

Index

a

alloy materials 221–228
 atomic metal doping of carbon materials 124–127
 Au based catalysts 400, 401, 473–474
 Au-based electrocatalyst
 porous metal-based materials for NRR 432
 Au-based porous nanocomposites 540

b

B and N co-doped nanodiamond (BND) 339
 Bi-doped Ni aerogel electrocatalysts 521
 bimetallic Fe/Ni-MIL-53 MOF 543
 bimetal materials, CO₂RR
 Cu-Ag 293–294
 Cu-Al 291–292
 Cu-Au 292–293
 Cu-Bi 287–288
 Cu-Ce 286–287
 Cu-Co 283
 Cu-Ga 284–286
 Cu-In 288–289
 Cu-Ni 283–284
 Cu-Zn 289–291
 binary heterostructured nanoplates 469
 binary metal alloys 221
 biomass conversion and utilization 511
 biomass oxidation reaction 539–547
 biomass reduction reaction 547–549
 bionic mineralization method 543

biopolymer polyfurylate (PEF) 515
 black phosphazene (BP) 149
 boron-doped carbon nanotubes (BCNTs) 185
 boron-doped diamond (BDD) 339
 branched-chain ruthenium nanocrystals 219

c

carbon-based catalysts 4, 103–104, 122, 184, 187, 190–191, 208, 234, 347–348, 497
 carbon-based materials 3
 CO₂ reduction reaction (CO₂RR)
 commercialization 347–348
 coordination environment control 345–346
 defects control 346
 group functionalization 344
 heteroatom doping 344–345
 in situ characterization 346–347
 metal/carbon composites 342–344
 metal-free carbon 337–340
 metal-N-C SACs 340–342
 nitrogen reduction reaction (NRR)
 carbon composite materials 422–424
 HDCBMs 417–421
 vacancy-abundant carbon nitride
 carbon-based materials 421–422
 carbon-based metal-free electrocatalysts (C-MFEC) 108–111, 128

- carbon-based metal free materials for ORR
 - carbon nanomaterials Co-doped with heteroatoms 186
 - carbon nanomaterials doped with non-nitrogen heteroatoms 185–186
 - nitrogen-doped carbon nanomaterials 184–185
- carbon-based metal-free porous ORR catalyst
 - heteroatom co-doped catalysts 206–207
 - N-doped carbon nanostructures 206
 - undoped carbon-based catalysts 207–208
- carbon-based non-noble metals, ORR 189–190
- carbon-based non-precious metal single atom catalyst
 - Fe-based single atom catalyst 187–188
 - non-Fe-based single atom catalyst 188–189
- carbon-encapsulated Co-Mo₂C
 - heterostructures (Co-Mo₂C-CN) 153
- carbon-encapsulated MoO₂-FeP
 - heterojunctions (MoO₂-FeP@C) 526
- carbon materials supporting COF for OER 267–268
- carbon nanomaterials Co-doped with heteroatoms 186
- carbon nanomaterials doped with non-nitrogen heteroatoms 185–186
- carbon quantum dots 108, 111–114
- carbon-supported metal/alloy 342–343
- catalyst activity 9, 14, 82, 112, 191, 523
- cellulose 511–512, 515
- central metal coordination materials
 - metal complex-based catalysts 406–407
 - MOF and COF-based catalysts 406
- cobalt-molybdenum phosphide (CoMoP)
 - nanotubes 147
- cobalt-nitrogen/carbon catalysts (CoN_x/C) 154
- cobalt phosphide (CoP) 89–91
- Co-based catalysts 404
- Co/CoP heterojunctions 527
- Co-edge Fourier Transform (FT) 219
- computational hydrogen electrode (CHE)
 - model 10
- conformational control 517
- conventional electrocatalysts materials 2
- CO pathway 456
- Co₂P@Co/N-C 488
- copper nitrides (Cu₃N) 387–391
- copper (I) sulfide (Cu₂S) 387, 388
- copper (II) sulfide (CuS) 386–387
- CO₂ reduction reaction (CO₂RR) 2
 - carbon-based materials
 - commercialization 347–348
 - coordination environment control 345–346
 - defects control 346
 - group functionalization 344
 - heteroatom doping 344–345
 - in situ characterization 346–347
 - metal/carbon composites 342–344
 - metal-free carbon 337–340
 - metal-N-C SACs 340–342
- Cu-based compounds
 - copper nitrides (Cu₃N) 387–391
 - copper (II) oxide (CuO) 382–383
 - copper (I) sulfide (Cu₂S) 387, 388
 - copper (II) sulfide (CuS) 386–387
 - cuprous (I) oxide Cu₂O 383–386
- Cu-based metal materials
 - bimetal materials 283, 294
 - trimetallic materials 295–296
- fundamentals of 334–336
- non-Cu metal-based materials
 - molecular catalysts 320–321
 - monometallic catalysts 308, 311
 - multi-metallic catalysts 311–314

