[Journal of Electrochemistry](https://jelectrochem.xmu.edu.cn/journal)

[Volume 28](https://jelectrochem.xmu.edu.cn/journal/vol28) Issue 9 [Special Issue on Water Electrolysis for](https://jelectrochem.xmu.edu.cn/journal/vol28/iss9) [Hydrogen Production \(](https://jelectrochem.xmu.edu.cn/journal/vol28/iss9)I)

2022-09-28

A Co Porphyrin with Electron-Withdrawing and Hydrophilic Substituents for Improved Electrocatalytic Oxygen Reduction

Hong-Bo Guo

Ya-Ni Wang

Kai Guo

Hai-Tao Lei

Zuo-Zhong Liang

Key Laboratory of Applied Surface and Colloid Chemistry, Ministry of Education, School of Chemistry and Chemical Engineering, Shaanxi Normal University, Xi'an 710119, China;, liangzuozhong@snnu.edu.cn

Xue-Peng Zhang

Key Laboratory of Applied Surface and Colloid Chemistry, Ministry of Education, School of Chemistry and Chemical Engineering, Shaanxi Normal University, Xi'an 710119, China;, zhangxp@snnu.edu.cn

Rui Cao

Key Laboratory of Applied Surface and Colloid Chemistry, Ministry of Education, School of Chemistry and Chemical Engineering, Shaanxi Normal University, Xi'an 710119, China;, ruicao@snnu.edu.cn

Recommended Citation

Hong-Bo Guo, Ya-Ni Wang, Kai Guo, Hai-Tao Lei, Zuo-Zhong Liang, Xue-Peng Zhang, Rui Cao. A Co Porphyrin with Electron-Withdrawing and Hydrophilic Substituents for Improved Electrocatalytic Oxygen Reduction[J]. Journal of Electrochemistry, 2022 , 28(9): 2214002. DOI: 10.13208/j.electrochem.2214002

Available at:<https://jelectrochem.xmu.edu.cn/journal/vol28/iss9/7>

This Article is brought to you for free and open access by Journal of Electrochemistry. It has been accepted for inclusion in Journal of Electrochemistry by an authorized editor of Journal of Electrochemistry.

$\begin{array}{r} \hbox{\Leftrightarrow} \quad \quad \mathcal{H} \quad \nexists \quad \quad \mathcal{H} \quad \$ Substituents for Improved Electrocatalytic Oxygen Reduction $\begin{array}{c} \text{\LARGE{4.5}}\\ \text{\LARGE{4.6}} \end{array} \begin{array}{l} \text{\L$ $\begin{array}{r} \mathcal{L} & \mathcal{L} \\ \mathcal$, Kai Guo, Hai-Tao Lei, Zuo-Zhong Liang* $\begin{array}{lll} \hline \texttt{#} & \# \\ \hline \texttt{#} & \# \\ \texttt{9D1: } 10.13208/j.electrochem. 2214002 & & & & & \\ \hline \end{array} \quad \begin{array}{lll} \hline \texttt{Htp://electrochem.xml.edu_en} \\ \hline \texttt{Htp://electrochem.xml.edu_en} \\ \hline \end{array}$
 $\begin{array}{lll} \hline \textbf{Electron-With drawing and Hydrophilic} \\ \hline \texttt{Wood Electrocatalytic Oxygen Reduction} \\ \texttt{Wang", Kai Guo, Hai-Tao Lei, Zuo-Zhong Liang",} \\ \hline \end{array} \quad \begin{array}{$ $\frac{2214002}{1002}$ (1 of 11)

Ehem.2214002 Http://electrochem.xmu.edu.cn
 ithdrawing and Hydrophilic
 ocatalytic Oxygen Reduction

Hai-Tao Lei, Zuo-Zhong Liang^{*},

Rui Cao^{*}
 Ministry of Education, School of Chemis (Key Laboratory of Applied Surface and Colloid Chemistry, Ministry of Education, School of Chemistry and Colloid Chemistry, Ministry of Education, School of Chemistry and Colloid Chemistry, Ministry of Education, School o $[Article] \begin{tabular}{c} {\footnotesize \begin{tabular}{l} \hline & $\#\$ \end{tabular} \end{tabular} \begin{tabular}{l} \hline & $\#\$ \end{tabular} \end{tabular} \begin{tabular}{c} \hline & $D11120809, 2214002 (1 of 11) \end{tabular} \end{tabular} \begin{tabular}{c} \hline & $D113208/j.electrochem.2214002 \end{tabular} \end{tabular} \begin{tabular}{c} \hline \hline & $Htyp//electrochem.xml.edu.cn \end{tabular} \end{tabular} \begin{tabular}{c} \hline \hline & $A$$ 电 化 学

J. Electrochem. 2022, 28(9), 2214002 (1 of 11)

DOI: 10.13208/j.electrochem.2214002
 ith Electron-Withdrawing and Hydrophilic

Example 12. A. Electrochem, 2022, 28(9), 2214002 (1 of 11)

DOI: 10.13208/j.electrochem.2214002 Http://electrochem.xmu.edu.cn
 **Altrix With Electron-Withdrawing and Hydrophilic

for Improved Electrocatalytic Oxygen Redu LE Electrochem. 2022, 28(9), 2214002 (1 of 11)**

(Article)

1001: 10.13208 $\hat{\beta}$, electrochem.2214002
 A Co Porphyrin with Electron-Withdrawing and Hydrophilic
 Substituents for Improved Electrocatalytic Oxygen Reduc tional design of efficient ORR catalysts. Regulating catalyst electronic structure is commonly used to fine-tune electrocatalytic ORR activity. However, modifying the Hydrophilic Comparison of catalysts has been rarely reported to improve ORR, which happens at the liquid of catalystic of catalystic Comparison of Chemical High and Hydrophilic Substituent *L. Electrochem.* 2022, 28(0), 2214002 (1-of 11)

DOI: 10.132085/selectrochem.2214002
 **A. Co Porphyrin with Electron-Withdrawing and Hydrophilic

Substituents for Improved Electrocatalytic Oxygen Reduction

Hong-Bo Guo^{4**} DOI: 10.132085/electrochem.2214002
 A Co Porphyrin with Electron-Withdrawing and Hydrophilic
 Substituents for Improved Electrocatalytic Oxygen Reduction

Hong-Bo Guo², Ya-Ni Wang^a, Kai Guo, Hai-Tao Lei, Zuo-Zhong $_{2}$ -CoP **A Co Porphyrin with Electron-Withdrawing and Hydrophilic Substituents for Improved Electrocatalytic Oxygen Reduction

Hong-Bo Guo², Ya-Ni Wang², Kai Guo, Hai-Tao Lei, Zuo-Zhong Liang²,

(***Key Laboratory of Applied* **A Co Porphyrin with Electron-Withdrawing and Hydrophilic Substituents for Improved Electrocatalytic Oxygen Reduction

Hong-Bo Guo⁴, Ya-Ni Wang^a, Kai Guo, Hai-Tao Lei, Zuo-Zhong Liang²,

(Key** *Laboratory of Applied* **1 Electron-Withdrawing and Hydrophilic**
 roved Electrocatalytic Oxygen Reduction

Wang^{*}, Kai Guo, Hai-Tao Lei, Zuo-Zhong Liang^{*},

Xue-Peng Zhang^{*}, Rui Cao^{*}
 cand Colloid Chemistry, Ministry of Education, Scho **ion**
 ion
 i al for the ra-
 atalytic ORR
 ns at the liq-
 akis (4-nitro-
 talytic ORR
 he NO₂-CoP
 n by 60 mV.
 c-CoP is also

ve strategy to

be also valu-**A Co Porphyrin with Electron-Withdrawing and Hydrophilic**
 Substituents for Improved Electrocatalytic Oxygen Reduction

Hong-Bo Guo⁵, Ya-Ni Wang⁴, Kai Guo, Hai-Tao Lei, Zuo-Zhong Liang²,
 $K = \text{Peng Zhang}'$, Rui Cao^{*}
 more efficient than 5F-CoP to bind with an O_2 molecule to form $Co^{\text{III}}-O_2$. This work provides a simple but an effective strategy to **hdrawing and Hydrophilic**
 atalytic Oxygen Reduction

ai-Tao Lei, Zuo-Zhong Liang⁺,

cui Cao^{*}

cui Cao^{*}

ministry of Education, School of Chemistry and

restriy, Xi' an 710119, China)

respective strategy to the **Substituents for Improved Electrocatalytic Oxygen Reduction**

Hong-Bo Guo", Ya-Ni Wang", Kai Guo, Hai-Tao Lei, Zuo-Zhong Liang",
 α Wey Laboratory of Applied Surface and Colloid Chemisty, Minitary of Education, School **EXERCISE SECT ASSOCIATE SECT ASSOCIATE SECT CONSULTS.** However the design of the Hong-Bo Guo⁴, Ya-Ni Wang⁴, Kai Guo, Hai-Tao Lei, Zuo-Zhong Liang²,

(Key Laboratory of Applied Surface and Colisial Chemistry, Miniary of Education, School of Chemistry and

Chemical Engineering, Shaamsi Narmal Univ *Chemical Engineering, Shamati Normad University, Xi' an 710119, China)*
 SITACI: Understanding factors that influence the catalyst activity for avygen reduction reaction (ORR) is essential for the ra-

and dasign of ef **Abstract:** Understanding factors that influence the catalyst activity for oxygen reduction reaction (ORR) is essential for the rund design of efficient ORR catalysts. Regulation designs and stor-turn device is commonly u **A histract:** Understaming factors that influence the catalyst activity for oxygen reduction reaction (ORR) is essential for the rational design of efficient ORR catalysts. Regulating catalyst electrons is tractuaries is **ADSETER**: Understanding factors that influence the catalytic for oxygen reduction (nearch (SRR) essential for the cathodic CRR)

tional design of efficient ORR attaching earling earling earling cathomic iteration in the tonal design of the
neutrino (Necessites Megulations discrete interventions from the section
and the properties of the substitutents of each step and the substitutents of
the substitutents of the substitutency for the sub energy, However, mondpage ine appropainted to ranges anso earn are propained to improve to the was in the approximately relative to the same the phenyippersis and the steeler and the sheet and the properties of 5.10.15.20-The system method in many hote of the representative increase the comparison in the system at the physical system in the system attracted in the system of the system of the method in the system of the system of computer o phasynophymical Section and Section Computer of the computer of the considerational decades and the SE-CoP by shifting the ORR half-wave potential to the easely consider a by-CoP showed higher electrocatalytic activity th **5**, **ktni** σ **Chand Example 1 Control** σ **Chand Example 1 Control** *Chand University, Xi' an 710119, China CoRR* is essential for the rativersity, *Xi' an 710119, China* **Controllarity** of *Controllarity* of University, Xi' an 710119, China)

University, Xi' an 710119, China)

ity for oxygen reduction reaction (ORR) is essential for the ra-

is structure is commonly used to fine-tune electrocatalytic ORR

in rarely reported ity for oxygen reduction reaction (ORR) is essential for the ra-
ic structure is commonly used to fine-tune electrocatalytic ORR
n rarely reported to improve ORR, which happens at the liq-
nenety, NO₂-CoP (Co complex of riy for oxygen reduction reaction (ORR) is essential for the ra-
e structure is commonly used to fine-tune electrocatalytic ORR
in rarely reported to improve ORR, which happens at the liq-
merly, NO₋CoP (Co complex of 5 ity for oxygen reduction reaction (ORR) is essential for the ra-
e structure is commonly used to fine-tune electrocatalytic ORR
marely, resported to improve ORR, which happens at the liq-
mente), resported to improve or 5 is estructure is commonly used to fine-tune electrocatalytic ORR
n rarely reported to improve ORR, which happens at the liq-
amely, NO₋CoP (Co complex of 5,10,15,20-tertakis(4-nitro-
(pentafluorophenyl)porphyrin), and t arely reported to improve ORR, which happens at the liq-
ly, NO₂-CoP (Co complex of 5,10,15,20-tetrakis(4-nitro-
taffuloropheny)/porphyrin), and their electrocatalytic ORR
drophilic property of the meso-substituents, the amely, NO₂-CoP (Co complex of 3, 10, 13, 20-tetrakis (4-nitro-
(pentallorophenyl)porphyrin), and their electrocatalytic ORR
If hydrophilic property of the meso-substituents, the NO₂-CoP
he ORR half-wave potential to th

FIRENT CONDUCITY expanse meduction reaction (ORR) systematically modified to investigate structure-fung-
is involved in many new energy conversion and stor-
time relationships^{togra}! Among these studied metal po-
age r Electrocatalytic oxygen reduction (ORR) systemature into the sugar and sin-
sin specified in many new variety conversion and stor-
the relationships⁹⁰⁻⁸²¹. Among these studied metal po-
retrist¹⁵⁴¹, The efficiency of is involved in many new energy conversion and stor-

to relationships^{ness}. A mong these studies near the terriques, including fuel cells and metal- in the particular studies of the carbides of ORR^{na-30}. However, furth **Key words:** molecular electrocatalysis ovegen reduction; Co populyrin; hydrophilicity; electroic structure of metal porphyrins can be
Electrocatalytic oxygen reduction reaction (ORR) systematically modified to investigat Extremely the EF-Cor, the constrained methods of
the catalystic activity than the SF-CoP by shifting the ORR half-wave potential to the and
de direction by 60 mV.
Compared with the F-C-CoP is also comes by the catallactic. Compared with the 5F-CoP, the complex NO-CoP was more hydrophile. Theoretical calculations suggest that NO-CoP is also
numere efficient lahm ST-CoP (b bind with an O₂ model to form Coⁿ-Cy⁻. This weak provides a simp more efficient than \$1-CoP to bind with an O₁ molecule to form Coⁿ-O₂⁻. This work provides a simple but an effective structgy to
improve ORR activity of Co porphyrins by using electron-withdrawing and hydrophilic improve ORR activity of Co porphyrins by using electron-withdrawing and hydrophilic substituents. This strategy will be also valuable for the design of other ORR molecular electrocatalysts. Oxopphyrin: hydrophilicity; ele she for the design of other ORR molecular electrocatalysts.
 Key words: molecular electrocatalysis; oxygen reduction; Co poplyrini; hydrophilicity; electronic structure
 HI Introduction and slaso (2) the structure of

1 Introduction and also (2) the structure of metal porphyrins can be

benaluoropenyiporphymn, and their electrocally OK

I hydrophilic property of the meso-substituents, the NO₂-CoP

he ORR half-wave potential to the anodic direction by 60 mV.

