

Index

Note: *Italic* page numbers refer to *figure* and **Bold** page numbers reference to **tables**.

a

A β 42 (amyloid- β 42) 165–167
 absorption energy 18
 acenaphthylene 63
 acetylcholine (ACh) 111
 ACh (acetylcholine) 111
 acrylamide derivatives 72–73
 actin-GFP 253
 actin-myosin interaction 242
 adenosine triphosphate (ATP) assay 125–126
 synthesis and thermogenesis 169–171, 172
 Ag₂S nanoparticles 235, 235, 250
 aggregation-induced emission (AIE) 81
 AIE (aggregation-induced emission) 81
 alternative oxidase (AOX) 267
 ambient temperature 218
 2-aminopurine (Ap) 76
 amyloid- β 42 (A β 42) 165–167
 1-(*N*-*p*-Anisyl-*N*-methyl)-amino-3-(9-anthryl)-
 propane (AMAAP) 52, 52–53
 ANP (A-type natriuretic peptide) 140, 159
 anthracene 52
 anthracene moiety 232
 AOX (alternative oxidase) 267
Aplysia californica 194
 apoptosis signal-regulating kinase 1 (ASK1) 160
Arabidopsis thaliana 197
 Arrhenius equation 22
 8-aryl-boron-dipyrromethene (BODIPY)
 derivatives 34, 146
 ASK1 (apoptosis signal-regulating kinase 1) 160
 ATP assay: see adenosine triphosphate (ATP) assay
 Atto488 212–213

Atto565 212–213

A-type natriuretic peptide (ANP) 140, 159
 6-aza-2-thiothymine 87

b

Baffou's criticism 215, 217, 222–224
 BAM15 (N5,N6-bis(2-fluorophenyl)-[1,2,5]-
 oxadiazolo[3,4-*b*]pyrazine-5,6-diamine)
 196–197
 β -CD (β -cyclodextrin) 54–55
 β -cyclodextrin (β -CD) 54–55
 bear 5, 5
 beige adipocytes 157
 benzofurazan (2,1,3-benzoxadiazole) 63
 B form (B-DNA) 76
 bigeye tuna (*Thunnus obesus*) 5, 6
 bimaterial microcantilevers 199–200, 200
 biopolymers 217
 biotechnology 258–262
 bi-phasic heat wave 111
 N5,N6-bis(2-fluorophenyl)-[1,2,5]
 oxadiazolo[3,4-*b*]pyrazine-5,6-diamine
 (BAM15) 196–197
 1,3-bis-(1'-pyrenyl)-propane (PYPYP) 50, 51
 N,N'-bis(2,5-di-*tert*-butylphenyl)-3,4,9,10-
 peryleneedicarboximide (BTBP) 39
 black bear (*Ursus americanus*) 5, 5
 blinking 80
 BODIPY (8-aryl-boron-dipyrromethene)
 derivatives 34, 146
 body temperature
 bigeye tuna (*Thunnus obesus*) 5, 6
 black bear (*Ursus americanus*) 5, 5

Intracellular Thermometry with Fluorescent Molecular Thermometers, First Edition. Seiichi Uchiyama.

© 2024 Wiley-VCH GmbH. Published 2024 by Wiley-VCH GmbH.

of humans 2–4, 3
 physiological and behavioral strategies for 8
 brain edema 167–168
 1-BrNp (1-bromonaphthalene) 55
 1-bromonaphthalene (1-BrNp) 55
 brown adipocytes 156–163, **157–158**, 159,
 161–163, 218
 brown fat cells 156, 198
 Brownian nanocrystals 94
 BTBP (N,N'-bis(2,5-di-*tert*-butylphenyl)-
 3,4,9,10-perylenedicarboximide) 39

c

C18-RG 59
Caenorhabditis elegans (*C. elegans*) 173, 173, 242,
 243, 244
 calcein 81
 calibration curve 212–215, 214, 216, 266
 cAMP (cyclic adenosine monophosphate)
 level 150
 capsaicin 11
 carbon dots (C-dots) 87–89, **90–91**
 carbonyl cyanide 3-chlorophenylhydrazone
 (CCCP) 136–137, 146, 196
 carbonyl cyanide 4-(trifluoromethoxy)
 phenylhydrazone (FCCP) 136–137, 146, 166,
 185, 201, 242
 6-carboxyfluorescein (6-CF) 212, 213
 CaSki cells 190–191
 cationic biomacromolecule 116–118,
 116–119
 cationic fluorescent polymeric
 thermometers 119, 119–120
 CCCP (carbonyl cyanide 3-chlorophenylhy-
 drazone) 136–137, 146, 196
 CCK-8 (cell counting kit-8) 124–125
 CD-MSN@UP38 functions 96
 C-dots (carbon dots) 87–89, **90–91**
 CdSe/ZnS quantum dots 85
 CdS/ZnS quantum dots 85, 212
 CdTe quantum dots 85, 87
 cell counting kit-8 (CCK-8) 124–125
 cell-cycle dependent thermogenesis 133–135,
 134
 cell-penetrating peptides 117
 “cell thermoregulation” 241
 cellular biotechnology 12
 cellular thermal conductivity 224
 Jurkat cell 226
 cellular thermometry. *see* non-fluorometric
 cellular thermometry
 centrosome 131, 131
 6-CF (6-carboxyfluorescein) 212, 213

