439
 - 46° 440
 - crystal size responsible for 440, 451

- frequency of occurrence of 440, 451
- lunar 439
- Handedness, of vibration ellipse 346
- Harmonic approximation 74
- Harmonic oscillator 70
 - energy levels of, quantized 77
- Harmonic wave 133
- Hartley bands 100
- Heating rate profiles, atmospheric
 - for absorption of solar radiation 331
 - for absorption of terrestrial radiation 331
- Henye–Greenstein *see* Phase function
- Herzberg band 102
- Heterodyning 143, 176
- Homonuclear molecule 81
- Horizon sky
 - color of, role of particles 406–408, 447
 - radiance of 401, 403–405
- Hue 218
- Huggins bands 100
- Ice
 - absorption spectrum of, visible 261
 - absorption spectrum over several decades 53
 - bubbly, color of 273–275
 - in near-infrared, compared with that of liquid 285
- Illuminance 206
- Image, defined 24
- Impact parameter 430
- Index of refraction *see* Refractive index
- Infrared-active gases 33, 81
- Insulation, basic physics of 37
- Intensity 204
- Interference
 - constructive 134
 - defined 134
 - destructive 134
 - of orthogonally polarized waves 349
 - of waves in different directions 146–148
 - of waves with different frequencies 136
 - when it can be ignored 249–250
- Inversion, of measurements 164, 245
- Iridescence 260, 429
- Iridescent clouds 429
- Irradiance
 - defined 207
 - diffuse transmitted 261–263
 - Monte Carlo calculation of 312
 - profiles 317–320
 - from quadrature 310
 - from radiance 207
 - vector 212, 295
- Isotope shift, of heavy water 82, 121
- Isotropic
 - medium 256, 295
 - radiation 59, 256, 295
 - scattering 256, 374
- Jacobian, of transformation 8
- Kirchhoff's law 15, 40, 89, 277
 - applied to averages 20
 - validity of 20, 40
- Koschmieder's law 416, 448
- Lambert's law *see* Bouguer's law
- Lambertian detector 209
- Lapse rate of temperature
 - average 419
 - mid-latitude summer 91
- Laser speckle 139, 176
- Line absorptivity 108
 - of carbon dioxide 110
- Line shape 85, 90, 102–104
 - Doppler broadened 102
 - foreign broadened 102
 - Lorentz 73
 - natural 102
 - and remote sensing of water vapor 105–106
 - self-broadened 102
 - Voigt 103
- Line strength 90
- Longwave radiation, defined 22
- Lorentz force 227
- Lorentz line shape *see* Line shape
- Lorenz–Mie theory 177
- Luminance 200
- Luminescence
 - defined 41
 - and fluorescence, distinction between 41
- Luminous efficiency 11, 200

- MacAdam ellipses 224, 229
- Magnetic field 227
- Marshall–Palmer distribution *see* Raindrops
- Maxwell–Boltzmann distribution 6, 38, 39
 - for molecular velocity component 145
 - in two dimensions 122
- Mean free path, photon
 - absorption 254
 - probability distribution for 253–254, 301–303
 - scattering 254
 - total 254
- Mean-value theorem 5, 190
- Mesopic vision 200
- Metamerism 218
- Meteorological optics 397, *see* Airlight, *see* Corona, *see* Glory, *see* Green flash, *see* Halo, *see* Iridescent clouds, *see* Mirages, *see* Rainbow, *see* Sun dog
- Methane
 - absorption spectrum of 93
 - normal modes of 101
- Mie theory 165
- Mirage
 - defined 418
 - extraterrestrial 423–425
 - inferior 422
 - multiple image 422, 448
 - superior 422
 - terrestrial 418–423, 448
- Mock sun *see* Sun dog
- Molecules, scattering by *see* Rayleigh’s scattering law
- Monte Carlo method
 - atmospheric applications of 315–335
 - basic principles of 300–315
- Moon illusion 418, 448
- Mueller matrix 367
 - for specular reflection 368
- Multiple scattering *see also* Radiative transfer
 - in an absorbing medium 264–268
 - defined 241
 - medium, coherent 241
 - medium, incoherent 241
- Neutral points 377
- Nitrous oxide
 - absorption spectrum of 93
 - normal modes of 101
- Normal coordinates, of harmonic oscillator 76
- Normal frequencies
 - of carbon dioxide 83, 101
 - of carbon monoxide 101
 - of harmonic oscillator 76
 - of methane 101
 - of nitrous oxide 101
 - of ozone 101
 - of water molecule 81, 101
- Normal modes, of harmonic oscillator 76
- Optical beating *see* Heterodyning
- Optical constants *see also* Refractive index
 - compendium of 178
 - defined 160
 - of water 160
- Optical depth 256
 - absorption 256
 - distinction between optical thickness 257
 - scaled 257
 - scattering 256
 - total 256
- Optical mixing *see* Heterodyning
- Optical thickness
 - absorption 55
 - along an arbitrary path 401
 - of a molecular atmosphere 400, 402
 - of a molecular atmosphere, approximate expression for 402
 - of a pile of plates 245
 - scattering 257
 - tangential 403
- Optically homogeneous medium 51
- Optically smooth surface 2
- Optically thick medium 258
- Overtones, of fundamental frequencies 82, 100
- Oxygen
 - absorption optical thickness for Earth’s atmosphere 321
 - absorption spectrum of 93
- Ozone
 - absorption spectrum of 93
 - and blue of twilight sky 409–415
 - Chappuis bands of 411