non-Cu metal compounds 314–319
 single-site M-N-C catalysts 321–323
 porous materials
 COF 364–370
 metal-organic framework 364–366
 core-shell Pt nanostructures 170
 CO₂RR fundamentals of electrocatalytic 42–45
 Co-SAs@NC 217
 coupled reactors 455–456
 covalent organic frameworks (COFs) 2, 546
 composites for OER
 carbon materials supporting 267–268
 metal hybrids containing 268
 CO₂RR
 copper based derived porous materials 370–373
 metal bipyridyl 368–370
 nickel based derived porous materials 373–376
 phthalocyanine covalent organic framework 369
 porphyrin covalent organic framework 364–367
 derivatives for OER 269
 for NRR 446–448
 pristine for OER 265–267
 crystal orbital Hamilton population (COHP) 11, 16
 Cu-based compounds CO₂RR
 copper nitrides (Cu₃N) 387–391
 copper (II) oxide (CuO) 382–383
 copper (I) sulfide (Cu₂S) 387, 388
 copper (II) sulfide (CuS) 386–387
 cuprous (I) oxide Cu₂O 383–386
 Cu-based metal materials, CO₂ reduction reaction
 bimetal materials 283, 294
 trimetallic materials 295–296
 cuprous (I) oxide Cu₂O 383–386

d

de-alloying techniques 144
 defect engineering 2, 78, 108, 115, 235, 237, 296, 334, 449, 490, 522–525, 530
 density functional theory for
 electrocatalysis evaluation
 electronic structures 11
 hydrogen evolution reaction 12–16
 nitrogen reduction reaction (NRR) 22–26
 oxygen reduction reaction (ORR) 15–22
 reaction free energy 10–11
 dicarbonylfuran (DFF) 460, 515, 530
 direct hydrazine fuel cells (DHFC) 497
 direct liquid fuel cells (DLFC) 497
 direct methanol fuel cells (DMFC) 456, 468, 484

e

electrocatalysis, definition of 1
 electrocatalytic hydrogenation or deoxygenation (ECH) 514, 549
 electrocatalytic hydrogen evolution reaction
 metal-based materials for 54
 metal compounds 76–92
 electrocatalytic oxidation 474, 483–491, 514, 540, 543
 electrocatalytic process 2, 33–35, 55, 56, 123, 267, 402, 415, 516, 539
 electrocatalytic reaction mechanism for energy conversion
 CO₂RR 42–45
 electrocatalytic HER 37–38
 electrochemical parameters 35, 37
 NRR 45–46
 OER 38–41
 oxygen reduction reaction (ORR) 41–42
 electrocatalytic technology development of 9, 33, 555
 electrochemical catalysis 3, 513

electrochemical CO₂RR 283, 287, 292,
294, 295, 305–308, 314, 316,
320–323, 382, 386, 455

electrochemical hydrogen production
233

electrochemical liquid fuel oxidation
(ELFO) 455, 456, 474, 475

electrochemical parameters
exchange current density 36–37
Faradic efficiency 35
Gibbs free energy 35–36
overpotential 35
Tafel slope 36
turnover frequency (TOF) 36

electrode materials, properties of 1

electrolytic cell reactors 475

electronic structures, in electrocatalysis
11–12

energy storage materials 2

ethanol oxidation reaction (EOR)
456–458, 461–463, 468–471,
473, 484, 487–491,
518–521