chemical stimulation **219–222**
 cherry blossoms 10
 Chinese hamster ovary (CHO) cells 110–111
Chlorella pyrenoidosa 254
 chlorobenzene 60
 5-(and-6)-chloromethyl-2',7'-
 dichlorodihydrofluorescein diacetate
 (CM-H₂DCFDA) 126
 CHO (Chinese hamster ovary) cells 110–111
 CM-H₂DCFDA (5-(and-6)-chloromethyl-2',7'-
 dichlorodihydrofluorescein diacetate) 126
 copolymers 63
 copper nanoclusters 94–95
 COS7 cells 201, 216
 CP@Fe₃O₄ microswimmers 255
 Cu₅ metal cluster 94
 CuTPP (5,10,15,20-tetraphenyl-21H,23H-
 porphyrin copper(II)) 46–47
 cyanines 35–36
 cyclic adenosine monophosphate (cAMP)
 level 150
 cytoplasm 127, 130, 211
 cytotoxicity assessment 121–126
 adenosine triphosphate (ATP) assay 125–126
 cell counting kit-8 (CCK-8) 124–125
 for fluorescent molecular thermometers **123**
 methylene blue assay 125
 MTT 123–124
 propidium iodide (PI) 122
 reactive oxygen species (ROS) 126
 WST-1 assay 124
 yeast cells 125

d

$\Delta 9$ -fatty acid desaturase (DESAT1) 165, 166
 DBD (N,N-dimethylaminosulfonyl-
 benzofurazan) 63
 delayed fluorescence 23, 24
 DESAT1 ($\Delta 9$ -fatty acid desaturase) 165, 166
 p-DHMPA (9,10-di(p-hydroxymethylphenyl)
 anthracene) 83
 diamond nanocrystals 112
 (9,10-di(p-hydroxymethylphenyl)anthracene)
 (p-DHMPA) 83
Dicronorhina derbyana 244, 245
 Diels–Alder reaction 36, 37
 diethylamino substituent group 25
 3,3'-diethyl oxadiazabicyclopentane iodide
 (DODCI) 35, 36
 4-(N,N-dimethylamino) benzonitrile
 (DMABN) 55, 56
 N,N-dimethylaminosulfonyl-benzofurazan
 (DBD) 63

dimethyl sulfoxide (DMSO) 138
 3-(4,5-dimethylthiazol-2-yl)-2,5-diphenyl
 tetrazolium bromide (MTT) 123–124
 1,4-dioxane (Dx) 63, **64**
 1,2-dipalmitoyl-*sn*-glycero-3-phosphocholine
 (DPPC) liposomes 256, 256
 dipyrren-1-yl(2,4,6-triisopropylphenyl)borane
 (DPTB) 34–5
 DMABN (4-(*N,N*-dimethylamino)
 benzonitrile) 55, 56
 DMEM (Dulbecco's modified eagle
 medium) 143
 DNA 76–79
 DNA-AgNC (DNA-templated silver
 nanocluster) 95
 L-DNA molecular beacon 77, 115
 DNA-templated silver nanocluster
 (DNA-AgNC) 95
 DODCI (3,3'-diethyl oxadiazocyanine
 iodide) 35, 36
 dodecyl sulforhodamine 218
 double input–single output logic gates **320**
 DOX (drug doxorubicin) 257
 drug-delivery system 257
 drug doxorubicin (DOX) 257
 $\delta T/\delta FS$ value 205–207
 dual-modal polymeric imaging 255
 Dulbecco's modified eagle medium
 (DMEM) 143
 DyLight 549 155

e

EGFP (enhanced green fluorescent protein)
 79–80, 80
 ELP-TEMP 130–131
 El-Sayed's rule 19
 embryonic development, by local heating
 171–173, 173
 emGFP-Mito 146
 emission intensity ratio 236, 250
 naphthalene excimer 51
 of pyrene 50
 of quantum dots 133
 temperature measurements by 234
 emission spectra 233
 endo-1 36, 37
 endogenous thermogenesis 215–233
 endoplasmic reticulum (ER) 153, 154, 231
 endotherms 2, 7
 endotoxin 194
 energy 18
 enhanced green fluorescent protein (EGFP)
 79–80, 80

environmental temperature 8, 12
 variations 218
 environment-sensitive fluorophore 61–76,
 275–293
 ER thermo yellow 153, 256, 257
Escherichia coli 80
 ethylrhodanine moiety 40
Eucalyptus Robusta 266
 europium (Eu^{3+})-doped silicon nanoparticles
 (Eu@SiNPs) 95
 europium(III) thenoyltrifluoroacetate
 (EuTTA) 111, 111–112, 138
 for cellular thermometry 112
 europium(III)-tris(dinaphthoylethane)-bis-
 trioctylphosphine oxide (Eu-DT) 244
 Eu@SiNPs (europium (Eu^{3+})-doped silicon
 nanoparticles) 95
 EuTTA . *see* europium(III)
 thenoyltrifluoroacetate (EuTTA)
 excimers 49–54
 exciplexes 49–54
 excitation process 18, 18
 experimental errors 208

f

fabricated sensor 198
 Fabry–Perot optofluidic planar microcavity 80
 FAM (Fluo-4 AM) 265
 FCCP (carbonyl cyanide 4-(trifluoromethoxy)
 phenylhydrazone) 136–137, 146, 166, 185,
 201, 242
 Fe_3O_4 nanoparticles 255, 255
 fever 4
 first fluorescent polymeric thermometer 65–71
 flow injection analysis (FIA) reactor 43
 Fluo-4 AM (FAM) 265
 fluorescein 39–40, 208
 fluorescence intensity of 208
 fluorescence measurements of 209
 fluorescein 27, 39
 fluorescence
 basics of 18–19
 internal conversion 19
 lifetime 22
 temperature-dependent 19
 fluorescence intensity ratio 20, 21, 40, 266
 of delayed fluorescence 23
 gTEMP 129, 130
 mT-Sapphire unit 122
 of NapCD 54
 of N-doped carbon dots 88
 polymeric thermometer 140
 of PtOEP 46