- vertical profile of 411
- Parhelia *see* Sun dog
- Particle, defined 60
- Phase, of wave, defined 133
- Phase function
 - defined 295
 - Henye–Greenstein 304
 - Henye–Greenstein, compared with Mie theory 307
 - normalization of 295
- Phase matrix 383
- Phase speed 130, 133, 161
 - greater than c 161
- Phasor 135
- Photoelectric effect 3, 37, 38
 - without photons 3, 38
- Photometry, defined 185
- Photon
 - angular momentum of 1, 45
 - energy of 1, 2
 - linear momentum of 1, 45
 - mass of 1, 37
 - path length distributions of 315, 320
- Photopic vision 200
- Pilot's bow *see* Glory
- Planck distribution 6, 8, *see also* Blackbody radiation
 - as a function of circular frequency 6
 - low-frequency limit 7
 - as a function of wavelength 9
 - large-wavelength limit 9
- Planck function *see* Planck distribution
- Plane of incidence 362
- Plane wave, defined 133
- Plane-parallel medium 59, 252
- Plasma frequency 155
- Polarizability 418
- Polarization
 - change upon specular reflection 362–365
 - circular 346–347
 - complete 347
 - degree of light scattered by water droplets 379
 - degree of, circular 357
 - degree of, elliptical 357
 - degree of, linear 357
 - degree of, linear, upon scattering by a dipole 373
 - degree of, linear, upon specular reflection 369
 - discovery of by Malus 385
 - dispersion of 378
 - elliptical 347
 - linear 347
 - and navigation by bees 383, 387
 - and navigation by Vikings 383, 387
 - partial 347, 354
 - of skylight 374–377, 386
 - unpolarized light 354–355
- Polarizing angle *see* Brewster angle
- Polarizing filter
 - circular 351
 - linear 350
- Poynting vector 185, 227, 345
 - time-averaged 349
- Poynting's theorem 227
- Precipitable water, defined 28
- Pressure broadening *see* Collisional broadening
- Probability density, defined 5
- Purity 218
 - of blue sky 221
 - chromatic 221
 - excitation 220
- Purkinje effect 200, 228
- Pyranometer 232
- Quadratures 296
- Quarter-wave plate 360
- Quasi-monochromatic radiation 355
- Radar reflectivity, defined 168
- Radiance
 - of airlight and skylight 399–409
 - of cumulus clouds 405
 - defined 189–191
 - of finite cloud 326
 - of horizon, relative to zenith 403–405
 - invariance of 191–192, 294
 - of isotropic radiation field 207
 - and luminance 200
 - mean 295
 - Monte Carlo calculation of 313–315
 - of objects under water 199, 209–211

- changes upon specular reflection and re-
fraction 196–200
- Radiation *see* Electromagnetic radiation
- Radiation pressure 47, 184
- Radiation torque 184
- Radiative balance *see* Global warming
- Radiative reaction 127, 175
- Radiative transfer
 - integro-differential equation for 294
 - line-by-line 92, 117
 - N -stream equations for 291–292
 - two-stream equations of 255–256
- Radiometry, defined 185
- Rainbow
 - color separation of 434
 - complete (360°) 431–432
 - double 432
 - infrared 450
 - primary 430–431
 - secondary 430, 432
 - supernumerary bows of 435, 450
 - tertiary 450
- Rainbow angles 430
- Raindrops
 - shape of 435
 - size distribution for 42
- Rayleigh's scattering law 128, 398, 446
- Reflection
 - by clouds 259–260
 - diffuse 197, 208
 - by objects when wet 275–276, 281
 - by paint 271–272
 - by a pile of plates 242–249
 - by a plane-parallel medium according to
two-stream theory 258
 - scattering interpretation of 126, 175
 - by a slab 156–158
 - by snow 272–273
 - specular, law of 363
 - specular, in photon language 2
 - specular, in wave language 2
 - total internal 390
- Reflectivity
 - of absorbing plane-parallel medium
267
 - coherent 157, 249
 - defined 15
 - incoherent 250
 - of laterally finite cloud 324
 - of a pile of plates 242–249
- Refraction
 - atmospheric 418–426
 - double 360, 385
 - law of 363
- Refractive index
 - of air at sea level 419
 - of air, variation with height 419
 - and colors of rainbows 434
 - complex, defined 159
 - of composite media 179
 - of a gas 418
 - and mass density 161
 - and phase speed 161–163
 - of water 160
- Retardance *see* Retarder
- Retarder, linear 359
 - fast axis of 359
 - quarter-wave plate 360
 - retardance of 361
 - slow axis of 359
- Saturation 218
- Scale height 402, 419
 - for molecules 409
 - for particles 409
 - for water vapor 121
- Scattering
 - by air 151–153
 - angular dependence of water droplets
174
 - coherent 125
 - conservative 257
 - cross section 129
 - defined 125
 - by a dipole 127–129
 - elastic 125, 128
 - by fractal-like particles 178
 - by hexagonally shaped ice crystals
437–440
 - by liquid water 153
 - multiple, defined 241
 - multiple, by a pile of plates 241–249
 - by nonspherical particles 178, 429
 - by oblate raindrops 435
 - phase shift upon 148–151
 - quasi-elastic 128
 - by an arbitrary sphere 165–168
 - by a small sphere 168

