Index

a
A, B and C, see continuum elasticity
α, thermal expansion 32, 35, 98
anelasticity 324
attenuation 167
– energy extraction 168
– linear 168
– how to measure Q 172
– why measure Q 171
– measurements of 324
– nonlinear 170, 175
– how to measure Q 174
– it’s the amplitude baby 175
– measurements in lead alloy 325
– wavevector dispersion 168
auxiliary fields 158, 236
– in nonlinear nondestructive evaluation 324, 336
– saturation 237
– temperature 242

b
backbone of hysteresis loop 138, 143
Biot theory 240, 267
brick and mortar 1, 95, 228–229

c
C-scan 354
– experimental example 355
CFA 178, 285, 291
– a resonance where there is none 195–197
– Berea sandstone, results 286
– example, constant strain curve 183, 292–293
– finding physical fields 193, 293
– granite, results 292–296, 298
– in/out of phase amplitudes 182, 193
– steps in analysis 182–184
– virtues 185
chemical potential 102, 238
chemical potential protocol 105–106, 240
ε_{ij} 29, 210
continuum elasticity 29
– A, B and C 41–47
– dynamics 31, 41–47
– linear 29, 44
– nonlinear 30, 45–47
– A, B and C 30, 272
crack 75
– as mechanical diode 327
– clapping 328
– crack model
– Hooke’s law 329
– harmonic generation 330
– spring model 327–328
– stick-slip behavior 328
– wave modulation 330

d
dislocations 324–325
– Granato–Lücke theory 324
DMG model 153–154
– frequency shift 156, 158
– Preisach space 153
– shift in Q 156
DORT 218, 225
dynamic-dynamic 267
– fast dynamics 275
– resonant bar 274
– earth 316
– slow dynamics 274
– wave mixing 268
– collinear 270
– collinear, parametric array 272–273
– collinear, scaling with x, A^2, k^2 270–271
Index

- KZK equation 274
- noncollinear 268
- noncollinear, geometry 269
- Northridge earthquake 318
- parametric array 313–314

dynamic–dynamic process 40

effective medium theory 76
- central dogma 78–79, 82
- examples 83
- FDEE 114
- Hertzian contact scaling 87
- Hertzian contacts 83
- in parallel 85
- in series 85
- van der Waals surfaces 87
- bookkeeping 90
- Preisach space 90
elastic state dynamics 153–157
endpoint memory 120
energy landscape 155, 209

Fast dynamics 6, 145, 274–277
- anomalous 308
- linear 145
- nonlinear 275
FDEE scaling 128, 285, 295, 301, 310
field experiments 313
- active probes 313
- resonant bar 315
- wave mixing 313
- passive probes 318
- Northridge earthquake 318
form factor
- $\tilde{F}$ 201
- $G, L + T \rightarrow T$ 52
- for $\tilde{\sigma}_{ijkl}(x)$ 207
- $H(R)$ 62
- normal modes 58

Green function 64–66
- free space 64
- resonant bar 65

Hermitian matrix 214, 225
Hertz–Mindlin contacts 70, 301
- EMT 83
- fcc lattice 138
- scaling of $c$ and $\beta$ 301
homodyne 177

Hysteresis 137
- observation in aluminum single crystal 324, 339
- endochronic model 136, 141
- FDEE 136
- fluid configurations 104–105
- Hertz–Mindlin contacts 136–138
- $k-S$ 121
- loop 121
- due to temperature 246
- time evolution 237, 246
- Masing rule 136, 139
- strain 4
- van der Waals material 92–93

Invasion percolation 239–240

Jones and Kotett 53–54, 268

Kaiser effect 232

Lennard–Jones interaction 15, 19
log time 4, 6, 162, 286, 297, 308, 310, 324
- resonant bar
- threshold 295
lumped element model 123, 173, 176

Materials
- Agar gelatin 264
- alluvium 320
- aluminium powder 1
- Berea 229–231, 233
- cement 3
- ceramic 3
- earth-Northridge 319
- glass beads 270, 301–304
- granite 262–263, 292
- limestone 270
- sandstone 2
- Berea 178–179, 229, 231, 233, 248, 270
- Berea and $T$ 244
- Castlegate 231, 234
- Fontainebleau 231
- Fontainebleau and neutrons 231
- Meule, $P$ and $S_W$ 266–267
- sandstones, TBC 257
- Sierra White granite 270
- soil 3, 231, 236
Index