ophilic. Theoretical calculations suggest th substitute property on the meso-sussomations, the 'ro-y-con-
he ORR half-wave potential to the andic direction by 60 mV.
ophilic. Theoretical calculations suggest that NO₂-CoP is also
m-O₂⁺. This work provides a sim the other with the with the same with the same of the same of the same of the same optic. Theoretical calculations suggest that NO-COP is also valu-

"-O₂". This work provides a simple but an effective strategy to

mg an ${}^{\text{m}}\text{-}O_2$ ". This work provides a simple but an effective strategy to
pg and hydrophilic substituents. This strategy will be also valu-
ophyrin; hydrophilicity; electronic structure
and also (2) the structure of met mg and hydrophilic substituents. This strategy will be also valu-
orphyrin; hydrophilicity; electronic structure
and also (2) the structure of metal porphyrins can be
systematically modified to investigate structure-funcpphyrin; hydrophilicity; electronic structure
and also (2) the structure of metal porphyrins can be
systematically modified to investigate structure-func-
tion relationships^[10-25]. Among these studied metal po-
rphyrin

 $\text{#}\{\&\#(J. Electron-withdrawing substitutions showed an\n and chloroform ($v.v = 1:1$).\n\nORR half-wave potential of $E_{1/2} = 0.76$ V versus\n **Synthesis of NO₂-CoP.** Pyrrole(670 mg, 10 mmol)\n\nreversible hydrogen electrode (RHE) in 0.1 mol·L⁻¹\n\nKOH solutions⁽⁴⁴⁾. On the other hand, ORR happens\nat the liquid/gas/solid interface. Therefore, the hy-
a4-1440°C. the mixture was then dried in vacuum to$ $\text{\#E}\nsubseteq J. \text{ *Electrochem.* } 2022, 28(9), 2214002 (2 of 11) \text{ strong electron-withdrawing substitutions showed an and chloroform (*v*:*v* = 1:1). \text{ ORR half-wave potential of } E_{1/2} = 0.76 \text{ V versus } \text{ Synthesis of NO}_2\text{-CoP. Pyrrole(670 mg, 10 mmol) \text{ reversible hydrogen electrode (RHE) in 0.1 mol·L⁻¹ and 4-nitrobenzaldehyde (1.51 g, 10 mmol) were added into aactic acid (100 mL). After stirring for 0.5 at the liquid/gas/solid interface. Therefore$ the $\mathbb{R}E^{\#}(J. \text{Electrochem.})$ 2022, 28(9), 2214002 (2 of 11)

strong electron-withdrawing substituents showed an

and chloroform ($v:v = 1:1$).

ORR half-wave potential of $E_{1/2} = 0.76$ V versus
 Synthesis of NO_x-CoP. Py $\frac{16}{2}$
 $\frac{16}{2}$

Electrochem.) 2022, 28(9), 2214002 (2 of 11)

Strong electron-withdrawing substituents showed an

and chloroform (v:v = 1:1).

ORR half-wave potential of $E_{12} = 0.76$ V versus
 Synthesis of NO_x Example 12
 Example 1 Example 1998 (*L Electrochem.*) 2022, 28(9), 2214002 (2 of 11)

strong electron-withdrawing substituents showed an and chloroform ($v.v = 1:1$).

ORR half-wave potential of $E_{1/2} = 0.76$ V versus Synthesis of NO_z-CoP. **in determining the activity**^{15, 46}. *Electrochem.*) 2022, 28(9), 2214002 (2 of 11)
 Strong electron-withdrawing substituents showed an and chloroform ($v: v = 1:1$).

ORR half-wave potential of $E_{12} = 0.76$ V versus **Example 10**
 Example 1 stituents.

KOH solutions¹⁴¹. On the other hand, ORR happens added into acctic acid (1

at the liquid/gas/solid interface. Therefore, the hy-

drophilicity of catalysts should also play crucial roles

in determining the activity¹⁴ form Co^{III} -O₂. This work therefore presents a simple siderations, we are interested in examining the ORR with reflux for 1.5 h. The mixture was dries

structure and hydrophilic property of the meso-sub-

structures.

Structures

structures

structures

structures.

Structur are and hydrophilic property of the meso-sub-

rein, we report on Co porphyrins, NO₂-CoP and

porphyrin (319.1 mg; yield 15

DrP, and their electrocatalytic ORR features.

CoP is more efficient than 5F-CoP for electro-
 trents.

ucnts.

Herein, we report on Co porphyrins, NO₂-CoP and

decomption (319.1 mg; yield 15%). Co acetate tertahy-

Herein, we report on Co porphyrins, NO₂-CoP and
 \sim -CoP_c and their electrocatalytic ORR feat Heren, we report on Co porphyrins, NO₂-Co^p and determination of the pentation of the residue to the residue of the residue into DMF
NO₂-CoP is more efficient than $5F$ -CoP for electro-
 (15 mL) . The mixture was s

 $\text{#}(E\#C)$. Electrochem.) 2022, 28(9), 2214002 (2 of 11)

strong electron-withdrawing substituents showed an

and chloroform (e:e = 1:1).

ORR half-wave potential of $E_{12} = 0.76$ V versus
 Synthesis of NO_PCoP. Pyrr the $\mathcal{L}^{\#}(L_{\ell}^{*}L_{\ell}^{*}L_{\ell}^{*}L_{\ell}^{*}L_{\ell}^{*}L_{\ell}^{*}L_{\ell}^{$ $#R \cong (L. Electrowe-ben) 2022, 28(9), 2214002 (2 of 11)$

Sing electron-withdrawing substituents showed an and chloroform ($vw = 1:1$).

RR half-wave potential of $E_{12} = 0.76$ V versus Synthesis of NO_PCOP. Pyrrole(670 mg, 10 mmol) 5F-CoP, and their electrocatalytic ORR features. the $\frac{d_1}{2}$ is more than than 5F-CoP. The contention of $\left(\frac{d_1}{2}$ is more hypothesis and contention of $\left(\frac{d_1}{2}$ is more than that the properties of $\frac{d_1}{2}$ is more than the other than $\left(\frac{d_1}{2}$ is the **Example 1982–7.** *Electrochema*, 2022, 28(9), 2214002 (2 of 11)
 Strong electron-withdrawing substituents showed an and chloroform ($e: v = 1:1$).

ORR half-wave potential of $E_{uv} = 0.76$ V versus **Synthesis of NO_PCoP EXECUTE:**

Strong electron-withdrawing usistic to a small electron-withdrawing institutions since the Single compared with ϵ_0 . ORR half-wave potential of $E_{12} = 0.76$ V versus Synthesis of NO₋C-OP. Pyrrole(670 mg, strong electron-withdrawing substituents showed an

and chloroform $(vx = 1:1)$.

ORR half-wave potential of $E_{C2} = 0.76$ V versus
 COP. Pyrrole(670 mg, 10 mmol)

reversible hydrogen electrode (RHE) in 0.1 mol + 2⁻¹ an ORR half-wave potential of $E_{t2} = 0.76$ V versus **Synthesis of NO₂-CoP.** Pyrrole(670 mg, 10 mmol)
reversible hydrogen clectrode (RHE) in 0.1 mol -1⁻¹ and 4-nitrohearaldehyde (1.51 g, 10 mmol) were
curversible hydroge reversible hydrogen electrode (RHE) in 0.1 mol -L⁻¹ and 4-nitrobenzaldehyde (1.51 g, 10 mmol) were

ROII solutions¹⁸⁸¹. On the other hand, ORR happens

and 4-nitrobenzaldehyde (1.51 g, 10 mmol) were

at the liquid/gas $\mu s^{4\mu}$. On the other hand, ORR happens added into acetic acid (100 mL). After stirring for 0.5 ass/solid interface. Therefore, the hy-
 $\mu s^{4\mu}$. On these therefore, the hy-

for catalysts should also play crucial r at the liquid/gas/solid interface. Therefore, the hy-

in at 140 °C, the mixture was then dried in vacuum to

drophilicity of cotalytis bould also play erucid roles

in determining the activity^{16.80}. Based on these condrophilicity of catalysts should also play crucial roles

move acetic acid, and was then recrystallized from

in determining the activity of R. S. The mainter measure of the side of these con-

side and these con-with ref in determining the activity^{145, aa}! Based on these con-

sidentions, we are interested in examining the ORR

such reflux for 1.5 h. The mixture was dried in vacu-

such view of CO porphyrins by fine-tuning electronic

s scrivity of Co porphyrins by fine-tuning electronic um to remove pyridine and then dried in vacuum as
structure and hydrophilic property of the meso-sub-
structures,
structures structures of the meso-sub-
structures,
He 28(9), 2214002 (2 of 11)

and chloroform (*v*:*v* = 1:1).
 Synthesis of NO₂-CoP. Pyrrole(670 mg, 10 mmol)

and 4-nitrobenzaldehyde (1.51 g, 10 mmol) were

added into acetic acid (100 mL). After stirring for 0.5

h at (9), 2214002 (2 of 11)

d chloroform ($v: v = 1:1$).
 Synthesis of NO₂-CoP. Pyrrole(670 mg, 10 mmol)

d 4-nitrobenzaldehyde (1.51 g, 10 mmol) were

ded into acetic acid (100 mL). After stirring for 0.5

at 140 °C, the m 28(9), 2214002 (2 of 11)

and chloroform ($v: v = 1:1$).
 Synthesis of NO₂-CoP. Pyrrole(670 mg, 10 mmol)

and 4-nitrobenzaldehyde (1.51 g, 10 mmol) were

added into acetic acid (100 mL). After stirring for 0.5

h at 140 28(9), 2214002 (2 of 11)

and chloroform ($v: v = 1:1$).
 Synthesis of NO₂-CoP. Pyrrole(670 mg, 10 mmol)

and 4-nitrobenzaldehyde (1.51 g, 10 mmol) were

added into acetic acid (100 mL). After stirring for 0.5

h at 140 28(9), 2214002 (2 of 11)

and chloroform ($v:x = 1:1$).
 Synthesis of NO₂-CoP. Pyrrole(670 mg, 10 mmol)

and 4-nitrobenzaldehyde (1.51 g, 10 mmol) were

added into acetic acid (100 mL). After stirring for 0.5

h at 140 28(9), 2214002 (2 of 11)
and chloroform ($v: v = 1:1$).
Synthesis of NO₂-CoP. Pyrrole(670 mg, 10 mmol)
and 4-nitrobenzaldehyde (1.51 g, 10 mmol) were
added into acetic acid (100 mL). After stirring for 0.5
h at 140 °C, 28(9), 2214002 (2 of 11)

and chloroform ($v: v = 1:1$).
 Synthesis of NO₂-CoP. Pyrrole(670 mg, 10 mmol)

and 4-nitrobenzaldehyde (1.51 g, 10 mmol) were

added into acetic acid (100 mL). After stirring for 0.5

h at 140 28(9), 2214002 (2 of 11)
and chloroform $(v \cdot v = 1:1)$.
Synthesis of NO_z-CoP. Pyrrole(670 mg, 10 mmol)
and 4-nitrobenzaldehyde (1.51 g, 10 mmol) were
added into acetic acid (100 mL). After stirring for 0.5
h at 140 °C, 28(9), 2214002 (2 of 11)
and chloroform $(v \cdot v = 1:1)$.
Synthesis of NO_z-CoP. Pyrrole(670 mg, 10 mmol)
and 4-nitrobenzaldehyde (1.51 g, 10 mmol) were
added into acetic acid (100 mL). After stirring for 0.5
h at 140 °C, 28(9), 2214002 (2 of 11)
and chloroform ($v: v = 1:1$).
Synthesis of NO₂-CoP. Pyrrole(670 mg, 10 mmol)
and 4-nitrobenzaldehyde (1.51 g, 10 mmol) were
added into acetic acid (100 mL). After stirring for 0.5
h at 140 °C, th 28(9), 2214002 (2 of 11)
and chloroform ($v: v = 1:1$).
Synthesis of NO₂-CoP. Pyrrole(670 mg, 10 mmol)
and 4-nitrobenzaldehyde (1.51 g, 10 mmol) were
added into acetic acid (100 mL). After stirring for 0.5
h at 140 °C, th 28(9), 2214002 (2 of 11)
and chloroform ($v \cdot v = 1:1$).
Synthesis of NO₂-CoP. Pyrrole(670 mg, 10 mmol)
and 4-nitrobenzaldehyde (1.51 g, 10 mmol) were
added into acetic acid (100 mL). After stirring for 0.5
h at 140 °C, t 28(9), 2214002 (2 of 11)
and chloroform ($v \cdot v = 1:1$).
Synthesis of NO_FCoP. Pyrrole(670 mg, 10 mmol)
and 4-nitrobenzaldehyde (1.51 g, 10 mmol) were
added into acetic acid (100 mL). After stirring for 0.5
h at 140 °C, th 28(9), 2214002 (2 of 11)
and chloroform ($v \cdot v = 1:1$).
Synthesis of NO₂-CoP. Pyrrole(670 mg, 10 mmol)
and 4-nitrobenzaldehyde (1.51 g, 10 mmol) were
added into acetic acid (100 mL). After stirring for 0.5
h at 140 °C, t 28(9), 2214002 (2 of 11)
and chloroform ($v \cdot v = 1:1$).
Synthesis of NO₂-CoP. Pyrrole(670 mg, 10 mmol)
and 4-nitrobenzaldehyde (1.51 g, 10 mmol) were
added into acetic acid (100 mL). After stirring for 0.5
h at 140 °C, t and chloroform ($v \cdot v = 1:1$).
 Synthesis of NO₂-CoP. Pyrrole(670 mg, 10 mmol)

and 4-nitrobenzaldehyde (1.51 g, 10 mmol) were

added into acetic acid (100 mL). After stirring for 0.5

h at 140 °C, the mixture was then and chloroform $(v \cdot v = 1:1)$.
 Synthesis of NO₂-CoP. Pyrrole(670 mg, 10 mmol)