ethylene glycol oxidation reaction
(EGOR) 458, 463–464, 471

exchange current density 14, 34, 36–37,
54, 56, 113, 141

extended-ray absorption fine structure
(EXAFS) 60, 219, 220, 341, 444,
449, 523, 525, 530, 531

f

Faradic efficiency 34, 35, 385

fast-solidification technique 144

Fe-based catalysts 245, 403, 405

Fe-based single atom catalyst
187–190

Fe-N₄SAs/NPC 221

Fe-NSDC 221

FeS 81

formic acid oxidation reaction 459,
465–468, 472–473

fuel cell 456
catalysts 166
hydrogen 456

functional materials
definition 1
electrochemical catalysis 3

2,5-furandicarboxylic acid (FDCA) 460,
513, 515–516, 531, 540–545, 547

g

g-C₃N₄ electrocatalysts for HER
121–122

geometric effect 129, 170, 245

Gibbs free energy
electrochemical parameters 35, 36
of hydrogen gas 10, 55, 57, 109
of proton-electron pairs 10

glycerol electrooxidation 459, 464, 465,
540

glycerol oxidation reaction (GOR)
458–459, 464–465, 471–472, 474

graphene-based electrocatalysts, HER
118–120, 128

graphitic carbon nitride 24, 61, 121, 154,
267, 339–340

graphitic-layer-encapsulated metal/alloy
343–344

h

Haber-Bosch process 22, 397, 408, 415,
419

hemicellulose 512

heteroatom co-doped carbon-based
porous ORR catalysts 206–207

heteroatom-doped carbon materials
hard-templating synthesis method
498
for HzOR 501–505
soft-templating synthesis 498–500
template-free synthesis 500–501

heteroatom-doped carbon nanomaterials
497

heteroatom doping carbon-based
materials (HDCBMs) 417–422

heteroatom doping, in electrocatalytic
materials 520–522

heterostructural nanosheets (HNSs) 471

heterostructuring 525–527

- Heyrovsky step 12, 38, 55, 84, 105, 111, 123
- hierarchically structured porous $\text{Ni}_3\text{S}_2/\text{Ni}$ foam electrocatalyst ($\text{Ni}_3\text{S}_2/\text{NF}$) 516
- high index facets (HIFs) 2, 170, 174, 175, 384, 462, 464
- hydrazine hydrate 484
- hydrogen evolution reaction 514
- carbon-based materials
 - atomic metal doping 124–127
 - low dimensional carbon material and hetero atom doped carbon 111–122
 - metal-free electrocatalysts 108–111
 - MOF derived electrocatalysts 122–124
 - descriptors 13–14
 - detailed computational methods 13
 - fundamentals of
 - electrocatalytic 37–38
 - kinetics and rate-determining steps 106–108
 - mechanistic of 105–106
 - metal-based materials 54–55
 - porous materials for 141–148
 - reaction mechanism 12–13
 - structure-activity relationship 14–16
- 5-hydroxymethylfurfural (HMF) oxidation reaction 460
- i**
- icosahedral Pt-enriched nanocage 173
- Ir and Ag-based materials 435
- Ir-based catalysts 225, 233
- Ir-based material 63–64
- Ir-modified BP catalysts 150
- Ir-Sn pair-site catalyst (Ir-Sn PSC) 241
- l**
- Langmuir adsorption model 140
- layered transition metal hydroxides
- $\text{Co}(\text{OH})_2$ 84
 - $\text{Ni}(\text{OH})_2$ 84
 - NiFeMo LDH 84–85
- ligand-based modification engineering 257–259
- lignin 455, 512
- liquid fuels 1, 288, 455, 483–491
- low dimensional carbon material and hetero atom doped carbon
- carbon nanotube catalysts for HER 114–118
 - carbon quantum dots 111–114
 - g- C_3N_4 electrocatalysts 121–122
 - graphene-based electrocatalysts 118–120
 - N-doped carbon electrocatalysts for HER 120–121
- low-loading noble metal catalysts 475
- m**
- mechanism of morphology regulation 518
- metal-based materials
- efficient HER catalyst 55–56
 - for electrocatalytic biomass conversion
 - challenges and prospects 530–531
 - defect engineering 522–525
 - heteroatom doping 520–522
 - heterostructuring 525–527
 - morphology control 517–519
 - single-atom modification 528–530
- electrocatalytic HER activity
- non-PGM-based materials 64–67
 - PGM-based materials 57–64
- ELFO 458
- ethanol oxidation reaction 457
- ethylene glycol oxidation reaction 458
- formic acid oxidation reaction 459
- glycerol oxidation reaction 459
- 5-hydroxymethylfurfural (HMF) oxidation reaction 460
- methanol oxidation reaction 456
- noble metal based electrocatalysts 473–474
- Pd-based electrocatalysts 468–473
- Pt-based electrocatalysts 460–468