– TBC 2, 231, 235
– various 310
mesoscopic elastic elements 69, 113
– cracks 75, 328
– FDEE
  – resonant bar 123
  – resonant bar, frequency shift 127–129
  – resonant bar, scaling 130
  – resonant bar, shift in Q 127–129
  – rules for behavior 116
  – wave mixing 130
  – wave mixing, ($f_1, f_2$) 131
  – wave mixing, ($f_1, f_2$) and phase portrait 132–135
– frictional 137
– frictional contact 122
– Hertz–Mindlin contact 70–71, 121, 137
– Hertzian asperities 72–73, 122
– hysteretic Hertz–Mindlin contact 72
– van der Waals surfaces 73–74, 121
MG model 113–115, 138–143, 153
modulus 233
– dynamic 233
– dynamic component 254–257
– granite 262
– hysteretic component 254–257
– one way 233, 238
– $P$ and $S_W$ 266
– two way 233, 238

NESS 277
– threshold 277, 298
neutron scattering
– internal stress 100
– internal/external strain gauge 230–232
nondestructive evaluation 323
– harmonics 327
– measurement of harmonics 337–338
nonlinear elastic wave spectroscopy (NEWS) 327
– imaging of nonlinear scatterers 353
– harmonic imaging 353, 355
– imaging applying time reversal nonlinear elastic wave spectroscopy (TR NEWS) 357, 359, 361
– modulation imaging 354, 358
– measurement of progressive fatigue 336, 347, 349
– experimental example 350–352
nonlinear nondestructive evaluation
– history 324
– nonlinear parameters 263
  – $A$, $B$, and $C$ 263
  – $\beta$ 264
nonlinear ringdown spectroscopy (NRS) 341
– experimental example 344
nonlinear ultrasound resonant spectroscopy (NRUS) 341
– experimental example 343
– resonant bar 341
Nonlinear Wave Modulation Spectroscopy (NWMS)
– experimental configuration 334
– in cracked plexiglas 333
nonlinear wave modulation spectroscopy (NWMS) 330
– experimental configuration 332
– experimental example 331, 340
– impact plus pure tone 337, 342
– in cracked metal 334
– in cracked steel 331
– summation average 339

p
peak bending 4, 57, 128, 178
perturbation treatment
– Luxemberg–Gorky 59
– resonant bar
  – FDEE 131
  – $L + L + L \rightarrow L$ 55
  – selection rules 53
– $t$ independent PT
  – NL normal mode tomography 220
  – normal-mode tomography 203
– time of flight tomography 202
– time reversal 209, 211–215, 218, 223
– wave mixing
  – $L + L \rightarrow L$ 49
  – $L + T \rightarrow T$ and $T + T \rightarrow L$ 51
phonon picture 13
– anharmonic 18, 324
– continuum limit 24
  – elastic constants 27
  – elastic constants, numerical 27
  – wave equations 28
– harmonic 16
– normal modes 17
– perturbation theory 16
– 3-phonon process 18, 40, 53–54, 133, 269
– 4-phonon process 53, 201
– second-order process 53
photomicrographs
– cracked, sintered metal 335
Index