and 4-nitrobenzaldehyde (1.51 g, 10 mmol) were

added into acetic acid (100 mL). After stirring for 0.5

h at 140 °C, the mixture was then **Synthesis of NO₂-CoP**. Pyrrole(670 mg, 10 mmol)
and 4-nitrobenzaldehyde (1.51 g, 10 mmol) were
added into acetic acid (100 mL). After stirring for 0.5
h at 140 °C, the mixture was then dried in vacuum to
remove acetic and 4-nitrobenzaldehyde (1.51 g, 10 mmol) were
added into acetic acid (100 mL). After stirring for 0.5
h at 140 °C, the mixture was then dried in vacuum to
remove acetic acid, and was then recrystallized from
acetone. The added into acetic acid (100 mL). After stirring for 0.5
h at 140 °C, the mixture was then dried in vacuum to
remove acetic acid, and was then recrystallized from
acetone. The resulted solid was added into pyridine
with re h at 140 °C, the mixture was then dried in vacuum to
remove acetic acid, and was then recrystallized from
acetone. The resulted solid was added into pyridine
with reflux for 1.5 h. The mixture was dried in vacuum
again to remove acetic acid, and was then recrystallized from
acetone. The resulted solid was added into pyridine
with reflux for 1.5 h. The mixture was dried in vacuum
again to give a purple solid of tetrakis(4-nitrophenyl)
porph tone. The resulted solid was added into pyridine
h reflux for 1.5 h. The mixture was dried in vacu-
to remove pyridine and then dried in vacuum a-
n to give a purple solid of tetrakis(4-nitrophenyl)
phyrin (319.1 mg; yiel with reflux for 1.5 h. The mixture was dried in vacu-
um to remove pyridine and then dried in vacuum a-
gain to give a purple solid of tetrakis(4-nitrophenyl)
porphyrin (319.1 mg; yield 15%). Co acetate tetrahy-
drate (74 um to remove pyridine and then dried in vacuum a-
gain to give a purple solid of tetrakis(4-nitrophenyl)
porphyrin (319.1 mg; yield 15%). Co acetate tetrahy-
drate (747.2 mg, 3 mmol) and tetrakis(4-nitrophenyl)
porphyrin gain to give a purple solid of tetrakis (4-nitrophenyl)
porphyrin (319.1 mg; yield 15%). Co acetate tetrahy-
drate (747.2 mg, 3 mmol) and tetrakis(4-nitrophenyl)
porphyrin (79.4 mg, 0.1 mmol) were added into DMF
(15 mL). porphyrin (319.1 mg; yield 15%). Co acetate tetrahy-
drate (747.2 mg, 3 mmol) and tetrakis(4-nitrophenyl)
porphyrin (79.4 mg, 0.1 mmol) were added into DMF
(15 mL). The mixture was stirred at 120 °C with re-
flux for 12 h drate (747.2 mg, 3 mmol) and tetrakis(4-nitrophenyl)
porphyrin (79.4 mg, 0.1 mmol) were added into DMF
(15 mL). The mixture was stirred at 120 °C with re-
flux for 12 h. After that, the mixture was rinsed with
H₂O (150 电化学(*J. Electrochem.*) 2022, 28(9), 2214002 (2 of 11)

ubstituents showed an and chloroform ($v:v = 1:1$).
 $E_{12} = 0.76$ V versus **Synthesis of NO₂-CoP**. Pyrrole(670 mg, 10 mmol)

(RHE) in 0.1 mol·L⁻¹ and 4-nitrobenza

3F-CoP, and their electrocalaytic ORR Fatames.

NO₇-CoP is more efficient than 5F-CoP for electro-

NO₇-CoP is more efficient than 5F-CoP for electro-

115 mL). The mixture was stirred at 120 °C with re-

conplex No₁ NO_{-C}COP is more efficient than 51-COP for electro-

candyic ORR by displaying a 60-FV and estin of

the ORR half-wave potential. Compared with SF-CoP, H₂O (150 mL) and then was then with the ORR half-wave potential. C eatalytic ORR by displaying a 60-mV anodic shift of Thux for 12 h. After that, the mixture was rinsed with
the ORR half-wave potential. Compared with SF-CoP,

Economic purification by column chromatography gave the pur-
c the ORR half-wave potential. Compared with NECO,

complex NO--CoP is more hydrophobic. Theoretical

equality and then was dried with MgSO₊ Further

column thromatography gave the pur-

celected than 5F-CoP to bind with complex NO-CoP is more hydrophobe. Theoretical

calculations saggest that NO_z-CoP is also more effi-

eient than 5F-CoP to bind with an O₂ modeule to Single crystals of NO₂-CoP (63.5 mg; yield 75%).

tient than 5F-C calculations suggest that NO-COP is also more effi-
ple solid product of NO_C-CoP (63.5 mg; yield 75%),
cient than SF-CoP to bind with an O_L molecule to simple crystals of NO_C-CoP were obtained by slow
form Co^m-O_C cient than 5F-CoP to bind with an O₂ molecule to Single crystals of NO₂-CoP were obtained by slow
form co^{all}-O₂. This work therefore presents a simple
but an effective strategy to improve eatalytic ORR in tetrahyd form Co^{nc}O₂. This work therefore presents a simple
vapor diffusion of n-heptane to the NO₂-CoP solution
but an effective strategy to improve catalytic ORR and the mathydroforan.
derothic substituents to molecular ca but an effective strategy to improve catalytic ORR

aristrations activity by introducing electron-withdrawing and hy-

actoric dress for the NO_T-CoP (CCDC
 2 Experimental Section
 2 complete data sets for the NO_Tactivity by introducing elector-withdrawing and hy-

activity by introducing elector-withdrawing and hy-
 2.2 Characterizations
 2.2 Experimental Section
 2.2 h. Syntheses of CoII Porphyrins (SF-CoP ed on an X-ray di drophilic substituents to molecular catalysts.

20046420 and SF-CoP (CCDC 21 **Experimental Section**

20046420 and SF-CoP (CCDC 2160347) were collected-
 20046201 and NG_F-CoP ed on an X-ray diffractometer (108 VENTURE, **2 Experimental Section**

2036420) and $5F-COP$ (CCDC 2150347) were collect-
 Synthess of CoII Porphyrins (SF-CoP ed on an X-ray diffurednemet (D8 VENTURE, But-
 and NO_FCoP¹⁹. Pyrrolc(670 mg, 10 mmol) coated with Pa **2.1 Syntheses of CoII Porphlyrins (SF-CoP** ed on an X-ray diffractometer (D8 VFNTURF, Bruk-
 and NO_F-CoP¹¹⁶. Pyrrole(670 mg, 10 mmol) coated with Paratone-N oil, suspended in a small

and pentalluorobenzaldehyde (1 **and NO_F-CoP)**

er). Single crystals suitable for X-ray analysis were
 **Synthesis of 5F-CoP¹¹, Pyrrole(670 mg, 10 mmol) were ther loop, and placed in a cooled gas stream at 153(2)

and equal toutobe therese in the s Synthesis of SF-CoP⁶⁷⁹**, Pyrrole(670 mg, 10 mmol) coated with Paratone-N oil, suspended in a small
and pentalluorobenzaldshipted (1.96g, 10 mmol) were there loop, and placed in a cooled gas stream at 153(2)
added into porphyrin (79.4 mg, 0.1 mmol) were added into DMF
(15 mL). The mixture was stirred at 120 °C with re-
flux for 12 h. After that, the mixture was rinsed with
H₂O (150 mL) and then was dried with MgSO₄. Further
purifica (15 mL). The mixture was stirred at 120 °C with re-
flux for 12 h. After that, the mixture was rinsed with
H₂O (150 mL) and then was dried with MgSO_{*} Further
purification by column chromatography gave the pur-
ple sol flux for 12 h. After that, the mixture was rinsed with H₂O (150 mL) and then was dried with MgSO₄. Further purification by column chromatography gave the pur-
ple solid product of NO₂-CoP (63.5 mg; yield 75%).
Singl H₂O (150 mL) and then was dried with MgSO₄. Further
purification by column chromatography gave the pur-
ple solid product of NO₂-CoP (63.5 mg; yield 75%).
Single crystals of NO₂-CoP were obtained by slow
vapor dif purification by column chromatography gave the pur-
ple solid product of NO₂-CoP (63.5 mg; yield 75%).
Single crystals of NO₂-CoP were obtained by slow
vapor diffusion of n-heptane to the NO₂-CoP solution
in tetrahy ple solid product of NO₂-CoP (63.5 mg; yield 75%).
Single crystals of NO₂-CoP were obtained by slow
vapor diffusion of n-heptane to the NO₂-CoP solution
in tetrahydrofuran.
2.2 Characterizations
Complete data sets Single crystals of NO₂-CoP were obtained by slow
vapor diffusion of n-heptane to the NO₂-CoP solution
in tetrahydrofuran.
2.2 Characterizations
Complete data sets for the NO₂-CoP (CCDC
2036420) and 5F-CoP (CCDC 21 SHELXS^[50] and refined against F^2 on all data by fullobtained by slow

: NO₂-CoP solution

NO₂-CoP (CCDC

3347) were collect-

VENTURE, Bruk--ray analysis were

bended in a small

as stream at 153(2)

sured using Mo K_{α}

bllection, indexing,

ents were carried

orre vapor diffusion of n-heptane to the NO₂-CoP solution
in tetrahydrofuran.
2.2 Characterizations
Complete data sets for the NO₂-CoP (CCDC
2036420) and SF-CoP (CCDC 2150347) were collect-
ed on an X-ray diffractomete in tetrahydrofuran.
 2.2 Characterizations

Complete data sets for the NO₂-CoP (CCDC

2036420) and 5F-CoP (CCDC 2150347) were collected

on an X-ray diffractometer (D8 VENTURE, Bruk-

er). Single crystals suitable for **2.2 Characterizations**
Complete data sets for the NO₂-CoP (CCDC
2036420) and 5F-CoP (CCDC 2150347) were collect-
ed on an X-ray diffractometer (D8 VENTURE, Bruk-
er). Single crystals suitable for X-ray analysis were
co Complete data sets for the NO₂-CoP (CCDC 2036420) and SF-CoP (CCDC 2150347) were collected on an X-ray diffractometer (D8 VENTURE, Bruker). Single crystals suitable for X-ray analysis were coated with Paratone-N oil, su 2036420) and SF-CoP (CCDC 2150347) were collected on an X-ray diffractometer (D8 VENTURE, Bruker). Single crystals suitable for X-ray analysis were coated with Paratone-N oil, suspended in a small fiber loop, and placed i ed on an X-ray diffractometer (D8 VENTURE, Bruk-
er). Single crystals suitable for X-ray analysis were
coated with Paratone-N oil, suspended in a small
fiber loop, and placed in a cooled gas stream at 153(2)
K. Diffractio er). Single crystals suitable for X-ray analysis were
coated with Paratone-N oil, suspended in a small
fiber loop, and placed in a cooled gas stream at 153(2)
K. Diffraction intensities were measured using Mo K_a
radiati coated with Paratone-N oil, suspended in a small
fiber loop, and placed in a cooled gas stream at 153(2)
K. Diffraction intensities were measured using Mo K_a
radiation ($\lambda = 0.71073 \text{Å}$). Data collection, indexing,
re

 $# \&L \# (J. Electron) 2022, 28(9), 2214002 (3 of 11)$ quality and a summary of residual values of refine-

ments are given in Table S1 for NO₂-CoP and Table

S2 for 5F-CoP.

to Equation 1.

UV-vis spectra were collected using a spe $# \&L \cong (J. \&Lectrochem.) 2022, 28(9), 2214002 (3 of 11)$

ality and a summary of residual values of refine-

ents are given in Table S1 for NO₂-CoP and Table
 $\frac{Ag}{AgCl}$ electrode and RHE is calculated according

for SF-CoP.
 tometer (U-3310, Hitachi). th (*Electrochem.*) 2022, 28(9), 2214002 (3 of 11)

quality and a summary of residual values of refine-

ments are given in Table S1 for NO₂-CoP and Table

S2 for SF-CoP.

UV-vis spectra we **EVALUATION 1999**
 EVALUATION (Bruker). High resolution mass spectra (HRMS) were $\frac{1}{2}$ resolution and 1600 r·min⁻¹. The potential between
thents are given in Table S1 for NO₇-CoP and Table $\frac{1}{2}$ of $\frac{1}{2}$ resolution 1.

UV-vis spectra w **EVALUAT THE READE THE READER IN THE READER IN THE READER (2) CONDITION and a summary of residual values of refine-**
 at 5 mV·s³ and 1600 r·min¹. The potential between

ments are given in Table S1 for NO₂-CoP and **EVALUATION 1999** (External phy measurements are given in Table S1 for No-CoP and Table 3. The motion of the spectrometric and RHE is calculated according

S2 for SF-CoP.

UV-vis spectra were collected using a spectroph **ELET ALACTE (Example 19:20)** \mathbb{R}^n (\mathbb{R}^n (\mathbb{R}^n and $\$ (Letternochem.) 2022, 28(9), 2214002 (3 of 11)

quality and a summary of residual values of refine-

at 5 mV·s² and 1600 r·min³. The potential between

ments are given in Table S1 for NO₂-CoP and Table
 $\Delta g/\Delta gCl$ e **Example 12**
 Example 12 THECT (Electrochem.) 2022, 28(9), 2214002 (3 of 11)

quality and a summary of residual values of refine-

ments are given in Table SI for NO₂-CoP and Table

S2 for 5F-CoP.

UV-vis spectra were collected using a spectr th(k²/ε *Khermohem.*) 2022, 28(9), 2214002 (3 of 11)

quality and a summary of residual values of refine-

at 5 mV·s' and 1600 r·min⁻¹. The potential between

ments are given in Table S1 for NO_r-CoP and Table
 \frac photoelectron spectroscopic (XPS) results were meaquality and a summary of residual values of refine-

ments are given in Table S1 for NO_r-CoP and Table

ments are given in Table S1 for NO_r-CoP and Table

S2 for 5F-CoP.

ments are given in Table S1 for NO_r-CoP and quality and a summary of residual values of refine-
near at 5 mV \cdot s² and 1600 r-min⁻¹. The potential between
near sar given in Table S1 for NO,-CoP and Table Ag/AgC electrode and RHE is calculated according
S2 for ments are given in Table S1 for NO₁-CoP and Table

22 for 5C -CoP.

22 for 5¹-CoP.

23 for 5¹-CoP.

UV-vis spectra were collected using a spectropho-

E_{RUF} = E<sub>*Q*-R_UF -0.197 + 0.059 × pH (V) (1)

tometer (</sub> S2 for 5F-CoP.

USQuation 1.