- metal-based materials (*contd.*)
 - mechanism of the electrocatalytic HER 54–55
 - for OER
 - alloy materials 221–228
 - single-atom materials 216–221
- metal-based nanocatalysts 3
- metal-based nanomaterials, NRR
 - central metal coordination 405–407
 - non-noble transition 401–405
 - precious metals 398–401
- metal bipyridyl COFs 368–370
- metal@carbon composite materials 422–424
- metal/carbon composites
 - carbon-supported metal/alloy 342–343
 - graphitic-layer-encapsulated metal/alloy 343–344
- metal chalcogenides
 - non-layered metal chalcogenides 80–81
 - transition-metal dichalcogenides 76–80
- metal complex-based catalysts 406–407
- metal compounds 3, 234, 314–319, 321, 516
 - as HER electrocatalysts
 - layered transition metal hydroxides 84–86
 - metal chalcogenides 76–81
 - transition-metal carbides and nitrides 85–88
 - transition metal oxides 82–83
 - transition-metal phosphide 88–92
- metal-free carbon
 - carbon nanotubes 338–339
 - graphene materials 337–338
 - graphitic carbon nitride 339–340
 - nanodiamond 339
- metal-free COFs for OER 265
- metal hybrids containing COF for OER 268
- metal hydroxides 242–247, 486–488
- supported nanoparticle materials 245, 246
- supported single-atom materials 245–247
- metal-organic frameworks (MOFs) 540
 - CO₂RR
 - copper based derived porous materials 370–373
 - nickel based derived porous materials 373–376
 - porphyrin-based metal organic framework 359–361
 - ZIFs 361–364
 - for NRR
 - composite electrocatalyst 441–443
 - MOF-derived carbon-based electrocatalyst 444–446
 - MOF-derived metal composite electrocatalyst 442–444
 - pristine 439–441
 - for OER
 - metal oxides (MOs) 262–264
 - metal phosphides (MPs) 264
 - metal sulfides (MSs) 264
 - M-N-PC 261–262
 - MOF/active species composites 261–265
 - MOF/support composites 259–261
 - pristine 257–259
- metal oxides supported nanoparticle materials 239–241
- metal oxides supported single-atom materials 241–243
- metal sites-containing COFs for OER 266–267
- methanol oxidation reaction (MOR) 456, 457, 461–462, 468–469, 473, 474, 484–489, 521
- 2-methylfuran (MF) 548–549
- mixed-metal node engineering 257
- M-N-PC, OER 261–262
- Mo-based catalysts 402–404
- MOF derived electrocatalysts 122–124, 540

molybdenum phosphide (MoP) 89, 91,
117, 147
monometallic catalysts 307–311
multifunctional catalysts 121, 475
multi-metallic catalysts 311–314