- of rhodamine B 28
 - temperature-dependence 56, 233
 - fluorescence polarization anisotropy (FPA) 243
 - fluorescent molecular rotor (FMR) 216
 - fluorescent molecular thermometers 17, 24
 - advantage of 17
 - calibration curve of 212–215, 214
 - cationic biomacromolecule 116–118, 116–119
 - cytotoxicity assessment for 121–126, **123**
 - excimers and exciplexes 49–54
 - excited-state relaxation in 22
 - fluorescent polymeric thermometers. *see* fluorescent polymeric thermometer
 - fluorescent proteins 79–80
 - functional requirement for 208
 - heat source and 231–233, 232
 - host–guest interactions 54–57, 56
 - inorganic nanomaterials 84–95
 - intracellular thermometry with. *see* intracellular thermometry/temperature
 - into living cell 112–121
 - microinjection 112
 - non-covalent systems 81–83
 - nucleic acids 76–79
 - optical tweezers 114
 - organelle-targeted 146–156
 - organometallic complexes 41–49
 - penetration of silicon nanowires 112–114, 114
 - peptides 79
 - polymers as a medium for 57–60
 - responses of 19–21, 20
 - rhodamine B 150
 - small organic molecules. *see* small organic molecules
 - synthetic cationic polymer 116
 - synthetic polymers 57–76
 - transfection reagents 114–115
 - fluorescent nanodiamonds 89, 92, 93, 113, 114, 129, 129, 145
 - Caenorhabditis elegans* with 242, 243
 - intracellular thermal conductivity using 228, 228
 - ODMR spectrum of 262
 - polycrystalline 261
 - fluorescent nanogel thermometers 214, 295, **296–298**, 299–300
 - fluorescent polymeric logic gates 307, **308–312**, 313–319
 - fluorescent polymeric thermometer
 - (FPT) 61–76
 - accuracy in 74
 - advantages 307
 - design concept of 62
 - development 62
 - first 65–71
 - functional independence of 211
 - functional temperature range of 72–73, 74
 - functioning in aqueous solution **276–283**
 - intracellular temperature mapping with 127
 - intracellular thermometry with 323
 - ionic units in 73
 - poly(NIPAM-co-DBD-AA) 67
 - sensitive 275
 - synthetic procedure for 65
 - ultrasound-switchable fluorescence 68
 - fluorescent proteins 79–80, 80, 258, 260, 260
 - fluorescent temperature sensing
 - systems **302–303**
 - fluorometric methods 224
 - fluorometry 208
 - FMR (fluorescent molecular rotor) 216
 - follower cells, leader cells vs. 135, 136
 - Förster resonance energy transfer (FRET) 56–57, 78, 131, 212
 - Fourier's law 217
 - FPA (fluorescence polarization anisotropy) 243
 - FPT. *see* fluorescent polymeric thermometer
 - Frank–Condon state 55
 - FRET (Förster resonance energy transfer) 56–57, 78, 131, 212
 - functional independence 208–212, 211
 - functional integration, of thermometer 257
- g**
- GAD (glutamic acid decarboxylase) 242
 - garden philodendron (*Philodendron selloum*) 6, 6
 - gelation 75–76
 - gel–liquid crystalline phase 110
 - gene expression 10
 - generalized polarization (G.P) value 110
 - genetically encoded fluorescent thermometer (gTEMP) 120–121, 122, 129, 130, 243
 - GFP. *see* green fluorescent protein
 - Gibbs energy dissipation 218
 - glutamic acid decarboxylase (GAD) 242
 - glycolytic metabolism 242
 - GNR-FND (gold nanorod-fluorescent nanodiamond) hybrids 259, 259
 - gold nanoparticles 77–78, 87, 145, 190, 232
 - fluorescent nanodiamonds and 257
 - silk film with 249
 - thermal conductivity using 229
 - in toluene 233
 - gold nanorod 231

gold nanorod-fluorescent nanodiamond (GNR-FND) hybrids 259, 259
 green fluorescent protein (GFP) 120, 122, 242–243
 Caenorhabditis elegans by 244
 gTEMP (genetically encoded fluorescent thermometer) 120–121, 122, 129, 130, 243

h

Hanks' balanced salt solution (HBSS) 188
 heat capacity, of lipid bilayers 230–231
 heat conduction equation 217
 heat diffusion equation 215
 heat shock proteins 11
 heat source
 density 216
 and fluorescent molecular thermometers 231–233, 232
 HEK293T (human embryonic kidney) 165, 167, 214, 259–260
 HeLa (human epithelial carcinoma) cells 115, 115–116, 116, 120, 138, 140, 143, 187, 211, 229, 261
 HepG2 (human hepatoblastoma) cells 197
 heterogeneous environment 215
 heterozygous myocytes 169
 hippocampal neurons 174
 homeostasis 8
 homopolymers, of acrylamide derivatives **72–73**
 host–guest interactions 54–57, 56
 hSeP (human SeP) 160
 human adipocytes 185
 human body temperature 2–4, 3
 human embryonic kidney (HEK293T) 165, 167, 214, 259–260
 human epithelial carcinoma (HeLa) cells 115, 115–116, 116, 120, 138, 140, 143, 187, 211, 229, 261
 human hepatoblastoma (HepG2) cells 197
 human ovarian cancer cells 215
 human papillary ovarian adenocarcinoma cells 219
 human SeP (hSeP) 160
 hybrid nanomaterials 95–96
 hydrogel system 38
 hydrogen bondings 88
 hydrophilic fluorescent nanogel thermometer 112
 hydrophilic poly(allylamine) hydrochloride (PAH) shell 139–140
 hydrophobic poly(methyl methacrylate) (PMMA) 139
 hyperthermia 250