US-vis spectra were collected using a spectropho-

the teme- F_{Ag} and 400 MHz

tometer (1-3310, Hitachi). H NMR spectra were ac-

quired on a spectrometer operating at 400 MHz

data at 2 UV-vis spectra were collected using a spectropho-

In the catalyst in the catalyst in the catalyst in the spectra were according to the distinguistical by measuring LSV

upuired on a spectrometr operating at 400 MHz

upui tometer (U-3310, Hitachi). ¹H NMR spectra were ac-

united on a spectrometer operating at 440 MHz

(Bruker). High resolution mass spectra (HRMS) were electrons transferred per O₁ molecule was calculated

(Bruker). Hig quired on a spectrometer operating at 400 MHz data at 2 mV·s⁻¹ and 1600 r·min⁻¹. The numb

(Bruker). High resolution inans spectra (HRMS) were

measured using high resolution liquid chromatogram

phy mass spectrometry ruker). High resolution mass spectra (HRMS) were

electrons transferred per O₂ molecule was calculated

surgence using high resolution liqiud chromategra-

by measurements, Co porphyrins were directly loaded on

and 160 measured using high resolution liquid chromatogra-

by measuring LSV with rotating ring-disk electrode

phymass spectrometry (Frukter). For electrocataly

constation and 1600 r-min⁺. The *n* is calculated with Equation
 phy mass spectrometry (Bruker). For electrocatalytic (RRDF; disk: 0.247 cm², ring: 0.186 cm³ at 5 mV·s⁻¹
carebon nanotubes (CNTplyins were firedly loaded on and 600 r-min¹. The *n* is calculated with Figuation 2.
 measurements, Co porphyrins were directly loaded on and 1600 r·min¹. The *n* is calculated with Equation 2.

cxNT hybrids were measured with a seaming electron

microscope (SFM, SU8020, Hitachi) and transmission

Herein carbon nanotubes (CNTs). Morphologies of catalyst@

CNT hybrids were measured with a scaning electron microscope (TEM, Tecnai G2 P20, FEI). X-ray

electron microscope (TEM, Tecnai G2 P20, FEI). X-ray

electron microscope CNT hybrids were measured with a scanning electron

Herein, i_k is the disk current, it is the ring current,

microscope (SEM, SU8002), Hitachi) and transmission

electron microscope (TEM, Tecnai G2 F20, FE1). X-ray

and

microscope (SEM, SU8020, Hitachi) and transmission

electron microscope (TEM, Tecni (72 P20, FFI), X-ray

and *N* is the collection efficiency of ring current (0.39)

electron microscope (TEM, Tecni (72 P20, FFI), X-ray
 electrom microscope (TFM, Tecnai (2 P20, FFI). X-ray and N is the collection perture of the priorition perture measure measure of the sum of Nutecky-Levich by those that are measured with a XPS (Thermo ESCALAB 250XI). Hyphotoelectron spectroscopic (XPS) results were mea.

surved with an XPS (Termo ESCALAB 200XI). Hy-

drophilicities were measured with a video-based con-

drophilicities were measured with a video-based con-

different rot sured with an XPS (Thermo ESCALAB 250X1). Hy-

(K-L) quatitonics (state and the ventaxe of the different rotating speeds.

different rotating speeds.

tact angle instrument (OCA 20, Dataphysics) for three

tact angle inst drophilicities were measured with a video-based con-

that single instrument (OCA 20, Dataphysis) for three $\frac{1}{I} = \frac{1}{I_k} + \frac{1}{k} = \frac{1}{R_{Bol}} \Rightarrow \frac{1}{I_k}$ (3)

times to obtain average values. Co porphyrin molecules

and tact angle instrument (OCA 20, Dataphysics) for three $\frac{1}{J} = \frac{1}{J_1} + \frac{1}{J_{\overline{x}}} = \frac{1}{J_{00}}$, $\frac{1}{J_0}$

dim so to botain average values. Co poprhyrin molecules

and the catalyst inks were coated on the slicon slic times to obtain average values. Co porphyrin molecules

and the catalyst inks were coated on the silicon slice

With the same loading on the electrode.

With the same loading on the electrode.

2.3 **Electrochemical Tests** and the catalyst inks were coated on the silicon slice
 $B = \frac{1.2nV}{\omega_0 V}$, \vec{J} is the current density measured with

the same bodding on the electrode.
 Extractable in the catalystic of the catalystic of the cataly with the same loading on the electrode.

LSV, I_n is the current density measure

LSV, I_n is the diffusion-limited J , K_n is the kine-

Flectrochemical Tests

The reaction coefficient (J_n is the angular vclocity, **2.3 Electrochemical Tests**

Eclimited L is v, it is the annuation-immed L, is it is considerably in the Far-

Eclimited L oi is the angular velocity, F is the Far-

Eclimical L oi is the angular velocity, F is the Far-
 Flectrocatalytic ORR measurements were carried

day constant (9648S C·mol⁹). *G_{is}* is the bulk cone-

out with a CHI 760E electrochemical vorkstation

and 4 Pins Ontail The DME care-

and 4 Pins Modulated Spected Rota out with a CHI 760E electrochemical workstation

article of Ω (1.2x10³ mol · L⁺). D_0 i. L⁺ (1.2x10³ mol · L⁺). D_0 i. L⁺ (2.9x10³ mol · L⁺). D_0 is the diffusion

and a Pine Modulated Speed Rotat and a Pine Modulated Speed Rotator in 0.1 mol \cdot L⁻⁴ tratem or Ω_2 (1.2x10^{*v*} mol \cdot L₁, *D₆* is the armshol

Kolt with a typical three-electrode system. Rotating

disk electrode (RDE, 0.196 cm³), carbon EXCH with a typical three-electrode system. Rotating contracts of $(1.8 \times 10^{-2} \text{ cm}^2 \text{ s})$ and $\text{L}_2 \times (1.8 \times 10^{-2} \text{ cm}^2 \text{ s})$ and $\text{L}_2 \times (1.8 \times 10^{-2} \text{ cm}^2 \text{ s})$ and state chereby (DET) courses that conceller (DD disk electrode (RDE, 0.196 cm²), carbon rod, and sat-

untafe AgAgCI electrode CROE (18/10/2012-em-s y⁻¹²,

untafe AgAgCI electrode, aware as the working

electrode, aware diverse used as the working

electrode, and r

 $#E\# (J. Electrochem.) 2022, 28(9), 2214002 (3 of 11)$ quality and a summary of residual values of refine-

ments are given in Table S1 for NO₂-CoP and Table

S2 for 5F-CoP.

to Equation 1.

UV-vis spectra were collected using a spe **E** *I*E *Electrochem.*) 2022, 28(9), 2214002 (3 of 11)

quality and a summary of residual values of refine-

ments are given in Table S1 for NO₂-CoP and Table

S2 for 5F-CoP.

UV-vis spectra were collected using a spe , 28(9), 2214002 (3 of 11)

at 5 mV·s⁻¹ and 1600 r·min⁻¹. The potential between

Ag/AgCl electrode and RHE is calculated according

to Equation 1.
 $E_{RHE} = E_{Ag/AgC1} + 0.197 + 0.059 \times pH (V)$ (1)

Tafel slopes were calculate $\frac{1002 (3 \text{ of } 11)}{11}$
 $\frac{1}{11}$ and 1600 r·min⁻¹. The potential between

electrode and RHE is calculated according

n 1.
 $\frac{1}{100}$ 197 + 0.059 × pH (V) (1)

lopes were calculated by measuring LSV (a), 2214002 (3 of 11)

at 5 mV·s⁻¹ and 1600 r·min⁻¹. The potential between

Ag/AgCl electrode and RHE is calculated according

to Equation 1.
 $E_{RHE} = E_{Ay/AgC1} + 0.197 + 0.059 \times pH (V)$ (1)

Tafel slopes were calculated by . 28(9), 2214002 (3 of 11)

at 5 mV·s⁻¹ and 1600 r·min⁻¹. The potential between

Ag/AgCl electrode and RHE is calculated according

to Equation 1.
 $E_{RHE} = E_{Ag/AgCl} + 0.197 + 0.059 \times pH (V)$ (1)

Tafel slopes were calculate $\frac{\text{H}(k\#(J. \text{Electrochem.}) 2022, 28(9), 2214002 (3 of 11))}{\text{Hual values of refine-}}$

at 5 mV·s⁻¹ and 1600 r·min⁻¹. The potential between

NO₂-CoP and Table Ag/AgCl electrode and RHE is calculated according

to Equation 1.

A using a spe

$$
E_{\text{RHE}} = E_{\text{Ag/AgCl}} + 0.197 + 0.059 \times \text{pH (V)} \tag{1}
$$

. 28(9), 2214002 (3 of 11)

at 5 mV·s⁻¹ and 1600 r·min⁻¹. The potential between

Ag/AgCl electrode and RHE is calculated according

to Equation 1.
 $E_{RHE} = E_{Ag/AgC1} + 0.197 + 0.059 \times pH (V)$ (1)

Tafel slopes were calculat (9), 2214002 (3 of 11)

5 mV·s⁻¹ and 1600 r·min⁻¹. The potential between

/AgCl electrode and RHE is calculated according

Equation 1.
 $E = E_{Ag/AgG} + 0.197 + 0.059 \times pH (V)$ (1)

Tafel slopes were calculated by measuring L , 28(9), 2214002 (3 of 11)

at 5 mV·s⁻¹ and 1600 r·min⁻¹. The potential between

Ag/AgCl electrode and RHE is calculated according

to Equation 1.
 $E_{RHE} = E_{Ag/dgCl} + 0.197 + 0.059 \times pH (V)$ (1)

Tafel slopes were calculated (3 of 11)

d 1600 r·min⁻¹. The potential between

rode and RHE is calculated according

0.197 + 0.059 × pH (V) (1)

s were calculated by measuring LSV

⁻¹ and 1600 r·min⁻¹. The number (*n*) of

ferred per O₂ molec . 28(9), 2214002 (3 of 11)

at 5 mV·s⁻¹ and 1600 r·min⁻¹. The potential between

Ag/AgCl electrode and RHE is calculated according

to Equation 1.
 $E_{RUE} = E_{Ag/AgC1} + 0.197 + 0.059 \times pH (V)$ (1)

Tafel slopes were calculat , 28(9), 2214002 (3 of 11)

at 5 mV·s⁻¹ and 1600 r·min⁻¹. The potential between

Ag/AgCl electrode and RHE is calculated according

to Equation 1.
 $E_{RHE} = E_{Ag/AgG} + 0.197 + 0.059 \times pH (V)$ (1)

Tafel slopes were calculate , 28(9), 2214002 (3 of 11)

at 5 mV·s⁻¹ and 1600 r·min⁻¹. The potential between

Ag/AgCl electrode and RHE is calculated according

to Equation 1.
 $E_{RUE} = E_{Ag/AgG} + 0.197 + 0.059 \times pH (V)$ (1)

Tafel slopes were calculate min⁻¹. The potential between

RHE is calculated according

0.059 × pH (V) (1)

alculated by measuring LSV

00 r·min⁻¹. The number (*n*) of

r O₂ molecule was calculated

n rotating ring-disk electrode

i, ring: 0.18 trial between

ed according

(1)

asuring LSV

umber (*n*) of

as calculated

isk electrode

b) at 5 mV \cdot s⁻¹

l Equation 2.

(2)

ring current, -1 $28(9)$, 2214002 (3 of 11)

at 5 mV·s⁻¹ and 1600 r·min⁻¹. The potential between

Ag/AgCl electrode and RHE is calculated according

to Equation 1.

E_{REWE} = $E_{Ag/Ag}$ -4 - 0.197 + 0.059 × pH (V) (1)

Tacil slopes were 8(9), 2214002 (3 of 11)

5 mV·s⁻¹ and 1600 r·min⁻¹. The potential between
 y/AgCl electrode and RHE is calculated according

Equation 1.
 $\text{He} = E_{\text{Ag/AgCl}} + 0.197 + 0.059 \times \text{pH (V)}$ (1)

Tafel slopes were calculated potential between
ilculated according
if (V) (1)
oy measuring LSV
The number (*n*) of
ule was calculated
ring-disk electrode
86 cm²) at 5 mV · s⁻¹
d with Equation 2. (2)
is the ring current,
Fring current,
Fring curre 28(9), 2214002 (3 of 11)

at 5 mV·s⁻¹ and 1600 r·min⁻¹. The potential between

Ag/AgCl electrode and RHE is calculated according

to Equation 1.
 $E_{R I E} = E_{A_0/\sqrt{s}}$ 1 + 0.197 + 0.059 × pH (V) (1)

Tafel slopes were cal $\frac{1}{28(9)}$, 2214002 (3 of 11)

at 5 mV·s⁻¹ and 1600 r·min⁻¹. The potential between

Ag/AgCl electrode and RHE is calculated according

to Equation 1.
 $E_{\text{RIE}} = E_{\text{Ag/AG}} + 0.197 + 0.059 \times pH (V)$ (1)

Tafel slopes were $(2.28(9), 2214002(3 \text{ of } 11))$

at 5 mV·s⁻¹ and 1600 r·min⁻¹. The potential between

Ag/AgCl electrode and RHE is calculated according

to Equation 1.
 $E_{RUE} = E_{Ag/ag} - 0.197 + 0.059 \times pH (V)$ (1)

Tafel slopes were calculat at 5 mV·s⁻¹ and 1600 r·min⁻¹. The potential between
Ag/AgCl electrode and RHE is calculated according
to Equation 1.
E_{RWE} = $E_{\text{Ag/ag(3)}} + 0.197 + 0.059 \times pH (V)$ (1)
Tafel slopes were calculated by measuring LSV
data at $E_{Rum} = E_{Ag/agd} + 0.197 + 0.059 \times pH (V)$ (1)

Tafel slopes were calculated by measuring LSV

data at 2 mV·s⁻¹ and 1600 r·min⁻¹. The number (n) of

electrons transferred per O₂ molecule was calculated

by measuring LSV w **Example 12**
 Tafel slopes were calculated by measuring LSV

a at 2 mV·s⁻¹ and 1600 r·min⁻¹. The number (n) of

ctrons transferred per O₂ molecule was calculated

measuring LSV with rotating ring-disk electrode

R

$$
n = 4 \frac{i_d}{i_d + i_r/N}
$$
 (2)

$$
\frac{1}{J} = \frac{1}{J_L} + \frac{1}{J_K} = \frac{1}{B\omega^{1/2}} + \frac{1}{J_K}
$$
 (3)

$$
B = 0.2nFC_0D_0^{23}v^{-1/6}
$$
 (4)

hologies of catalyst@
 $n = 4$ $\frac{1}{i}$, i/N (2)

th a scanning electron
 $\frac{1}{i}$ and N is the disk current, i , is the ring current,

iai G2 F20, FE1). X-ray

Then in i is its disk current, i , is the ring current data at 2 mV·s⁻¹ and 1600 r·min⁻¹. The number (*n*) of
electrons transferred per O₂ molecule was calculated
by measuring LSV with rotating ring-disk electrode
(RRDE; disk: 0.247 cm², ring: 0.186 cm²) at 5 mV·s⁻ icelectrons transferred per O₂ molecule was calculated
by measuring LSV with rotating ring-disk electrode
(RRDE; disk: 0.247 cm², ring: 0.186 cm²) at 5 mV·s⁻¹
and 1600 r·min⁻¹. The *n* is calculated with Equatio by measuring LSV with rotating ring-disk electrode

(RRDE; disk: 0.247 cm², ring: 0.186 cm²) at 5 mV·s⁻¹

and 1600 r·min⁻¹. The *n* is calculated with Equation 2.
 $n = 4 \frac{i_d}{i_d + i/N}$ (2)

Herein, i_d is the disk c (RNDE; disk: 0.247 cm², ring: 0.186 cm³) at 5 mV·s⁻¹

and 1600 r·min⁻¹. The *n* is calculated with Equation 2.
 $n = 4 \frac{i_d}{i_d + i_r/N}$ (2)

Herein, i_d is the disk current, *i*, is the ring current,

and *N* is the c 0.186 cm^2 at 5 mV·s⁻¹
 0.186 cm^2 at 5 mV·s⁻¹

alated with Equation 2.