n

nanodiamond 339
“Nanoplatelet-on-Nanoarray” NiCo
hydroxide-based electrocatalysts
(t-NiCo-MOF) 543–544
N-doped carbon
Co single atoms 217
electrocatalysts for HER 120–121
N-doped CNT (CNT@NCNT) catalysts
184
N-doped porous carbon (NPC) 59, 66,
109, 417, 423, 444
N, F, P ternary doped macro porous
carbon fibers (NFPC) 186
Ni-based two-dimensional metal-organic
frameworks 543
nickel-diketimine-linked COFs
(Ni-DKI-COFs) 547
nickel(II)-modified covalent-organic
framework 546
nickel phosphide (NiP) 91
nickel sulfide (NiS_x) 81
NiCo-LDH 521
Ni(OH)₂ nanoclusters 84
nitrogen-containing carbon nanotubes
(VA-NCNTs) catalyst 184
nitrogen-doped carbon-based porous ORR
catalysts 206
nitrogen-doped carbon nanomaterials
184–185
nitrogen-doped graphene layer 152
nitrogen reduction reaction (NRR)
carbon-based materials
carbon composite materials
422–424
HDCBMs 417–421
vacancy-abundant carbon nitride
materials 421–422
descriptors 24–25

detailed computational methods
23–24
Ir and Ag-based materials 435–436
metal-based nanomaterials
central metal coordination
405–407
non-noble transition 401–405
precious metals 398–401
porous materials
Au-based electrocatalyst 432
COFs 446–448
Ir and Ag-based materials 435–436
metal-organic frameworks
439–446
noble-based electrocatalysts
436–439
Pd-based electrocatalyst 432–435
Ru-based electrocatalyst 435
reaction mechanism 22–23
structure-activity relationship 25–26
nitrogen-rich doping 146
Ni_xB-modified foam Ni 516
noble metal-based catalysts 201, 233
noble metal based (NMB) nanostructures
455
noble metal-based porous ORR catalysts
precious metals 201
Pt-based catalysts 200–201
Pt-based porous ORR catalysts
197–200
non-carbon-based catalysts 234
non-CO pathway 456
non-Cu metal-based materials, CO₂
reduction reaction
molecular catalysts 320–321
monometallic catalysts 308, 311
multi-metallic catalysts 311–314
non-Cu metal compounds 314–319
single-site M-N-C catalysts 321–323
non-Cu metal compounds, CO₂RR
metal carbides and nitrides 318–319
metal chalcogenides 316–318
metal oxides 314–316
non-Fe-based single atom catalyst
188–189

- non-layered metal chalcogenides 80, 81
 - CoSe₂ 80–81
 - FeS 81
 - NIS 81
- non-noble metal catalysts
 - single metal catalyst 485, 486
 - transition metal hydroxides 486–488
 - transition metal nitrides (TMNs) 490–491
 - transition metal oxides 485–487
 - transition metal phosphide (TMPs) 488–489
 - transition metal sulfides 489–490
- non-noble transition metal-based catalysts
 - Co-based catalysts 404–405
 - Fe-based catalysts 405
 - Mo-based catalysts 402–404
- non-PGM-based materials 57, 64–67
- nonporous Au-Ag alloy electrode 540
- non-precious metal transition metals 223
- non-Pt-based metal materials for ORR 175
- N₂ reduction (NRR), fundamentals of 45–46
- N₂ reduction reaction (N₂RR) 1, 2
- O**
 - 1D hollow geometric structure 145
 - one-dimensional nanocrystal catalysts 174
 - 1D nanostructures 141, 144, 148
 - overpotential, definition of 35
 - oxygen-defect-rich LDH nanosheet arrays 523
 - oxygen defects 287, 524
 - oxygen evolution reaction (OER)
 - fundamentals of electrocatalytic 38–41
 - metal-based materials for
 - alloy materials 221–228
 - single-atom materials 216–221
 - metal hydroxides 244–245
 - supported nanoparticle materials 245–247
 - supported single-atom materials 245–247
 - metal oxides 234–238
 - supported nanoparticle materials 239–241
 - supported single-atom materials 241–243
 - porous materials for 255
- oxygen reaction reduction (ORR)
 - carbon-based metal free materials
 - carbon nanomaterials Co-doped with heteroatoms 186
 - nitrogen-doped carbon nanomaterials 184–185
 - non-nitrogen heteroatoms 185–186
- carbon-based non-noble metals 189–190
- carbon-based non-precious metal single atom catalyst
 - Fe-based single atom catalyst 187–188
 - non-Fe-based single atom catalyst 188–189
- descriptors 19–20
- detailed computational methods 18–19
- fundamentals of electrocatalytic 41–42
- metal-based materials
 - non-Pt-based 175
 - Pt-based materials 166–175
- porous materials for
 - carbon-based metal-free catalysts 206–208
 - noble metal-based porous catalysts 197–201
 - transition metal-based catalysts 201–205
- reaction mechanism 17–18
- structure-activity relationship 20–22
- oxygen vacancies 226, 239, 287, 386, 389, 400, 405, 439, 444, 486, 524, 525, 530