i

iBMDMs (immortalized bone marrow-derived macrophages) 194
 ICG (indocyanine green) 58, 253
 immortalized bone marrow-derived macrophages (iBMDMs) 194
 indenoquinacridone (IQA) 59
 indocyanine green (ICG) 58, 253
 infertility 9
 influenza virus 142, 142
 infrared radiation detectors 17
 infrared thermography 185
 of skin temperature 4
 infrared thermometry 185, 186
 inorganic luminescent thermometers 233
 inorganic metal species 321
 inorganic nanomaterials 84–95
 carbon dots (C-dots) 87–89, **90–91**
 fluorescent nanodiamond 89, 92, 93
 gold nanoparticles 87
 others 94–95
 quantum dots (Q-dots) 84–87, 86
 upconversion nanoparticles (UCNPs) 93–94
 inorganic substances 17
 internal conversion 19
 intersystem crossing 19
 activation energy for 22
 non-radiative 20
 small organic molecules in 21–25
 intracellular heat diffusion 224
 intracellular temperature variation
 biological mechanisms in 135
 in brain edema 167–168
 chemical stimulus 135–140
 hippocampal neurons 174
 by ionomycin 139
 local heating 143–145, **144**, 145
 ryanodine receptor 1 (RYR1) 168–169
 virus infection 140–143
 intracellular thermal conductivity 223, 224
 determination of 224–230
 of lipid bilayers 226, 227
 living cell **224–225**
 photothermal lens spectroscopy 230
 intracellular thermometry/temperature 109–174, 160
 absolute measurements 262–263, 263
 amyloid- β 42 (A β 42) 165–167
 applications of 241–267
 ATP synthesis and thermogenesis 169–171, 172
 in biological fields 163–174

- of brown adipocytes 156–163, **157–158**, 159, 161–163
 - cell-cycle dependent 133–135
 - cytotoxicity assessment 121–126
 - distribution 215
 - early attempts for 109–112
 - endoplasmic reticulum-targeted 153, 154
 - fluorescent molecular thermometers and 273
 - with fluorescent nanodiamonds 114
 - with genetically encoded fluorescent thermometers 129
 - leader cells vs. follower cells 135, 136
 - living cells 112–121
 - in magnetic hyperthermia treatment 254
 - mapping techniques 208, 215, 223
 - measurements 197, 217
 - with microinjected fluorescent nanogel thermometers 113
 - by microscale silicon-based Au/Pd thermocouple 196
 - microscale thermocouple for 194
 - by micro-sized W/Pt thermocouple 195
 - mitochondria-targeted 146–153, 147, 149
 - with organelle-targeted fluorescent thermometers 146–156
 - photoacoustic 187
 - of plant cells 265–267
 - plasma membrane-targeted 154–156, 155
 - rational analysis of 215
 - realization 241
 - reliability issue in 205–236
 - significance 13–14
 - simultaneous monitoring 263–265, 265
 - temperature distribution 126–133
 - temperature variation. *see* intracellular temperature variation
 - intracellular thermophoresis 241
 - intracellular thermoregulation 230
 - intramolecular charge transfer (ICT) state 33
 - in vitro* maturation 174, 174
 - in vivo* photothermal therapy 254
 - in vivo* temperature measurements 241, 242–250
 - Caenorhabditis elegans* 244
 - of fruit fly larvae 245
 - mouse 245, 246, 249
 - reliability 250
 - upconversion nanothermometer for 246
 - using fluorescent proteins 244
 - zebrafish larva and 242, 243
 - in vivo* ultrasound-switchable fluorescence 70, 71
 - 2-(4-iodophenyl)-3-(4-nitrophenyl)-5-(2,4-disulfophenyl)-2H-tetrazolium, monosodium salt (WST-1) 124
 - 3-iodothyronamine (T1AM) 140, 141
 - ionic SPA (3-sulfopropyl acrylate) units 73
 - ionomycin 138–140, 139, 231
 - IQA (indenoquinacridone) 59
 - iron oxide microparticles 187
- j**
- Jabłoński diagram 18, 18
 - Jurkat cell 226
- k**
- Kiton Red. *see* sulforhodamine B
 - Krebs Cycle 150
 - Kunming mouse inflammatory model 247
- l**
- lanthanides 44–46
 - LCST (lower critical solution temperature) 62, 65, 68
 - leader cells vs. follower cells 135, 136
 - ligand field (LF) states 42
 - ligand-to-metal energy transfer 60
 - linear colorimetric response 125
 - lipid bilayers
 - heat capacities of 230–231
 - membrane 81
 - thermal conductivity of 226, 227
 - lipofectamine 2000 (lipofectamine) 115, 115
 - lipopolysaccharide (LPS) 194, 250
 - living/live cell
 - of chemical species 212
 - by chemical stimulation **221–222**
 - Si sensor attached 218
 - temperature gradient within **221**
 - temperature variations in 215
 - thermal conductivity **224**
 - living things, temperature for 1–14
 - local heating 143–145, **144**, 145, 171–173, 173
 - lower critical solution temperature (LCST) 62, 65, 68
 - LPS (lipopolysaccharide) 194, 250
 - luminescent thermometers 233–236
 - emission band shape in 234
 - temperature resolutions 236
 - lysosome 164
 - and mitochondria 164
 - temperature monitoring at 163–164
- m**
- macromolecules 17