(2)
 $t, i,$ is the ring current,

y of ring current (0.39).

d on Koutecky-Levich

measuring LSV data at

(3)

(3)

(4)

ensity measured and 1600 r min⁻¹. The *n* is calculated with Equation 2.
 $n = 4 \frac{i_d}{i_d + i_r/N}$ (2)

Herein, i_d is the disk current, i_r is the ring current,

and *N* is the collection efficiency of ring current (0.39).

The n was also ed with Equation 2.

(2)

is the ring current,

fring current (0.39).

on Koutecky-Levich

asuring LSV data at

(3)

(3)

(4)

sity measured with

J, J_k is the kinet-

ocity, F is the Fara-

is the bulk concen-

D₀ is $n = 4 \frac{i_d}{i_d + i_r/N}$ (2)

Herein, i_d is the disk current, i_r is the ring current,

and *N* is the collection efficiency of ring current (0.39).

The n was also calculated based on Koutecky-Levich

(K-L) equations (3 and $\binom{-1}{1}$ [52]. $n = 4 \frac{1}{t_d + t_i/N}$ (2)

Herein, i_d is the disk current, i_r is the ring current,

and *N* is the collection efficiency of ring current (0.39).

The n was also calculated based on Koutecky-Levich

(K-L) equations (3 and Herein, i_d is the disk current, i_r is the ring current,

d N is the collection efficiency of ring current (0.39).

en was also calculated based on Koutecky-Levich

-L) equations (3 and 4) by measuring LSV data at

ffe and *N* is the collection efficiency of ring current (0.39).

The n was also calculated based on Koutecky-Levich

(K-L) equations (3 and 4) by measuring LSV data at

different rotating speeds.
 $\frac{1}{J} = \frac{1}{J_L} + \frac{1}{J_K} =$ The n was also calculated based on Koutecky-Levich

(K-L) equations (3 and 4) by measuring LSV data at

different rotating speeds.
 $\frac{1}{J} = \frac{1}{J_L} + \frac{1}{J_K} = \frac{1}{B\omega}^{1/2} + \frac{1}{J_K}$ (3)
 $B = 0.2nFC_0D_0^{3/2}v^{1/6}$ (4)

(K-L) equations (3 and 4) by measuring LSV data at
different rotating speeds.
 $\frac{1}{J} = \frac{1}{J_L} + \frac{1}{J_K} = \frac{1}{B\omega^{1/2}} + \frac{1}{J_K}$ (3)
 $B = 0.2nFC_0D_0^{3\gamma_0 \cdot 1/6}$ (4)
Herein, *J* is the current density measured with
LSV, different rotating speeds.
 $\frac{1}{J} = \frac{1}{J_L} + \frac{1}{J_K} = \frac{1}{B\omega^{1/2}} + \frac{1}{J_K}$ (3)
 $B = 0.2nFC_0D_0^{3}v^{-1/6}$ (4)

Herein, *J* is the current density measured with

LSV, J_L is the diffusion-limited *J*, J_K is the kinet $\frac{1}{J} = \frac{1}{J_L} + \frac{1}{J_K} = \frac{1}{B\omega}^{1/2} + \frac{1}{J_K}$ (3)
 $B = 0.2nFC_0D_0^{3}v^{-1/6}$ (4)

Herein, *J* is the current density measured with

LSV, J_L is the diffusion-limited *J*, J_K is the kinet-

ic-limited *J*, ω is J_L J_K $B\omega^{0.2}$ J_K (4)
 $B = 0.2nFC_0D_0^{3\gamma}v^{1/6}$ (4)

Herein, J is the current density measured with

LSV, J_L is the diffusion-limited J , J_K is the kinet-

ic-limited J , ω is the angular velocity, F $B = 0.2nFC_0D_0^{xy}v^{1/6}$ (4)

Herein, *J* is the current density measured with

LSV, *J*_L is the diffusion-limited *J*, *J*_K is the kinet-

ic-limited *J*, *ω* is the angular velocity, *F* is the Fara-

day constant (Herein, *J* is the current density measured with
LSV, J_L is the diffusion-limited J , J_R is the kinet-
ic-limited J , ω is the angular velocity, F is the Erra-
day constant (96485 C·mol⁺), C_0 is the bulk c LSV, J_L is the diffusion-limited J , J_R is the kinet-
ic-limited J , ω is the angular velocity, F is the Fara-
day constant (96485 C·mol⁻¹), C_0 is the bulk concen-
tration of O_2 (1.2×10³ mol·L⁻¹), ic-limited *J*, ω is the angular velocity, *F* is the Fara-
day constant (96485 C·mol⁻¹), C_0 is the bulk concen-
tration of O_2 (1.2×10⁻³ mol·L⁻¹), D_0 is the diffusion
coefficient of O_2 (1.9×10⁻³ cm day constant (96485 C·mol⁻¹), C_0 is the bulk concentration of O_2 (1.2×10³ mol·L⁻¹), D_0 is the diffusion coefficient of O_2 (1.9×10³ cm²·s⁺) and *v* is the kinematic viscosity of electrolyte (1.0×10 tration of O₂ (1.2×10³ mol·L¹), D_0 is the diffusion
coefficient of O₂ (1.9×10⁵ cm²·s⁻¹) and *v* is the kine-
matic viscosity of electrolyte (1.0×10² cm²·s⁻¹)^[32].
2.4 Theoretical Calculations
De efficient of O₂ (1.9x10^o cm⁻·s^c) and v is the kine-
tite viscosity of electrolyte (1.0x10² cm²·s⁻¹)^[83].
4 Theoretical Calculations
Density functional theory (DFT) calculation results
obtained with Gauss matic viscosity of electrolyte (1.0x10⁻ cm⁻·s⁻)^[24].
 2.4 Theoretical Calculations

Density functional theory (DFT) calculation results

are obtained with Gaussian 16 program^[53]. Geometry

optimization and ha

(LSV) was measured in O₂-saturated 0.1 mol \cdot L⁻¹ KOH phyrins (Figure 1a and 1b) were synthesized. Their

He $\ell \neq (I. Electmchen.)$ 2022, 28(9), 2214002 (4 of 11)

He monoclinic space group P21/c with a mass-to-charge ratio of 1030,9750, which

He monoclinic space group P21/c with a calculated value of 1030,9756

(Figure S2). Complex 11.878.1 (Figure 12.857) and purity were confirmed by 'H NMR and

HRMS (Figure S1-S4), Complex SF-CoP displayed an

ion with a mass-to-charge ratio of 1030.9750, which

is consistent with the calculated value of 1030.9750 $+6/4\%$ Electrochem, 2022, 28(9), 2214002 (4 of 11)

dentity and purity were confirmed by ¹H NMR and

HRMS (Figure S1.54). Complex 5F-CoP displayed an

in on with a mass-to-charge ratio of 1030.9750, which

figures S2) identity and purity were confirmed by ¹H NMR and

HRMS (Figure S1-S4). Complex SF-CoP displayed an

ion with a mass-to-charge ratio of 1030.9750, which

is consistent with the calculated value of 1030.9750, which

a mas Hence it is a dependent of the SC-Cop and three states in SC-Cop and SC-Cop an IIRMS (Figure S1-S4). Complex 5F-CoP displayed an
is consistent with the calculated value of 1030.9756
is consistent with the calculated value of 1030.9756

(Figure S2). Complex NO_T-CoP displayed an ion with

a mass-to ion with a mass-to-charge ratio of 1030.9750, which

is consistent with the calculated value of 851.1031, marching well

The calculated value of 851.1034 (Figure S4).

Since CS). Complex NO_r-CoP displayed an ion with

a is consistent with the calculated value of 1030.9756

Crigows 20; Complex NO-CoP displayed an ion with

a mass-to-charge ratio of 851.1041 (Figure S4).

Single crystal X-ray structures of NO-CoP and

Single crystal X-ray (Figure S2). Complex NO₂-CoP displayed an ion with

an mass-to-charge ratio of 851.1044 (Figure S4).

Single crystal X-ray structures of NO₂-CoP and

Single crystal X-ray structures of NO₂-CoP and

Single crystal Xa mass-to-charge ratio of 851.1031, matching well

with the calculated value of 851.1031, matching well

Single crystal X-ray structures of NO₁-CoP and

Single crystal X-ray structures of NO₁-CoP and

Single crystal X with the calculated value of 851.1044 (Figure S4).

Since crystal

Since CoP were obtained, further confirming the formacion

of these Co porphyrins (Figure 1e and 1d). Crys-

tallographic studies reveal that the NO_C-Co Single crystal X-ray structures of NO-CoP and

stic-CoP were obtained, thirther confining the formal in formal

tion of these Co porphyrins (Figure 1c and 1d). Crystal

and $\beta = 109.280(3)$, $\lambda_1 = 16.795(13)$, $\lambda_2 = 13.$ SF-CoP were obtained, further confirming the forma-

tallographic studies Co porphyrins (Figure 1 and 1d). Crys

atallographic studies reveal that the NO_r-CoP rystal-

lized in the monoclinic space group $P2/e$ with $a =$ con of these Co-porphyrins (Figure 1e and 1d). Crys-

Itland propheric structures reveal that the NO₂-Co¹ crystal-

Itland in the monoclinic space group $P2_6$ e with $a =$

10.8572(9) Å, $b = 16.7957(13)$ Å, $c = 13.224$ tallographic studies reveal that the NO_r-CoP erystal-

ilzed in the monoclinic space group $P_{2i}e$ with $a = 1.3257(9)$, λ , $b = 16.7957(13)$, λ , $c = 13.2441(10)$, λ ,

and $\beta = 109.280(3)^{\circ}$ (Table S1), while t Example 1 the monoclinic space group P_2/c with $a =$

EST2(9) Å, $b = 16.7937(13)$ Å, $c = 13.234(10)$ Å, $c = 24.902$

Salized in the orthorhombic space group P_1nnn

Figure 1 Molecular structures (a, b) and thermal ellipso 2(9) λ , $b = 16.7957(13)$ λ , $c = 13.2241(10)$ λ .

Elized in the critechnosity process or \mathbb{R}^2 was mean \mathbb{R}^2 in $\mathbb{R$ and $\beta = 109.280(3)°$ (Table S1), while the SF-CoP

erystallized in the orthombories (age group *Phamm* **Figure 1** Molecular structures (a, b) and thermal ellipsoid plots

with $a = 7.3850(8)$ Å, $b = 14.4400(14)$ Å, $c = 24$ exal in the orthorhombic space group $Pnnm$
 Figure 1 Molecular structures (a, b) and thermal ellipsoid plots

7.3850(8) Å, $b = 14.4400(14) \text{ Å}, c = 24.902$ (50% probability) of the X-ray erystal structures (c, of o liv with $a = 7.3850(8)$ Å, $b = 14.4400(14)$ Å, $c = 24.902$ (⁵⁰⁸⁶ probability) of the X-ray crystal structures (c, d) of NQ-

(3) Å (Table S2). In both NQ-CoP and 3F-CoP, the Co core and 5F-CoP. Color ordos: geone Co, red O, (3) Å (Table S2). In both NO₂-CoP and SF-CoP, the Co^{cor} and SF-CoP. Color codes green Co, red 0, blue N₁ yel-
ingand through tour N dioms, leading to the same
ingand through four N dioms, leading to the same
Co-N₁

mol·L⁻¹ Bu₄N(PF₆) DMF solution under N₂ was mea- $Co¹/Co⁰$ for the 5F-CoP appeared at -1.12 V ar and 1.991(3) λ for 5F-CoP. Furthermore, the plane of (TEM), indicating the absence of aggregated Co por-
both pentalloarobenzem and 4-nitrobenzeme sub-phyrin particles in the hybrid. Scanning TEM and cl-
bstituents is both pentafluorobenzene and 4-nitrobenzene sub-

phyrin particles in the hybrid. Scanning TFM and el-

stitutents is preprodicular to the leane of their por-

ement disrubition images of Co, N_a and O showed

phyrin macr situents is perpendicular to the plane of their por-

emcnt distribution images of Co, N, and O showed

phyrm imacrocycles. These results showed that the that NO-CoP molecules were evenly loaded on

ecoordination structur phyrin macrocycles. These results showed that the that NO-CoP molecules were evenly loaded on and str-CoP are similar to each other. With ND_2 -CoP C^2 and S^2 is N^2 is $(T^2R \times T^2R \times T^2R \times T^2R \times T^2R \times T^2R \times T^2R \times T$ coordination structures of the Co ions with NO₁-CoP CNTs (Figure 2d). Similar results were also obtained

and Fr-CoP are similar to each other.

Cyclic voltammogram of Co porphyrins in 0.1 X-ray photoclectron spectrosco and SF-CoP are similar to each other.