p

- Paris Climate Agreement 333
- π Back-Donation 419, 422
- Pd-based electrocatalyst
 - ethanol oxidation reaction (EOR) 469–471
 - ethylene glycol oxidation reaction (EGOR) 471
 - formic acid oxidation reaction (FAOR) 472–473
 - glycerol oxidation reaction 471–472
 - methanol oxidation reaction (MOR) 468–469
 - porous metal-based materials for NRR 432–439
- Pd-based materials 62
- Pd-based porous ORR catalysts 200–201
- Pd@Pt_{1L} core-shell octahedral 172
- PGM-based materials
 - Ir-based material 63–64
 - Pd-based materials 62–63
 - Pt-based materials 57–60
 - Rh-based materials 61–62
 - Ru-based materials 60–61
- phthalocyanine covalent organic framework 366–369
- porous materials 4
 - for biomass oxidation reaction 539–547
 - for biomass reduction reaction 547–549
- CO₂ reduction reaction(CO₂RR)
 - COF 364–370
 - metal-organic framework 364
- nitrogen reduction reaction (NRR)
 - Au-based electrocatalyst 432
 - COFs 446–448
 - Ir and Ag-based materials 435
 - metal-organic frameworks 439–446
 - nonnoble-based electrocatalysts 436–439
 - Pd-based electrocatalyst 432, 435
 - Ru-based electrocatalyst 435
- for ORR
 - carbon-based metal-free catalysts 206–208
 - noble metal-based porous catalysts 197–201
 - transition metal-based catalysts 201–205
- for oxygen evolution reaction
 - COFs 265–269
 - MOF 257–265
- porous materials for electrocatalytic HER
 - 1D nanomaterials 144, 148
 - 2D nanomaterials 148–153
 - 3D nanomaterials 153–156
 - performance of 141
- porous metal-based electrocatalyst 539
- porous nanostructured CeO₂/NiV-LDH
 - composite catalyst 472, 488
- porphyrin-based metal organic framework 359–361
- porphyrin covalent organic framework 364–367
- potential-determining step (PDS) 10, 19, 24–26, 290, 388, 436, 441, 444
- precious metal-based catalysts
 - Au-based catalysts 400, 401
 - Pt, Pd-based catalysts 398–400
 - Ru, Rh-based catalysts 400
- precious metal-free trimetallic layered double hydroxide (NiCoFe-LDHs) nanosheets 516
- precious metals, as electrocatalysts 515
- pristine COFs for OER
 - composites 267–269
 - metal-free 265–266
 - metal sites-containing 266–267
- pristine MOF electrocatalyst 439–441
- pristine MOFs for OER
 - ligand-based modification engineering 257–259
 - mixed-metal node engineering 257
 - structure engineering 259
- projected density of states (PDOS) 11, 25, 26, 401, 446, 448, 463, 487