- Madin–Darby canine kidney (MDCK) 114
 magnetite nanoparticle 251
 MBAM (N,N'-methylenebisacrylamide) 75, 75
 MBAM (N,N'-methylenebisacrylamide) 75, 75
 MDCK (Madin–Darby canine kidney) 114
 mean intracellular thermal conductivity 229
 membrane transport protein transferrin
 (Tf-QDs) 156, 156
 menthol 11
 mercury-filled thermometer 1
 mESCs (mouse embryonic stem cells) 148
 metal-to-ligand charge transfer (MLCT)
 state 42–43
 2-methacryloyloxyethyl phosphorylcholine
 (MPC) 143
 N-methylaniline 53
 9-methylanthracene 21, 21–22
 N,N'-methylenebisacrylamide (MBAM) 75, 75
 methylene blue assay 125
 methyl ester of rhodamine B (RhB-Me) 150
 microelectromechanical systems (MEMS) 45,
 85, 194
 microfabricated thermistor 201
 microfluidic systems 25
 with rhodamine B 29
 microinjection technique 112, 242
 microthermocouple arrays 222
 micro-thin-film thermocouple array 198
 mitochondria 132, 132
 intracellular thermometry 146–153, 147, 149
 lysosome and 164
 by organelle-targeted fluorescent
 thermometers 163–164
 ratiometric imaging of 188
 Mito-Q 173–174, 174
 Mito-RTP 120, 121
 Mito-TEM 150–151
 Mito thermo yellow 148
 MitoTracker orange 187, 187–188
 MLE-12 (murine lung epithelial) cells 194
 MnF₂O₄ nanoparticles 155
 molecular logic gates 263
 monitoring system 218
 mouse 245, 246
 mouse embryonic stem cells (mESCs) 148
 mouse mononuclear macrophages 219
 MPC (2-methacryloyloxyethyl
 phosphorylcholine) 143
 mT-Sapphire 120, 243
 MTT (3-(4,5-dimethylthiazol-2-yl)-2,5-diphenyl
 tetrazolium bromide) 123–124
 MTT-AuNP 148
 multi-cell thermometry system 194
 multiparametric thermal sensing 235
 murine lung epithelial (MLE-12) cells 194
 myxofibrosarcoma 4
- n**
 N-allyl-N-methylaniline (NA) 53
 nanocapsules 58
 nanodiamond theranostics 253
 nanoheater/fluorescent thermometer
 hybrids 258–262
 nanoparticles 58, 252
 magnetic characteristic of 254
 in silicone composite 94
 nano-scale temperature profile 232
 NapCD (naphthalene-linked β -cyclodextrin) 54,
 54
 naphthalene 48
 naphthalene fluorophore (azaNap) 48, 48
 naphthalene-linked β -cyclodextrin (NapCD) 54,
 54
 naphthalene moiety 54
 2-naphthol 38
 NBD (nitrobenzofurazan) 63
 NBD-NHPr. *see* 4-n-propylamino-7-nitro-2,1,3-
 benzoxadiazole
 NBD-PC (2-(12-N-NBD-amino)
 dodecanoyl-1-hexadecanoyl-sn-glycero-3-
 phosphocholine) 109–110, 110
 ND-NG-ICG 253
 N-doped carbon dots 88, 88
 near-field scanning optical microscopy
 (NSOM) 54
 near-infrared (NIR) laser 93, 143, 231–232
 neonatal rat cardiomyocytes 140, 141
 neural developments 12
 neurite, in neuronal cells 133, 133
 neuronal cells 133, 133
 Ni:chrome wire 43
Nicotiana tabacum 267
 nicotinamide adenine dinucleotide (NADH) 124
 NIPAM 62, 66, 72
 nitrobenzofurazan (NBD) 63
 2-(12-N-NBD-amino)dodecanoyl-1-
 hexadecanoyl-sn-glycero-3-phosphocholine
 (NBD-PC) 109–110, 110
 non-covalent systems 81–83, 301, 304–305
 non-fluorometric cellular thermometry
 bimaterial microcantilevers 199–200, 200
 excellent review article 183
 infrared thermometry 185, 186
 methods 224, 262
 micro-thermocouple array 198
 overview 183