Cyclic voltamongeram of Co porphyrins in 0.1 \sim r-arg phatecelectron spectroscopic (XPS) analysis

Cyclic voltamongeram of Co porphyrins in 0.1 \sim r-arg phatecelectron spectrosco

ement distribution images of Co, N, and Co, T and SE-CoP. Color codes: green Co, red O, blue N, yellow green F, white C. (color on line)
CNT (Figure 2b and 2c) by scan Figure 1 Molecular structures (a, b) and thermal ellipsoid plots

(50% probability) of the X-ray crystal structures (c, d) of NO₂-CoP and 5F-CoP. Color codes: green Co, red O, blue N, yel-

Low green F, white C. (color Figure 1 Molecular structures (a, b) and thermal ellipsoid plots
(50% probability) of the X-ray crystal structures (c, d) of NO₂-
CoP and 5F-CoP. Color codes: green Co, red O, blue N, yel-
low green F, white C. (color o Figure 1 Molecular structures (a, b) and thermal ellipsoid plots

(50% probability) of the X-ray crystal structures (c, d) of NO₂-CoP and 5F-CoP. Color codes: green Co, red O, blue N, yel-

buy green F, white C. (color Example 1 Molecular structures (a, b) and thermal ellipsoid plots
% probability) of the X-ray crystal structures (c, d) of NO₂-
P and SF-CoP. Color codes: green Co, red O, blue N, yel-
green F, white C. (color on line)
 Figure 1 Molecular structures (a, b) and thermal ellipsoid plots
(50% probability) of the X-ray crystal structures (c, d) of NO₂-
CoP and SF-CoP. Color codes: green Co, red O, blue N, yel-
low green F, white C. (color **Figure 1** Molecular structures (a, b) and thermal ellipsoid plots (50% probability) of the X-ray crystal structures (c, d) of NO₂-CoP and 5F-CoP. Color codes: green Co, red O, blue N, yel-low green F, white C. (color o **Figure 1** Molecular structures (a, b) and thermal ellipsoid plots
(50% probability) of the X-ray crystal structures (c, d) of NO₂-
CoP and 5F-CoP. Color codes: green Co, red O, blue N, yel-
low green F, white C. (color

ions are coordinated by the corresponding porphyrin

ligon through form N atoms, leading to the same

ligond through four N atoms, leading to the same

Co-N, square-planar coordination structure. The av-

CNT (Figure 2b a ligand through four N atoms, leading to the same
Co-N₁ square-planar coordination structure. The av-
CNT (Figure 2b and 2c) by scanning electron micros-
erage Co-N bond distance is 1.974(3) Å for NO₇-CoP copy (SEM) an to redox potentials of Co^{II}/Co^{I} and Co^{I}/Co^{0} , respec-
NO₂-CoP/CNT showed XPS signal of O 1s at 533.4 the same

The av-

CNT (Figure 2b and 2c) by scanning electron micros-

copy (SEM) and transmission electron microscopy

plane of (TEM), indicating the absence of aggregated Co por-

the sub-

phyrin particles in the hybr Co-N₁ square-planar coordination structure. The av-

CNT (Figure 2b and 2c) by scanning electron microssenge Co-N bond distance is 1.974(3) Å for SN-Co-N² compy (SEM) and transmission electron microscopy

and 1.991(3) erage Co-N bond distance is 1.974(3) Å for NO_T-CoP copy (SEM) and transmission electron microscopy

and 1.991(3) Å for S^P-CoP. Furthermore, the plane of TEM), indicating the absence of aggregated Co por-

both pentall (50% probability) of the X-ray crystal structures (c, d) of NO₂-
CoP and 5F-CoP. Color codes: green Co, red O, blue N, yel-
low green F, white C. (color on line)
CNT (Figure 2b and 2c) by scanning electron microscopy
(T CoP and 5F-CoP. Color codes: green Co, red O, blue N, yel-
low green F, white C. (color on line)
CNT (Figure 2b and 2c) by scanning electron microscopy
(TEM), indicating the absence of aggregated Co por-
phyrin particles low green F, white C. (color on line)

CNT (Figure 2b and 2c) by scanning electron microscopy

(TEM), indicating the absence of aggregated Co por-

phyrin particles in the hybrid. Scanning TEM and el-

ement distribution i CNT (Figure 2b and 2c) by scanning electron microscopy (SEM) and transmission electron microscopy (TEM), indicating the absence of aggregated Co por-
phyrin particles in the hybrid. Scanning TEM and element distribution i CNT (Figure 2b and 2c) by scanning electron microscopy (SEM) and transmission electron microscopy (TEM), indicating the absence of aggregated Co por-
phyrin particles in the hybrid. Scanning TEM and el-
ement distribution copy (SEM) and transmission electron microscopy
(TEM), indicating the absence of aggregated Co por-
phyrin particles in the hybrid. Scanning TEM and el-
ement distribution images of Co, N, and O showed
that NO₂-CoP molec (TEM), indicating the absence of aggregated Co por-
phyrin particles in the hybrid. Scanning TEM and el-
ement distribution images of Co, N, and O showed
that NO₂-CoP molecules were evenly loaded on
CNTs (Figure 2d). Si phyrin particles in the hybrid. Scanning TEM and element distribution images of Co, N, and O showed
that NO₂-CoP molecules were evenly loaded on
CNTs (Figure 2d). Similar results were also obtained
for the 5F-CoP/CNT.
Xement distribution images of Co, N, and O showed
that NO₂-CoP molecules were evenly loaded on
CNTs (Figure 2d). Similar results were also obtained
for the 5F-CoP/CNT.
X-ray photoelectron spectroscopic (XPS) analysis
of t that NO₂-CoP molecules were evenly loaded on
CNTs (Figure 2d). Similar results were also obtained
for the SF-CoP/CNT.
X-ray photoelectron spectroscopic (XPS) analysis
of these hybrids was made to further confirm the ex-
 CNTs (Figure 2d). Similar results were also obtained
for the SF-CoP/CNT.
X-ray photoelectron spectroscopic (XPS) analysis
of these hybrids was made to further confirm the ex-
istence of Co porphyrins (Figure S8). From high the 5F-CoP/CNT.
X-ray photoelectron spectroscopic (XPS) analysis
these hybrids was made to further confirm the ex-
nece of Co porphyrins (Figure S8). From high res-
nece of Co porphyrins (Figure S8). From high res-
tition

images of NO₂-CoP/CNT. (e) XPS spectra of Co 2p for NO₂-CoP/CNT and 5F-CoP/CNT. (f) XPS spectrum of O 1s for NO₂-CoP/CNT.

Example 2. (a) Preparation of molecule CNT hybrids, (b) SLM image, (c) TLM image, (d) seaming TLM und corresponding elemental timeses of NO_C-CoPCNT. (c) XPS spectra of Co 2p for NO_C-CoPCNT. The CV curve of To 2p for **Example 2018**
 Example 2018
 Example 2018
 Example 2018
 Example 2019
 Example 2019
 Example 3019
 Example 3019 Example 10.1
 Example 10.1 Control in the sum of th Figure 2 (a) Preparation of molecule CNT (a) Figure 1.1 The Eq. and The Textile of the Section of Figure 2.1 (a) Preparation of molecule CNT hybrids (b) Shiding electrode (c) TEM image, (d) scanning TEM and correspondin **Example 19**
 Example 2 (a) Pregnation of molecule CNT hybrids. (b) SEM image, (c) TEM image, (d) canning TEM and corresponding elsmental

images of NO.-CoP/CNT. (c) XPS spectra of Co 2p for NO.-CoP/CNT and SE-CoP/CNT. **Eigure 2** (a) Preparation of molecule/CNT hybrids. (b) SEM image, (c) TEM image, (d) scanning TEM and corresponding elemental
images of NO_C-CoP/CNT. (e) XPS spectra of Co 2p for NO_C-CoP/CNT and SF-CoP/CNT. (f) XPS sp **Figure 30** (1) The Commercial Pt/C
 Example 10 (Commercial Proposition of the commercial Ptical Pti (g) XPS spectrum of F 1s for SF-CoP/CNT (color on line)

hybrids for ORR were evaluated in 0.1 mol - L⁻¹ KOH than the unmodified CNTs ($F_{t/2} = 0.72$ V versus

aqueous solutions (Figure 3). The CV curve of NO₂ RHF) fo hybrids for ORR were evaluated in 0.1 mol -L⁺ KOH than the unmodified CNTs ($E_{12} = 0.72$ V versus aqueous solutions (Figure 3). The CV curve of NO₂ RHE) for electrocatalytic ORR. The ORR Tafel slope CoP/CNT showed la hybrids for ORR were evaluated in 0.1 mol -L³ KOH than the unmodified CNTs $(E_D = 0.72 \text{ V}$ versus agueous solutions (Figure 3). The CV curve of NO_P RHE) for electrocatalytic ORR. The ORR Tafel slope CoP/CNT showed lar hybrids for ORR were evaluated in 0.1 mol L^{\perp} KOH than the unmodified CNTs ($E_{12} = 0.72$ V versus aqueous solutions (Figure 3). The CV curve of NO₂-CoP/CNT (31 mV·dec)¹ CoP/CNT showed large canalytic current aqueous solutions (Figure 3). The CV curve of NO_F RHE) for electrocatalytic ORR. The ORR Tafel slope
CoP/CNT showed large catalytic currents under O₂ of NO_F-COP/CNT (44 mV-dec³) was smaller than that
CFigure 3a), CoP/CNT showed large catalytic currents under O_2 of NO₂-CoP/CNT (31 mV·dec⁺) was smaller than that (Figure 3a), indicating its electronatily acciding to set $S\text{-CoPC/NT}$ (44 mV·dec⁺). (Figure 3c). Tatel
(ORR. The (Figure 3a), indicating its electrocatalytic activity for

of SF-CoP/CNT (44 mV · decy') (Figure 3c). Tafel

ORR. The ORR peak potential with the NO₂-CoP/CNT

(0.74 V) was more positive than that of the SF-CoP/C slopes

hybrids for ORR were evaluated in 0.1 mol \cdot L⁻¹ KOH than the unmodified CNTs ($E_{1/2} = 0.72$ V versus **Solution**
 Solution

Solution 2.5 and 2.6 and 3.6 and 3.6 and 5.6 control in the unmodified CNTs ($E_{1/2} = 0.72$ V versus RHE) for electrocatalytic ORR. The ORR Tafel slope of NO₂-CoP/CNT (31 mV·dec⁻¹) was smaller $\, , \,$ respectively. **ISBN 0608**
 EXECUTEREN image, (d) scanning TEM and corresponding elemental

d SF-CoP/CNT. (f) XPS spectrum of 0 1s for NO₂-CoP/CNT.

In the unmodified CNTs ($E_{1/2} = 0.72$ V versus

HE) for electrocatalytic ORR. The **Example 12**
 Example 12

EXACTLE 12.19 For the SECT COP/CNT (Figure 3d). Similar and SF-CoP/CNT (f) XPS spectrum of 0 1s for NO₂-CoP/CNT.

than the unmodified CNTs ($E_{12} = 0.72$ V versus RHE) for electrocatalytic ORR. The ORR Tafel slope

of 3.1 sas eso the Supering TEM and corresponding elemental
singley (c) TEM image, (d) scanning TEM and corresponding elemental
and 5F-CoP/CNT. (f) XPS spectrum of O 1s for NO₂-CoP/CNT.
than the unmodified CNTs $(E_{1/2} = 0.$ sa

say (sv)

say (sv)

(c) TEM image, (d) scanning TEM and corresponding elemental

and SF-CoP/CNT. (f) XPS spectrum of O 1s for NO₂-CoP/CNT.

than the unmodified CNTs $(E_{1/2} = 0.72 \text{ V} \text{ versus}$

RHE) for electrocatalyti (c) TEM image, (d) scanning TEM and corresponding elemental
and 5F-CoP/CNT. (f) XPS spectrum of O 1s for NO₂-CoP/CNT.
than the unmodified CNTs $(E_{1/2} = 0.72 \text{ V}$ versus
RHE) for electrocatalytic ORR. The ORR Tafel slop (5) LEM image, (a) scanning FEM and contesponancy elementar

and 5F-CoP/CNT. (f) XPS spectrum of 0 1s for NO₂-CoP/CNT.

flan the unmodified CNTs $(E_{1/2} = 0.72 \text{ V}$ versus

RHE) for electrocatalytic ORR. The ORR Tafel s than the unmodified CNTs $(E_{12} = 0.72 \text{ V}$ versus RHE) for electrocatalytic ORR. The ORR Tafel slope
of NO₂-CoP/CNT (31 mV·dec⁻¹) was smaller than that
of SF-CoP/CNT (31 mV·dec⁻¹) (Figure 3c). Tafel
slopes of CNT a than the unmodified CNTs $(E_{12} = 0.72 \text{ V}$ versus

RHE) for electrocatalytic ORR. The ORR Tafel slope

of NO₂-CoP/CNT (31 mV·dec⁻¹) was smaller than that

of 5F-CoP/CNT (44 mV·dec⁻¹) (Figure 3c). Tafel

slopes of C an the unmodified CNTs $(E_{12} = 0.72 \text{ V}$ versus
HE) for electrocatalytic ORR. The ORR Tafel slope
NO₂-CoP/CNT (31 mV·dec⁻¹) was smaller than that
5F-CoP/CNT (44 mV·dec⁻¹) (Figure 3c). Tafel
ppes of CNT and Pt/C wer than the unmodified CNTs $(E_{12} = 0.72 \text{ V}$ versus

RHE) for electrocatalytic ORR. The ORR Tafel slope

of NO₂-CoP/CNT (31 mV·dec⁻¹) was smaller than that

of SF-CoP/CNT (44 mV·dec⁻¹) (Figure 3c). Tafel

slopes of C RHE) for electrocatalytic ORR. The ORR Tafel slope
of NO₂-CoP/CNT (31 mV·dec⁻¹) was smaller than that
of 5F-CoP/CNT (44 mV·dec⁻¹) (Figure 3c). Tafel
slopes of CNT and Pt/C were 55 and 70 mV·dec⁻¹,
respectively.
In of NO₂-CoP/CNT (31 mV · dec⁻¹) was smaller than that
of 5F-CoP/CNT (44 mV · dec⁻¹) (Figure 3c). Tafel
slopes of CNT and Pt/C were 55 and 70 mV · dec⁻¹,
respectively.
In addition, the number (*n*) of electrons tran of SF-CoP/CNT (44 mV \cdot dec⁻¹) (Figure 3c). Tafel
slopes of CNT and Pt/C were 55 and 70 mV \cdot dec⁻¹,
respectively.
In addition, the number (*n*) of electrons transferred
for ORR was determined with the RRDE measur

For the contact angle of 8.6° (Figure 51). The contact angles of CNTs and differently discrete also ensured the contact angle of 11.4° (Figure 51). The contrast, $5F$ -CoP/CNT (c) and NO₂-CoP/CNT (f). (color on lin **Formally contained.** The Condomination of the CNTs and CNTs were stay.