- wavelength dependence of, by oil droplets 173
- Scattering angle 150
- Scattering coefficient 155
 - in Mie theory 166
- Scattering matrix
 - for arbitrary sphere 378
 - for spherically symmetric dipole 373
- Scattering plane 370
- Schumann–Runge bands 102
- Scotopic vision 200
- Selection rules 82, 83
- Shortwave radiation, defined 22
- Signal speed 163, 178
- Single-scattering albedo
 - defined 257
 - of a plate 248
 - of a water droplet 269
- Size constancy 194, 227
- Size parameter, defined 167
- Sky color, theories of 398
- Skylight *see also* Airlight
 - polarization of 374–377
 - spectrum of 214, 399, 447
 - spectrum of, for hypothetical molecular atmospheres 405
- Snel's law 363
 - generalized to a stratified medium 421
- Snow
 - color of 273–275
 - reflection by 272
 - reflection, reduced by soot 273
- Solar constant *see* Solar irradiance
- Solar irradiance 23
- Solar point 377
- Solar spectrum 23, 24, 41
- Solid angle
 - defined 187
 - of sun at Earth 187
- Soot 273
- Speckle *see* Laser speckle
- Spectrum locus 219
- Standard observer, CIE 217
- Stefan–Boltzmann constant 12
- Stefan–Boltzmann law 12
- Stigler's law of eponymy 53, 115
- Stokes parameters 349–356
- Stokes vector 352
- Subsun 198, 228
 - and UFOs 198
- Sun, color of low 409
- Sun dog 437–440
- Sunrise and sunset, colors of 408–409
- Supernumerary bows *see* Rainbow
- Superposition, of waves 134–136
- Surfaces of constant phase 133
- Sylvanshine 451
- Terrestrial radiation, defined 22
 - Time-reversal symmetry 14, 40
 - Tip angle 198, 439
 - Titanium dioxide, particles in paint 271, 281
 - Transmission axis of linear polarizing filter 350
 - Transmissivity
 - of atmosphere 94
 - defined 32
 - of a pile of plates 246, 249
 - of plane-parallel medium, role of multiple scattering 259, 260
 - of plane-parallel medium, two-stream and Monte Carlo compared 316
 - Tristimulus values *see* Colorimetry
 - Twilight 409–415, 447
 - Two-stream theory 254–268
 - compared with Monte Carlo 316, 317
 - Umov's rule 391
 - Uniform chromaticity scale 223
 - Vibration ellipse 346, 347, *see also* Polarization
 - at different scattering angles, for a sphere 380
 - Vibration-rotational bands 83
 - Visibility 415
 - Visual range 415
 - and highway safety 448
 - maximum, at sea level 417
 - Voigt line shape *see* Line shape
 - Volumetric absorption cross section *see* Cross section
 - Volumetric scattering cross section *see* Cross section
 - Water
 - absorption spectrum of ice 53, 261, 280

- absorption spectrum of liquid 53, 160, 261, 280
- absorption spectrum of vapor 65, 93
- color of 82–83, 117
- normal modes of 81, 101
- Water vapor
 - remote sensing of 105–106, 119
- Water vapor, and visibility 417
- Wave
 - acoustic 142–143
 - homogeneous 348
 - inhomogeneous 348
 - on a string 129–134
- Wave equation
 - one-dimensional 130
 - three-dimensional 141
- Wave vector 348, 362
- Wavenumber 10, 79
- White, absolute, nonexistence of 224–226
- Whiteout 24
- Wien's displacement law 10
- Window region 45
 - of Earth's atmosphere 92