- photoacoustic thermometry 186–188, 187
- Raman thermometry 188–191
- resonant thermal sensor 197–198, 199
- summary **184–185**
- thermistor 200–201, 201
- thermocouples 193–197
- transmission spectroscopy 191–193
- non-radiative intersystem crossing 20
- non-radiative relaxation process 19, 22
- norepinephrine (NE) 159, 161, 199, 223
- novel fluorescent thermometers 62, 63
- novel sensing techniques 210
- novel thermocouple 194
- 4-*n*-propylamino-7-nitro-2,1,3-benzoxadiazole (NBD-NHPr) 33, 63
- fluorescence properties of **64**
- NSOM (near-field scanning optical microscopy) 54
- nucleic acid-based fluorescent thermometers 77, 78
- nucleic acids 76–79, 217
- nucleus 126–131, 211
- o**
- 2,3,7,8,12,13,17,18-octaethyl-21H,23H-porphyrin platinum(II) (PtOEP) 46
- ODMR (optically detected magnetic resonance) techniques 173, 262
- OGD (oxygen glucose deprivation) 168
- O–H stretching Raman band 188, 189
- oligophenylenevinylene (OPV) 60
- onion skins 266, 267
- oocytes, by Mito-Q 173–174
- optically detected magnetic resonance (ODMR) techniques 173, 262
- optical tweezers 114
- organelle-targeted fluorescent thermometers 146–156
- mitochondria by 163–164
- organisms 1, 11
- organized systems 217
- organometallic complexes 41–49
- lanthanides 44–46
- others 48–49
- porphyrins 46–48
- ruthenium 41–43
- oxadine-1, 37
- oxazole-1 (2-(4-pyridyl)-5-(4-*N,N*-dimethylaminophenyl)-1,3-oxazole) 38
- oxygen glucose deprivation (OGD) 168
- p**
- P4VP (poly(4-vinylpyridine)) 252
- P4VP-*b*-P(MPEGA-*co*-PEGA) nanoparticle 252
- PAH (poly(allylamine hydrochloride)) 116, 231
- pannexin-1 (Panx1) 160
- PBS (phosphate-buffered saline) 58, 152, 235, 249
- PDA-FND (polydopamine-coated fluorescent nanodiamond) 228, 228
- PDMS (poly(dimethylsiloxane)) 31, 59, 66, 197, 198, 200
- PEGA (poly(ethylene glycol) acrylate) 252
- peptides 79
- perdeutero-poly(methyl methacrylate) 45
- PERK (PKR (protein kinase R)-like ER kinase) 160
- perylene 50, 53, 53–54, 247
- phenylboronic acid moiety 264
- phenyl isocyanide molecules 188, 190, 190
- Philodendron selloum* 6, 6
- phosphate-buffered saline (PBS) 58, 152, 235, 249
- phosphatidylcholines 81
- phosphorescence 19, 55, 83
- phosphorylated STAT3 (pSTAT3) 10
- photoacoustic intracellular thermometry 187
- photoacoustic thermometry 186–188, 187
- photothermal nanolens effects 229
- physical stimulation 143, **219–220**
- physiological events, temperature with 2
- PKR (protein kinase R)-like ER kinase (PERK) 160
- plant cells, intracellular thermometry of 265–267
- plant species 6–7
- plasma membrane-targeted fluorescent molecular thermometer (tsGFP1-F) 154–156, 155
- PMMA (poly(methyl methacrylate)) 116
- PMMA-MA (poly(methyl methacrylate-*co*-methacrylic acid)) 260, 261
- PMPEGA (poly(methoxy poly(ethylene glycol) acrylate)) 252
- PNIPAM (poly(*N*-isopropylacrylamide)) 62–63, 65, 70, 72, 191, 193, 254
- PNNPAM (poly(*N*-*n*-propylacrylamide)) 72
- poly(4-vinylpyridine) (P4VP) 252
- poly(allylamine hydrochloride) (PAH) 116, 231
- poly(dimethylsiloxane) (PDMS) 31, 59, 66, 197, 198, 200
- poly(methoxy poly(ethylene glycol)acrylate) (PMPEGA) 252
- poly(methyl methacrylate) (PMMA) 116
- poly(methyl methacrylate-*co*-methacrylic acid) (PMMA-MA) 260, 261