The CNTs were also means the CNTs were hy-

The CNTs were also means of $5F$ -CoP/CNT (b) and NO₂-CoP/CNT (f) (color on line)

EXV curves, (c) Tafe denoted by the contact angle of 111.4° (Figure 313). The contact angles of RF-CoP/CNT shares with a large contact angle of 11.4° (Figure 513). The contact angles of SF-CoP/CNT (s) and molecule/CNT (s) and $\frac{100}{2}$ (Fig E
 $\frac{1}{2}$
 $\frac{1}{2}$
 $\frac{1}{2}$
 $\frac{1}{2}$
 $\frac{1}{2}$

LSV curves, (c) Tafel plots, and (d) *n* values of 5F-CoP/CNT,

1 mol-L⁴ KOH. Conditions: RRDE, 5 mV·s⁻¹, and 1600 r-min⁻¹.

alues of 5F-CoP/CNT (e) and NO₂ 5F-CoP/CNT is a mand on the CNTs and 136.6°, re-
The COP/CNT, 1 mol -L⁴ KOH. Conditions: RRDE, 5 mV·s⁻¹, and 1600 r-min⁻¹.
In alues of SF-CoP/CNT (e) and NO_C-CoP/CNT (f), (color on line)
featuring a small contact

bind with an O_2 molecule to afford $Co^{\mathbb{II}}-O_2$. Herein, $Co^{\mathbb{I}}(1.251 \text{ Å})$ is larger than that of 5F-CoP (1.248 Å), **Figure 4** LV-vis spectra of μ O μ 500 μ 500 μ 500 μ Wavelength/mm
 Figure 4 LV-vis spectra of (a) NO₂-CoP and (b) 51-CoP measured under N₃ and O₂ (color on line)

spectrively (Figure 5c and 5d). The **Example 19.** Wavelength/mm
 Example 19.1 Wavelength/mm
 Example 19.6 Wavelength/mm
 Example 19.6 Specified of 19.10-CoP and (b) SF-CoP measured under N- and O- (color on line)

specificity (Figure 5 c and 5d). Thes **Figure 4** LV-vis spectra of (a) NO₁-CoP and (b) S1-CoP measured under N₃ and O₂ (color on line)
spectively (Figure 5c and 5d). These results showed the UV-vis measurements of NO₂-CoP and SF-CoP.
that alter hoding space of the figure of the finding of the measure of the UV-vis measurements of NO-CoP and SF-CoP.
spectively (Figure 5c and 5d). These results showed the UV-vis measurements of NO-CoP and SF-CoP.
that after loading on CN

Example 19
 Example 1
 Example 10 700

400 500 600 700

Wavelength/mm

CoP measured under N₃ and O₂, (color on line)

showed the UV-vis measurements of NO₂-CoP and 5F-CoP.

CoP/CNT In addition, the spin density distributions of Co^m-O₂⁻

are an **EXECUTE:**
 EXECUTE: $\frac{1}{2}$ **EXECUTE:** $\frac{1}{2}$ **Example 19**
 Example 10 association Example 10 association Example 10 Example 1 length in the $Co^{III}-O_2$ ^{*} form of NO₂-CoP is 1.86 Å, $\frac{-5F-C0P \text{ under } N_2}{-5F-C0P \text{ under } O_2}$
 $\frac{526 \text{ mm}}{+5F-C0P \text{ for } O_2-C0P \text{ and } 5F-C0P \text{ for } O_2-C0P \text{ for } O_2-C$ $\frac{-5F-CoP \text{ under } N_2}{-5F-CoP \text{ under } O_2}$
 $\frac{526 \text{ mm}}{326 \text{ mm}}$

A00 500 600 700

Wavelength/mm

mder N₂ and O₂. (color on line)

the UV-vis measurements of NO₂-CoP and 5F-CoP.

In addition, the spin density distribution F-CoP under N₃

S26 nm

S26 nm

S26 nm

Wavelength/nm

Inder N₃ and O₂. (color on line)

UV-vis measurements of NO₂-CoP and SF-CoP.

In addition, the spin density distributions of Co^{III}-O₂⁻

are analysed (Fi er, the O-O bond length in the Co^{III} -O₂ form of NO₂-For CoP mate N₃
 $\frac{500}{360}$ (600 $\frac{600}{700}$ $\frac{700}{700}$

Wavelength/mm

ander N₂ and O₂ (color on line)

the UV-vis measurements of NO₂-CoP and 5F-CoP.

In addition, the spin density distributions of Co^m **Example 10** $\frac{500}{130}$ $\frac{600}{130}$ $\frac{600}{700}$ $\frac{700}{700}$

Wavelength/mm

the UV-vis measurements of NO₂-CoP and 5F-CoP.

In addition, the spin density distributions of Co^m-O₂⁻

are analysed (Figure 6b

 Co^{III} -O₂⁻ formed with NO₂-CoP (b) and 5F-CoP (c) fro

 $# \&L \# (J. Electrochem.) 2022, 28(9), 2214002 (8 of 11)$ with fine-tuned electronic structures, NO₂-CoP outper-

formes over 5F-CoP for O₂ activation, which is consis

tent with the experimental results.

(2): 130-137.

(6) Wang D

4 Conclusions

**EVACONTIFY ALTERT (EXECT AND AND AND ALTERT ACT AND ALTERT AND ASSEMBLATED AND ALTERT AND ALTERT AND ALTERT AND ALTERT AND AND ALTERT (2) i.130-137.

In the Aperimental results and their electrocatalysts in fiel cell[J] FEATURE THE EXAMON CONDUMBERT AND THE EXAMON CONDUCT AT UNITELY (***B. Bestimal ORR Linity***). The electronic structure and the electronic structure and the electronic structure and the electronic structure and the electro EVAPUAL Enterochem.** 2022, 28(9), 2214002 (8 of 11)

With fine-tuned electronic structures, NO₂-CoP outper-

search progress for non-Pressed oxygen reduction reac-

formes over SF-CoP for O₂ activation, which is cons tte ft² (*L Flectrochem.*) 2022, 28(9), 2214002 (8 of 11)

with fine-tuned electronic structures, NO_P-CoP outper-

search progress for non-P-based oxygen reduction reac-

formes over 5F-CoP for O₂ activation, wh 4 (E≠CoP. Intertunce and SECOP is more than the NO-CoP exhibited an E₁₂

Sigman (SECOP) is more different and the NO2-CoP external and the NO2-CoP exhibited and the NO2-CoP exhibited and the NO2-CoP exhibited and the **EVALUATION CONTINUATION**

With fine-tuned electronic structures, NO_T-CoP outper-

search propers for non-Pt-based oxygen reduction reac-

formes over SF-CoP for O₂ activation, which is consis

(2): 130-137.

(2): 130 molecular m **EXECT THE THE SECT AS EXECT AND THE SECT AND THE SECTION THEORE** $\frac{\text{right}}{12}$ **Example 1998**

State of the control of the control of the control of the control of the controllation of the controllation of the superage superator of the superator of the superator of the superator of the 6 (*k* \mathcal{L} *k*). *Electrochem*, 2022, 28(9), 2214002 (8 of 11)

with fine-tuned electronic structures, NO--CoP outper-

formes over 5F-CoP for O₂ activation, which is consis

to electrocatallysts in fuel cell[*I*]. with fine-tuned electronic strategy to the strategy to the strategy to the properties of the strength particles.

Forms over SF-CoP for O₁ activation, which is consis

for the decrectarly strategies from P-blased oxyge with fine-tuned electronic structures, NO_FCoP outper-

forms over 58-CoP for 0, activation, which is consis

tent with the experimental results.

(2): 100-137.

tent with the experimental results.

(3) Wang D, Pan XN, Y formes over 5F-CoP for O₃ activation, which is consis

tion electrocatalysts in fiel cell[J]. Electrochem,

tent with the experimental results.

In summary, we reported on two Co porphyrins,

If Wang D, Am M Z. Transiti **CONCINSIONS**

In summary, we reported on two Co porphyrins, Z_{map} Z_1 and W_2 . Transition metal and utrogen Co-

In summary, we reported on two Co porphyrins,
 Z_{map} Q_1 Q_2 and W_3 correspondents with In summary, we reported on two Co porphyrins,
 μ and σ and σ and their electrocatalytic ORR

Nopel carbon-based electrocatalyts for the oxygen reduc-

NoPel and the relectron structure and the signal of preservat NO_T-CoP and SF-CoP, and their electrocating
the charge technomic cector-content and sign of precumenness concernent and
frequencies the medicinal stretuture and sign of precumenness concernent and sign of precumenness a features. By fine-tuning the electronic structure and

sign of precursors and structures)[1], ChemSueChem, 2021,

hydrophilic feature, the NO-CoP displayed signifie-

TFI 24h0 T. Leo E G, Wang X, Ge J 1, Liu C P, Xing W. hydrophilic feature, the NO₂-CoP displayed signific-

2021030329 and GKP activity compared with the $\frac{|7|2\ln\alpha|}{\alpha}$ is 16, Wang X, Ge J J, Liu C P, Xing W. Chal-

2122 are coP. Importantly, the NO₂-COP chalibited an ratly imporved ORR activity compared with the $^{[7]}$ Chao T, Lao E G, Wung X, Ge J J, Lai C P, Xing W, Chal-

SF-CoP, Importantly, the NO₁-CoP exhibited on E_{10} ward ORRJ J. Electrochem, 2020, 26(1): 84-95,

varia OR SF-CoP. Importantly, the NO_r-CoP exhibited an E_{12} lengts in the activity and stability of P-based catalysts to-
value of 0.82 V (versus RHF), making it one of the ward ORR/L) Lietercohem, 2020, 26(1): A4-95.

must A value of 0.82 V (versus RHE), making it one of the

walue of 0.82 V (versus RHE), making it one of the

its Yamar A, Zhang V, Jina V, San X M, Redax chem-

itserves are chief in the control and theoretical lyst of N-Fe⁻

Acknowledgements:

studies suggested that NO_r-CoP is more efficient than

1911 Polucarum S, Lee Y M, Nam W. Recent progress in pro-

25F-CoP to bind vith O₂. Therefore, this work pro-

videos a strategy to use substituents to fine-tune t CoP to bind with O. Therefore, this work production and stage of hydrogen peroxide[J], Chin J Catal,

Sa strategy to use substitutents to fine-tune the 2021, 42(§): 1241-1252.

as strategy to use substitutents to fine-tun cell of the Central Universities (R_s and America, and weak to the state of mole and by the properties are stated by the state of mole and hydrophilic feature of molecular chem. Interpret and hydrophilic feature of molec So a strategy to two substruction of me-tune the

2021, 40(33): 1783-217872.

2021, 60(33): 1783-217852.

2021, 60(33): 17832-17852.

2021, 60(33): 1783-217852.

2020, 60(5): 11). 1983 B(1). Nat. Rev., Chem, 2021, 60(33): electron estructure and nydrophile teature of molecal

elarconalisysts for improved ORR.

durant of Subara Contentingly, Nat Rev. Chem, 2017, (102) 098.

Acknowledgements:

Authors are grateful for supports from National [centalysts for improved ORR.

care cartootic plane and vection [J]. Nat Rev. Chem., 2017, [(12): 0098.

namely degree from Stational vections of China (22178213,

during a Markov between reaction by about provide the stat **III** Dress ML, Wiese CF, Martin D, J, Niet Lectrocation and societies:

Authors are graded for supports from National

UII Dress ML, Wiese CF, Martin D1, Mayer JM. Oxygen to-

analysed JL, Chem. Rev., 2018, 118(s): 240-2 Authors are grateful for supports from National

und Science Foundation of China (22178213,

und Sosicion by homogeneous molecular

ural Science Foundation of China (22178213,

catalysts[J]. Chem. Rev., 2018, 118

earch F Natural Science Foundation of China (22178213,

2018/03030, Futalmout of the Hamal Solence Content and the content and the Central Universities (CK

21773146, 2211/176, and 202003030, Fundamental direction

20200309 and G 73146, 22171176, and 22003036), Fundamental $[12]$ Tamg W, Lui W, Z, Cao R. Energy-related small tracks for the Central Universities (GK

activation reactions: Oxygen reduction and by

103029 and GK202103045), Key Researc

References:

-
-
-
-
-

9), 2214002 (8 of 11)
search progress for non-Pt-based oxygen reduction reac-
tion electrocatalysts in fuel cell[J]. J. Electrochem., 2015, 21
(2): 130-137.
Wang D, Pan X N, Yang P X, Li R P, Xu H, Li Y, Meng F,
Zhang J Q, 电化学(*J. Electrochem.*) 2022, 28(9), 2214002 (8 of 11)

ures, NO₂-CoP outper-

search progress for non-Pt-based oxygen reduction reac-

vation, which is consis

tion electrocatalysts in fuel cell[J]. J. Electrochem., 20

- then the tuned electronic structures, NO₂-CoP outper-

with fine-tuned electronic structures, NO₂-CoP outper-

formes over 5F-CoP for O₂ activation, which is consis

tent with the experimental results.

(2): 130-13 $#E#(J. Electrochem.)$

With fine-tuned electronic structures, NO₂-CoP outper-

formes over SF-CoP for O₂ activation, which is consis

tent with the experimental results.

tent with the experimental results.

(2): 130-137.

(In summary, we reported on two Co porphyrins, (2) 2002 (8 of 11)
search progress for non-Pt-based oxygen reduction reac-
tion electrocatalysts in fuel cell[J]. J. Electrochem., 2015, 21
(2): 130-137.
Wang D, Pan X N, Yang P X, Li R P, Xu H, Li Y, Meng F,
Zhang J Q, An (2)), 2214002 (8 of 11)

search progress for non-Pt-based oxygen reduction reac-

tion electrocatalysts in fuel cell[J]. J. Electrochem., 2015, 21

(2): 130-137.

Wang D, Pan X N, Yang P X, Li R P, Xu H, Li Y, Meng F,

Zha 28(9), 2214002 (8 of 11)
search progress for non-Pt-based oxygen reduction reac-
tion electrocatalysts in fuel cell[J]. J. Electrochem., 2015, 21
(2): 130-137.
[6] Wang D, Pan X N, Yang P X, Li R P, Xu H, Li Y, Meng F,
Zha (a) 2214002 (8 of 11)

Search progress for non-Pt-based oxygen reduction reac-

tion electrocatalysts in fuel cell[J]. J. Electrochem., 2015, 21

(2): 130-137.