pore space 104
  – epoxy 229–230
Preisach space 118–119
  – density 249
  – FDEE 116
  – for fluid configurations 239
  – inversion 122–124, 247
  – saturation 250
  – two component, many component 252
  – uniform density approximation 117, 125, 254
  – van der Waals surfaces 91
probe 300, 310
  – in slow dynamics 276
  – Luxemberg–Gorky 59–64, 201
  – NESS 295, 298
pump 300, 310
  – in slow dynamics 276
  – Luxemberg–Gorky 59–64, 201
  – NESS 295, 298
q
  Q, see attenuation
quasiharmonic approximation 20
  – dT 22
  – dV 21
  – dV^2dT, Luxemberg–Gorky 22, 59
  – dVdT 21
  – dW, an auxiliary field 21
  – numerical estimates 24
quasistatic measurements 227
quasistatic process 40
quasistatic/dynamic measurements 261
  – pressure/dynamic 261
  – A, B and C 262
  – saturation/dynamic 265
  – temperature/dynamic 264
quasistatic/dynamic process 40, 46
r
  ratchet 159, 277
  rearrangement 232
  reciprocity 213, 224
  relaxation rates 152
  – broad spectrum 149–153
resonance
  – observations in materials containing dislocations 325
resonant bar 55, 57, 177–178
  – CFA analysis 180–186
  – frequency shift 179
  – lumped element model 123, 176
  – modulation in aluminum 327
  – NESS and generic behavior 278–279
  – shift in Q 179
  – synthetic data 181–182, 188–189
  – CFA analysis 184–185
  – temperature
  – resonance frequency by ear 244
resonant bar slow dynamics
  – AF 276
  – IF 276
  – case study, glass beads 301
  – constant strain measurement 291
  – defined 276–280
  – elastic state and NESS 279
  – log(t) 286, 297–299, 308–310
  – low strain behavior 289–290
  – elastic state and sweep rate 282–283, 285
  – elastic state time evolution 279
  – frequency protocols 280–281, 289, 296
  – thumper 315
  – frequency shift
  – earth 315
  – earth-Northridge 320
  – non-rock-like materials 305
  – rocklike materials 304
  – log(t) 288, 295, 317
  – low strain behavior 290
  – NESS
  – defined 280
  – threshold 299
  – Q^{-1} shift
  – non-rock-like materials 306
  – resonance curves
  – various materials 307
  – two mode experiment 298, 300–301
resonant ultrasound spectroscopy, RUS 200
RTMF 186
  – finding physical fields 187
  – scaling of \varepsilon and Q^{-1} 193–194
  – steps in analysis 186–189, 191
s
saturation 6, 159
  – chemical potential 102–108, 241
  – coupling to strain 32, 106, 239
  – internal forces 241
  – low saturation/tensile forces 239
  – effect on Preisach space 242
  – fluid configurations 104–108, 239
  – internal forces 108–111
saturation stays in 239
selection rules 53, 268
slow dynamics 6, 145–146, 158, 309
  – AC drive 161
Index

– in nondestructive evaluation 345
– linear 145, 152
– quasistatic hysteresis loops 235
– temperature 162, 164, 244, 245
slow dynamics diagnostics (SDD)
– experimental example 348
– slope amplifier 345
– slow dynamics 345
sound velocity 4
– \(c_L(P)\) 4, 262
– \(c_L\) 45
– \(c_L(P)\) 46, 229
– \(c_T\) 45
– numerical estimate 17
spectroscopy 199
– linear 199
– nonlinear 200, 204
– \(A(f)\) 200
– \(A(t)\) 200
– homogeneous 200
– inhomogeneous 202
strain stays in 233
stress protocol 117–119, 156
– elaborate 250–253
– quasi-static 248
– strain response to AC stress 150–151
– strain response to transient stress 148

\(t\)
temperature 6, 61, 97, 162
– equation of motion 59, 168
– hysteresis loop
– asymmetry 247
– slow dynamics 247
– internal forces 101–102, 243
temperature protocol 164, 243
– temperature chirp 244–245
tile model 78, 97
– brick and mortar 95, 103
– effective medium theory 78
– Hertz tile 83
– nonuniform 77
– notation 98, 103–104
– saturation 102
– percolation 110
– saturation strain coupling 102
– temperature 97
– temperature strain coupling 98
– tile space 80
– uniform 76
– van der Waals tile 87
time reversal 209
– linear 209
– amplitude training 215
– experimental protocol 213
– transfer matrix 213
– mirrors 211
– nonlinear 223
– amplitude training 225
– experimental protocol 224
– imaging of nonlinear scatterers 357
– time-reversal matrix 225
– transfer matrix 224
– time-reversal matrix 213
time-reversal
– linear
– amplitude evolution 217
– amplitudes 216
– mirror/scatterer geometry 212
time reversal nonlinear elastic wave spectroscopy (TR NEWS)
– impulse response 363
– isolating mines 362
– phase inversion method 361
– experimental example 364
– variable amplitude/scaling subtraction method 364
tomography 199, 202, 206
– linear
– normal mode 203
– normal mode, frequency shifts 208, 210
– normal mode, numerical example 206
– time of flight 202
– nonlinear
– normal mode 220
– time of flight 218
traditional theory of NL elasticity 39
– dynamic response 47
– \(\beta\) and \(\gamma\) 48
– linear 44
– Luxemburg–Gorky 59
– quasistatic response 41
– quasistatic/dynamic response
– \(a_\ell(P)\) 46
– resonant bar 55
– \(L+L+L\rightarrow L\) 55
– why not \(L+L\rightarrow L^2\) 56
– wave propagation 48
– \(f+f\rightarrow 2f\) 51
– higher-order processes 52–53
– \(L+L\rightarrow L\) 48
– \(T+T\rightarrow L\) and \(L+T\rightarrow T\) 51
– \(\mu^{(2)}+\times\) 51

\(x\)
\(X\), the conditioning field 112, 145, 158–159