- poly(*N*-isopropylacrylamide) (PNIPAM) 62–63, 65, 70, 72, 191, 193, 254
- poly(*N*-*n*-propylacrylamide) (PNNPAM) 72
- poly(*N*-propargylamide) 67
- poly(NIPAM-*co*-DBD-AA) 66–67
- poly(NIPAM-*co*-DBD-AE) 65–66, 66, 73, 75
- fluorescence intensity of 251, 251
- microfluidic chamber with 67
- poly(NIPAM-*co*-SPA-*co*-DBD-AA) 73
- poly(sodium 4-styrenesulfonate) (PSS) 231
- poly[1-(trimethylsilyl)phenyl-2-phenylacetylene] (PTMSDPA) 60
- poly[*-alt-co-*] (PPPV) 60
- poly(ethylene glycol) acrylate (PEGA) 252
- polyarginine 118
- poly(phenylene ethynylene) carboxylate (PPE-CO₂-7) 60
- poly(*N*-isopropylacrylamide) (PNIPAM)
- chain 148
- polycrystalline fluorescent nanodiamonds 261
- poly(ethylene glycol) dimethacrylate (PEGDMA)
- units 257
- polydopamine 228
- polydopamine-coated fluorescent nanodiamond (PDA-FND) 228, 228
- poly-L-lysine 116, 117, 118
- polymerase chain reaction (PCR) 31
- polymeric nanoparticles 84, 210
- polymers
- as fluorescent molecular thermometers 57–60
- of fluorescent monomer units 60–61
- polymethylene backbones (poly(OPV-DD)) 60
- poly(styrene-*co*-methacrylic acid) (PS-MA)
- nanoparticles 244
- polystyrene film 23, 53
- polystyrene microsensor 114
- polystyrene microspheres 140
- polyvinylpyrrolidone (PVP) 60
- porphyrins 46–48
- PPE-CO₂-7 (poly(phenylene ethynylene) carboxylate) 60
- predissociation 19
- prima facie* 215
- prostaglandin E₂ (PGE₂) 150, 151
- PS-MA (poly(styrene-*co*-methacrylic acid))
- nanoparticles 244
- PS-RhB (rhodamine B-labeled polystyrene) 60
- PTMSDPA (poly[1-(trimethylsilyl)phenyl-2-phenylacetylene]) 60
- PVP (polyvinylpyrrolidone) 60
- PYPYP (1,3-bis-(1'-pyrenyl)-propane) 50, 51
- pyrazole-1 38
- pyrene 50, 63
- emission intensity ratio of 50
- excimer fluorescence 68
- N*-(1-pyrenylmethyl)-1-pyreneacetamide (PMPAA) 50
- N*-(1-pyrenylmethyl)-1-pyrenebutanamide (PMPBA) 50
- 2-(4-pyridyl)-5-(4-*N,N*-dimethylaminophenyl)-1,3-oxazole (oxazole-1) 38
- q**
- Q-dots. *see* quantum dots
- QTracker cell labeling kit 139
- quantum dots (Q-dots) 84–87, 86, 117, 118, 133, 156
- CdSe/ZnS 85
- CdS/ZnS 85, 212
- emission intensity ratio of 133
- r**
- radiative fluorescence process 20
- Raman spectroscopy 188–191, 189
- of fission yeast cells 192
- with phenyl isocyanide molecules 190
- ratiometric fluorescent thermometer 117, 140
- ratiometric systems 39
- reactive oxygen species (ROS) 126
- red-eared slider turtle (*Trachemys scripta elegans*)
- 8, 10
- relative sensitivity 205, **206–207**
- relaxation processes 18, 18
- reliability issues, in intracellular
- thermometry 205–236
- calibration curve 212–215, 214, 216
- endogenous thermogenesis 215–233
- functional independence 208–212, 211
- near-infrared luminescent
- thermometry 233–236
- sensitivity and temperature resolution
- 205–208, **206–207**
- reptiles 8–9, 9
- resonant thermal sensor 197–198, 199
- “response to environmental temperature” 1, 7–11
- variations 11–13
- retro Diels–Alder reaction 36, 37
- RhB (rhodamine B) 25–33, 26, 31, 32, 57, 231
- RhBIV 152
- rhodamine B (RhB) 25–33, 26, 31, 32, 57, 231
- application **27**
- fluorescein 27 and 39
- fluorescence intensity 68
- fluorescence lifetime 28
- fluorescent molecular thermometers 150

- microfluidic system with 29
 - onion skin and 266, 267
 - radiometric temperature measurements by 30
 - temperature measurement of 31
 - rhodamine B-labeled polystyrene (PS-RhB) 60
 - RNA 76–79, 242
 - RNA-binding proteins 11
 - ROS (reactive oxygen species) 126
 - rotating substituent group 25–36
 - 8-aryl-BODIPY derivatives 34
 - cyanines 35–36
 - NBD-NHPr 33
 - rhodamine B 25–33, 26, 27, 29–33
 - triarylborons 34–35
 - $\text{Ru}(\text{bpy})_3^{2+}$ (tris(2,2'-bipyridyl)ruthenium(II))
 - complex 41–43, 42, 43
 - ruthenium 41–43
 - ryanodine receptor 1 (RYR1) 168–169, 171
 - RYR1 (ryanodine receptor 1) 168–169, 171
- s**
- Saccharomyces cerevisiae* strain SYT001, 120
 - Salmonella typhimurium* 194
 - sarco-endoplasmic reticulum Ca^{2+} -ATPase (SERCA) 153
 - SARS CoV-2 (severe acute respiratory syndrome coronavirus 2) 140, 185
 - scientific diplomacy 222
 - selenoprotein P (SeP) 160
 - self-assembled DNA tetrahedron 78
 - SERS (surface-enhanced Raman spectroscopy) 188
 - severe acute respiratory syndrome coronavirus 2 (SARS CoV-2) 140, 185
 - signal-to-noise ratio 208
 - silica microfiber 191, 193
 - silica nanoparticles 254
 - silicone composite, nanoparticles in 94
 - silicon nanowires 112–114, 114
 - silicon-vacancy nanodiamonds 93
 - silk film 249
 - Si microresonator 218
 - simultaneous monitoring 263–265, 265
 - single-nucleotide polymorphisms (SNPs) 76
 - SiO_2 nanoparticles 59
 - $\text{SiR-CH}_2\text{Cl}$ 152
 - Si resonant thermal sensor 197–198, 199
 - Si-rhodamine 152
 - Sirius 243
 - skunk cabbage (*Symplocarpus renifolius*) 7, 7
 - small organic fluorescent 120
 - small organic molecules
 - in intersystem crossing 21–25
 - other 39–41
 - reactive 36–38
 - with rotating substituent group 25–36
 - viscosity-sensitive 38–39
 - SNPs (single-nucleotide polymorphisms) 76
 - social stress 4
 - solid inorganic fluorescent thermometers 84
 - solid inorganic nanostructures 321
 - solid–liquid transition 82
 - spectrofluorometer 208
 - spermatogenesis 9
 - spontaneous thermogenesis 1, 2–7
 - bear 5, 5
 - human 2–4, 3
 - oceanic lives 5–6
 - plants 6–7
 - SQR22 81
 - Staphylococcus aureus* 151
 - Stenotaphrum variegata* 197
 - Stokes law 18
 - stress granules formation 11, 12
 - sulforhodamine B 32–33
 - surface-enhanced Raman spectroscopy (SERS) 188
 - synthetic cationic polymer 116
 - synthetic polymers 57–76
- t**
- T1AM (3-iodothyronamine) 140, 141
 - TAT (transactivating transcriptional activator) protein 117
 - TBBD (1,1'-(6,6'-((2,4,6-triisopropylphenyl)boranediyl)bis(pyrene-6,1-diyl))dipyrrolidine) 35
 - temozolomide (TMZ) 257
 - temperature 1
 - for living things 1–14
 - and organisms 1
 - with physiological events 2
 - “response to environmental temperature” 1, 7–11
 - spontaneous thermogenesis 1, 2–7
 - TRP channels 11, 13
 - temperature-dependent sex determination, in reptiles 8–9, 9
 - temperature distribution 126–133, 215
 - centrosome 131, 131
 - mitochondria 132, 132
 - neurite in neuronal cell 133, 133
 - nucleus 126–131
 - temperature gradient 241
 - temperature measurement system 197
 - temperature monitoring 143