- proton exchange membrane water electrolyzers (PEMWE) 233–238, 242, 248
- Pt-base alloy nanoframe catalysts 172–173
- Pt-based catalysts 57, 62, 105, 124, 165–176, 200, 456, 461, 465
- Pt-based electrocatalysts
- ethanol oxidation reaction (EOR) 462–468
 - ethylene glycol oxidation reaction (EGOR) 463–464
 - formic acid oxidation reaction (FAOR) 465–468
 - glycerol oxidation reaction (GOR) 464–465
 - methanol oxidation reaction (MOR) 461–462
- Pt-based materials 37, 57–60, 166–175
- Pt-based materials for ORR
- composition regulation of 166–167
 - structural design of
 - core-shell nanostructure 170–172
 - index crystal faces 169–170
 - nanoframe catalysts 172–173
 - nanowire 174–175
 - octahedral 167–169
- Pt-based porous ORR catalysts 197–200
- PtBi bimetallic nanoparticle decorated nonporous gold electrocatalyst 540
- PtBiPbNiCo hexagonal nanoplates (HEA HPs) 466, 467
- PtNi alloy nano-octahedra 169
- Pt/NiO core/shell nanowires 175
- Pt-Ni octahedral 167, 168
- PtNi octahedra nanocrystals 169
- PtNi₃ polyhedron 172
- PtPb/Pt core/shell nanoplate 170
- Pt, Pd-based catalysts 398–400
- Pt single-crystal tetrahedral 170
- r**
- rate-determining step (RDS) 13, 44, 46, 55, 60, 106–108, 110, 123, 140, 223, 239, 242, 419
- reaction free energy 10–11
- reaction mechanism, DFT calculations 12–13
- reversible hydrogen electrode (RHE) 79, 152, 307, 384, 416, 432, 543
- Rh based catalysts 61, 400, 474
- Rh-based materials 61–62
- Ru-based catalysts 127, 225
- RU-based electrocatalyst, porous metal-based materials for NRR 435
- Ru-based materials 60–61
- Ru-based polymetallic nanostructured electrocatalysts 223
- Ru, Rh-based catalysts 400
- s**
- Sabatier's law 140
- Sabatier's principle 104, 105
- self-supported porous 2D AuCu triangular nanoprisms 540
- single-atom catalysts (SACs)
- development of 528
 - non-carbon-supported 241
- single-atom doping and surface modification 241
- single-atom Ir-loaded Co₃O₄ (Ir-Co₃O₄) 528
- single-atom modification 528–530
- single metal catalyst 307, 485, 486
- 6-electron transfer process 456
- standard hydrogen electrode (SHE) 10, 59, 398
- supra-nanostructured Pd/Au composite 468
- t**
- Tafel step 12, 38, 84, 105, 106, 128
- ternary alloy electrodes 226
- ternary Au@PtIr core-shell catalyst 463
- 3D Ag/Cu foam composite 547

- three-dimensional self-supporting
metallic carbon nanostructures
488
- 3D porous nanomaterials 153–156
- transition metal-based porous ORR
catalysts
metal/carbon and nitrogen composite
204–205
metal/carbon composite 202–203
metal oxide/carbon composite
203–204
- transition-metal carbides and nitrides
 Co_xC 87–88
 Mo_xC 87
 MXenes 88
 W_xC 87
- transition metal dichalcogenide (TMDC)
76–80, 312, 316, 317, 386
- transition metal hydroxides 81, 84–85,
486–488, 515
- transition-metal nanoparticles 217
- transition metal nitrides (TMNs) 3, 76,
85, 190, 389, 490–491
- transition metal oxides 82, 83, 485, 487
 MoO_x 82–83
 TiO_2 nanomaterials 82
 WO_3 83
- transition metal phosphide (TMPs) 76,
88–92, 190, 488–489
carbon composites 190
 CoP 89–91
 FeP_x 89
 MoP 89
 NiP 91–92
- transition metal sulfides 3, 386, 489–490
- trimetallic materials CO_2 reduction
295–296
- turnover frequency (TOF) 34, 36, 89,
106, 312, 317, 368
- two-dimensional RuCu nanosheets 223
- 2D layered M_2XT_x 151
- 2D porous nanomaterials 148, 153
- U**
- ultrathin Co_3O_4 nanosheet catalyst 518
- ultra-thin CoO_x amorphous nanosheet
219
- undoped carbon-based porous ORR
catalysts 207–208
- V**
- vacancy-abundant carbon nitride
materials 421–422
- volcanic behavior 166
- volcanic maps 105
- Volmer–Heyrovsky 37, 55, 87, 106, 110,
128, 140
- Volmer–Tafel mechanism 140
- Volmer–Tafel steps 106
- W**
- wood biomass 511, 512
raw materials 511
- Z**
- zinc imidazolate frameworks (ZIFs) 217,
361–364
- Zn–N–C catalyst 189