- Caenorhabditis elegans* by 244
 HEK293 cells 155
 at lysosome 163–164
 in photothermal muscle 255
 temperature-responsive protein 12
 temperature-sensing system 81, 188
 “temperature uncertainty” 206
 5,10,15,20-tetraphenyl-21H,23H-porphyrin
 copper(II) (CuTPP) 46–47
 tetraphenylporphyrin (TPP) 47
 Tf-QDs (membrane transport protein
 transferrin) 156, 156
 theragnostics 250
 theranostics. *see* theragnostics
 thermal diffusivity 229
 thermal medicine 250–258
 thermal sensor 226
 thermal signaling 241
 thermistor 200–201, 201
 thermochromic fluorescent materials 38
 thermocouples 17, 193–197
 thermography 185
 thermometry, concept of 32
 thermoregulation system 4
 thermoresistance 242
 thermo-responsive moiety 62
 thermo-responsive polymers 61–76, 275–293
 of acrylamide derivatives 72–73
 and environment-sensitive
 fluorescent **302–303**
 nanogel thermometer composed of 75
 “threshold” fluorescent thermometer 59
 TIAR 11, 12
 TICT@AIE 82
 TICT (twisted intramolecular charge transfer)
 state 33, 34
 time constant 196–197
 TMZ (temozolomide) 257
 TPP (triphenylphosphonium) 148
 transactivating transcriptional activator (TAT)
 protein 117
 transient microscopic method 229
 transient receptor potential (TRP) channels
 11, 13
 in plasma membrane 13
 transient receptor potential vanilloid 4
 (TRPV4) 168
 transmission spectroscopy 191–193
 triarylborons 34–35
 1,1'-(6,6'-((2,4,6-triisopropylphenyl)
 boranediyl)bis(pyrene-6,1-diyl))dipyrrolidine
 (TBBD) 35
 triphenylamine moiety 40
 triphenylphosphonium (TPP) 148
 triplet–triplet annihilation (TTA) 246
 upconversion nanomicelles 82–83, 83
 triplet–triplet annihilation Nd nanophosphors
 (TTA-Nd-NPs) 246
 tris(thenoyltrifluoroacetato)europium(III)
 complex (EuTTA) 44, 44–45, 46
 tris(2,2'-bipyridyl)ruthenium(II) (Ru(bpy)₃²⁺)
 complex 41–43, 42, 43
 TRPV4 (transient receptor potential vanilloid
 4) 168
 tsGFP1-F (plasma membrane-targeted fluorescent
 molecular thermometer) 154–156, 155
 TTA (triplet–triplet annihilation) 246
 TTA-Nd-NPs (triplet–triplet annihilation Nd
 nanophosphors) 246
 tumors, heat production in 4
 twisted intramolecular charge transfer (TICT)
 state 33, 34
 type K thermocouple 197
- u**
 UCNPs. *see* upconversion nanoparticles
 UCP1 (uncoupling protein-1) 159
 UCP2 (uncoupling protein 2) 174, 185
 ultrasound-switchable fluorescence (USF) 68,
 69–71
 uncouplers 136–138, 137
 uncoupling protein-1 (UCP1) 159
 uncoupling protein 2 (UCP2) 174, 185
 upconversion nanoparticles (UCNPs) 82, 93–94,
 148, 163, 226, 227
 ratiometric 250
 upper critical solution temperature (UCST) 96
 USF (ultrasound-switchable fluorescence) 68,
 69–71
- v**
 vanadium dioxide (VO₂) 200
 microthermistor 201
 vanadyl 2,11,20,29-tetra-*tert*-butyl-2,3-
 naphthalocyanine (V-Nc) 261
 viscosity-sensitive small organic
 molecules 38–39
 V-Nc (vanadyl 2,11,20,29-tetra-*tert*-butyl-2,3-
 naphthalocyanine) 261
 VNP20009 194
 “volume phase transition temperature” 75
- w**
 “warmblooded” 2
 water molecules, Raman intensity ratio of 188
 wireless and precise muscle activation 255

W-PU-Pt thermocouple 194

WST-1 (2-(4-iodophenyl)-3-(4-nitrophenyl)-
5-(2,4-disulfophenyl)-2H-tetrazolium,
monosodium salt) 124

WST-1 assay 124

y

yeast cells 125, 185

yoshino cherry 11

z

Z-DNA (Z form) 76

zebrafish larva 242, 243

Z form (Z-DNA) 76

zinc complex (ZnTPP) 47

ZnO microcrystals 86

ZnTPP (zinc complex) 47