Wang D, Pan X N, Yang P X, Li R P, Xu H, Li Y, Meng F,

Zhang 9), 2214002 (8 of 11)
search progress for non-Pt-based oxygen reduction reac-
tion electrocatalysts in fuel cell[J]. J. Electrochem., 2015, 21
(2): 130-137.
Wang D, Pan X N, Yang P X, Li R P, Xu H, Li Y, Meng F,
Zhang J Q, 9), 2214002 (8 of 11)
search progress for non-Pt-based oxygen reduction reac-
tion electrocatalysts in fuel cell[J]. J. Electrochem., 2015, 21
(2): 130-137.
Wang D, Pan X N, Yang P X, Li R P, Xu H, Li Y, Meng F,
Zhang J Q, 9), 2214002 (8 of 11)
search progress for non-Pt-based oxygen reduction reac-
tion electrocatalysts in fiel cell[J]. J. Electrochem, 2015, 21
(2): 130-137.
Wang D, Pan X N, Yang P X, Li R P, Xu H, Li Y, Meng F,
Zhang J Q, 9), 2214002 (8 of 11)

search progress for non-Pt-based oxygen reduction reac-

tion electrocatalysts in fuel cell[J]. J. Electrochem., 2015, 21

(2): 130-137.

Wang D, Pan X N, Yang P X, Li R P, Xu H, Li Y, Meng F,

Zhang 28(9), 2214002 (8 of 11)
search progress for non-Pt-based oxygen reduction reac-
tion electrocatalysts in fitel cell[J]. J. Electrochem, 2015, 21
(2): 130-137.
[6] Wang D, Pan X N, Yang P X, Li R P, Xu H, Li Y, Meng F,
Zha (a), 2214002 (8 of 11)

search progress for non-Pt-based oxygen reduction reaction electrocatalysts in fiel cell[J]. J. Electrochem, 2015, 21

(2): 130-137.

Wang D, Pan X N, Yang P X, Li R P, Xu H, Li Y, Meng F, Zhang J 9), 2214002 (8 of 11)
search progress for non-Pt-based oxygen reduction reac-
tion electrocatalysts in fuel cell[J]. J. Electrochem., 2015, 21
(2): 130-137.
Wang D, Pan X N, Yang P X, Li R P, Xu H, Li Y, Meng F,
Zhang J Q, 28(9), 2214002 (8 of 11)
search progress for non-Pt-based oxygen reduction reac-
tion electrocatalysts in fuel cell[J]. J. Electrochem., 2015, 21
(2): 130-137.
[6] Wang D, Pan X N, Yang P X, Li R P, Xu H, Li Y, Meng F,
Zh (a), 2214002 (8 of 11)
search progress for non-Pt-based oxygen reduction reac-
tion electrocatalysts in fuel cell[J]. J. Electrochem., 2015, 21
(2): 130-137.
Wang D, Pan X N, Yang P X, Li R P, Xu H, Li Y, Meng F,
Zhang J (2), 2214002 (8 of 11)

search progress for non-Pt-based oxygen reduction reac-

tion electrocatalysts in fuel cell[J]. J. Electrochem., 2015, 21

(2): 130-137.

Wang D, Pan X N, Yang P X, Li R P, Xu H, Li Y, Meng F,

Wang 28(9), 2214002 (8 of 11)

search progress for non-Pt-based oxygen reduction reac-

tion electroceatalysts in fuel cell[J]. J. Electrochem., 2015, 21

(2): 130-137.

[6] Wang D, Pan X N, Yang P X, Li R P, Xu H, Li Y, Meng 9), 2214002 (8 of 11)

search progress for non-Pt-based oxygen reduction reac-

tion electrocatalysts in fuel cell[J]. J. Electrochem., 2015, 21

(2): 130-137.

Wang D, Pan X N, Yang P X, Li R P, Xu H, Li Y, Meng F,

Zhang 7), 2214002 (8 01 11)

search progress for non-Pt-based oxygen reduction reac-

tion electrocatalysts in fuel cell[J]. J. Electrochem., 2015, 21

(2): 130-137.

Wang D, Pan X N, Yang P X, Li R P, Xu H, Li Y, Meng F,

Zhang search progress for non-Pt-based oxygen reduction reac-
tion electrocatalysts in fuel cell[J]. J. Electrochem., 2015, 21
(2): 130-137.
[6] Wang D, Pan X N, Yang P X, Li R P, Xu H, Li Y, Meng F,
Zhang J Q, An M Z. Transitio ion electrocatalysts in fitel cell[J]. J. Electrochem, 2015, 21
2): 130-137.
2): 130-137.
2): 130-137.
Vang D, Pan X N, Yang P X, Li R P, Xu H, Li Y, Meng F, Ahang J Q, An M Z. Transition metal and nitrogen Co-
ohoped carb 2): 130-137.

Wang D, Pan X N, Yang P X, Li R P, Xu H, Li Y, Meng F, Ahang J Q, An M Z. Transition metal and nitrogen Co-

hang J Q, An M Z. Transition metal and nitrogen Co-

oloped carbon-based electrocatalysts for the o [6] Wang D, Pan X N, Yang P X, Li R P, Xu H, Li Y, Meng F, Zhang J Q, An M Z. Transition metal and nitrogen Co-
doped carbon-based electrocatalysts for the oxygen reduc-
tion reaction: From active site insights to the rat The magnetic metallical manual and mirrogeneous more conceptor and mitrogen Co-
oped carbon-based electrocatalysts for the oxygen reduc-
ion reaction: From active site insights to the rational de-
ign of precursors and st ioned carbon-based electrocatalysts for the oxygen reduction reaction: From active site insights to the rational de-
ign of precursors and structures[J]. Chem.SusChem, 2021,
4(1): 33-55.
hao T, Luo E G, Wang X, Ge J J, Liu
	-
	-
	-
	-
	-
	- 101 Dev S, Mondal B, Charlie S, Rana A, Amanullah S K, Dey A. Molecules of Precursors and structures [J]. ChemSusChem, 2021, 14(1): 33-55.

	(7) Zhao T, Luo E G, Wang X, Ge J J, Liu C P, Xing W. Challenges in the activity a ign of precursors and structures[J]. ChemSusChem, 2021,
4(1): 33-55.
4(1): 33-55.
hao T, Luo E G, Wang X, Ge J J, Liu C P, Xing W. Chal-
enges in the activity and stability of Pt-based catalysts to-
vard ORR[J]. J. Electro 4(1): 33-55.

	Ano T, Luo E G, Wang X, Ge J J, Liu C P, Xing W. Chal-

	4(1): 33-55.

	hao T, Luo E G, Wang X, Ge J J, Liu C P, Xing W. Chal-

	enges in the activity and stability of Pt-based catalysts to-

	vard ORR[J]. J. Ele Ano T, Luo E G, Wang X, Ge J J, Liu C P, Xing W. Chal-
enges in the activity and stability of Pt-based catalysts to-
enges in the activity and stability of Pt-based catalysts to-
enges in the activity and Stability of Pt-b 3797. ward ORR[J], J. Electrochem., 2020, 26(1): 84-95.

	[8] Kumar A, Zhang Y, Jia Y, Liu W, Sun X M. Redox chem-

	isty of N_e-Fe³⁺ in iron phthalocyanines for oxygen reduc-

	tion reaction[J]. Chin. J. Catal., 2021, 42(8): 14 Limar A, Zhang Y, Jia Y, Liu W, Sun X M. Redox chem-
stry of N_r-Fe²⁺ in iron phthalocyanines for oxygen reduc-
ion reaction[J]. Chin. J. Catal., 2021, 42(8): 1404-1412.
ukuzumi S, Lee Y M, Nam W. Recent progress in pro stry of N_rFe²¹ in iron phthalocyanines for oxygen reduction reaction[J]. Chin. J. Catal., 2021, 42(8): 1404-1412.

	ukuzumi S, Lee Y M, Nam W. Recent progress in pro-

	uction and usage of hydrogen peroxide[J]. Chin. J 10 Fraction (J. Chin. J. Catal., 2021, 42(8): 1404-1412.

	[9] Fukuzumi S, Lee Y M, Nam W. Recent progress in production and usage of hydrogen peroxide[J]. Chin. J Catal.,

	2021, 42(8): 1241-1252.

	[10] Dey S, Mondal B, Cha interius S, Lee Y M, Nam W. Recent progress in pro-
uction and usage of hydrogen peroxide[J]. Chin. J Catal.,
021, 42(8): 1241-1252.
Dey S, Mondal B, Chatterjee S, Rana A, Amanullah S K,
Dey A. Molecular electrocatalysts f uction and usage of hydrogen peroxide[J]. Chin. J Catal.,
021, 42(8): 1241-1252.
Dey S, Mondal B, Chatterjee S, Rana A, Amanullah S K,
Dey A. Molecular electrocatalysts for the oxygen reduction
reaction[J]. Nat. Rev. Chem. 021, 42(8): 1241-1252.

	Dey S, Mondal B, Chatterjee S, Rana A, Amanullah S K,

	Dey A. Molecular electrocatalysts for the oxygen reduc-

	tion reaction[J]. Nat. Rev. Chem., 2017, 1(12): 0098.

	Pegis M L, Wise C F, Martin D J [10] Dey S, Mondal B, Chatterjee S, Rana A, Amanullah S K,
Dey A. Molecular electrocatalysts for the oxygen reduc-
tion reaction[J]. Nat. Rev. Chem., 2017, 1(12): 0098.
[11] Pegis M L, Wise C F, Martin D J, Mayer J M. Oxyg Dey A. Molecular electrocatalysts for the oxygen reduction reaction[J]. Nat. Rev. Chem., 2017, 1(12): 0098.
Pegis M L, Wise C F, Martin D J, Mayer J M. Oxygen reduction by homogeneous molecular catalysts and electrocatalys ion reaction[J]. Nat. Rev. Chem., 2017, 1(12): 0098.
Pegis M L, Wise C F, Martin D J, Mayer J M. Oxygen re-
duction by homogeneous molecular catalysts and electro-
catalysts[J]. Chem. Rev., 2018, 118(5): 2340-2391.
Zhang W
	-
	-
	-
- Chem. Tanna 19 Chem. Early Chem. The Section and Development Program of Shanaxi, (2022GY-196), and

Complete Shanaxi, (2022GY-196), and

Complete Shanaxi, (2022GY-196), and

corrols-based systems[J], Chem. Rev., 2017, 117 20.100027 and OK. Lin J N, Win Syle November 1100 (1000267), And Convertise Properties in the rational correlation and the rational CO22007 (196), and Convertise Properties in the rational CO22007-196), and Convertise Pro Experiment Program or Shanamix (1022-1743), and

ing Talent final of University Association for Science 3797.

and Technology in Shanawi, China (20200602).

[13] Passend Q, Doguin D K, Qui M, T, Costemin clusters towards Ing Talent fund of University Association for Science and Technology in Shaanxi, China (20200602).

IT Passad G, Doguran D K, Qiu M T, Costensin C, Nocera

In G. Oxygen reduction reaction promoted by manguese

EFFENCES:

2 ence and Technology in Shaanxi, China (20200602).
 Exerces:
 Exerces and Technology in Shaanxi 1. This and S. Huangel H. You B, Xia B Y.

[14] Zhuo Y M, Yu G Q, Wung F F, Wei 9.1, Liu J G, Bioin-

[17] Zhuo Y M, Yu G [11] Pegis M L, Wise C F, Martin D J, Mayer J M. Oxygen reduction by homogeneous molecular catalysts and electrocatalysts [J]. Chem. Rev., 2018, 118(5): 2340-2391.

[12] Zhang W, Lai W Z, Cao R. Energy-related small molec duction by homogeneous molecular catalysts and electro-
catalysts[J]. Chem. Rev., 2018, 118(5): 2340-2391.
Zhang W, Lai W Z, Cao R. Energy-related small molecule
activation reactions: Oxygen reduction and hydrogen and
oxyg calytical Comparison and May 2013. The metric or in the BC is calculysts[J]. Chem. Rev., 2018, 118(5): 2340-2391.

Zhang W, Lai W Z, Cao R. Energy-related small molecule

activation reactions: Oxygen reduction and hydrogen Zhang W, Lai W Z, Cao R. Energy-related small molecule
activation reactions: Oxygen reduction and hydrogen and
oxygen evolution reactions catalyzed by porphyrin- and
corrole-based systems[J]. Chem. Rev., 2017, 117(4): 3717 activation reactions: Oxygen reduction and hydrogen and
extration reactions: Oxygen reduction and hydrogen and
express evolution reactions catalyzed by porphyrin- and
ecrrole-based systems[J]. Chem. Rev., 2017, 117(4): 371 example of the method of the method of the polynomic Correl changed CI Chan Rev., 2017, 117(4): 3717-

1797.

1797.

1797.

113] Passard G, Dogutan D K, Qiu M T, Costentin C, Nocera

D G. Oxygen reduction reaction promoted corrole-based systems[J]. Chem. Rev., 2017, 117(4): 3717-3797.

Passard G, Dogutan D K, Qiu M T, Costentin C, Nocera

D G. Oxygen reduction reaction promoted by manganese

porphyrins[J]. ACS Catal., 2018, 8(9): 8671-8679.
 3797.

Passard G, Dogutan D K, Qiu M T, Costentin C, Nocera

D G. Oxygen reduction reaction promoted by manganese

porphyrins[J]. ACS Catal., 2018, 8(9): 8671-8679.

Zhao Y M, Yu G Q, Wang F F, Wei P J, Liu J G. Bioin-

sp Passard G, Dogutan D K, Qiu M T, Costentin C, Nocera

D G. Oxygen reduction reaction promoted by manganese

porphyrins[J]. ACS Catal., 2018, 8(9): 8671-8679.

Zhao Y M, Yu G Q, Wang F F, Wei P J, Liu J G. Bioin-

spired tr D G. Oxygen reduction reaction promoted by manganese
porphyrins[J]. ACS Catal., 2018, 8(9): 8671-8679.
[14] Zhao Y M, Yu G Q, Wang F F, Wei P J, Liu J G. Bioin-
spired transition-metal complexes as electrocatalysts for
the
	-
	-

the (*J. Electrochem.*) 2022, 28(9), 2214002 (9 of 11)

Jin X T, Zhang Q X, Zhang W, Long R, Xiong Y J, Apfel

U P, Cao R. Controlling oxygen reduction selectivity

flamg Z Z, Zhang W, Cao R. Significantly boosted oxy-

g $# \{\& \#(J. \: \text{Electrochem.}) \: 2022, 28(9), 2214002 (9 of 11)$

U P, Cao R. Controlling oxygen reduction selectivity

U P, Cao R. Controlling oxygen reduction selectivity

through steric effects: Electrocatalytic two-electron and

f then the Henry Conservation steric effects: Electrochem. 19022, 28(9), 2214002 (9 of 11)

Un X T, Zhang Q X, Zhang W, Long R, Xiong Y J, Apfel

UP, Cao R. Controlling oxygen reduction selectivity

teric effects: Electroca $\frac{f_0(E)^\omega}{\omega}$
 four-electron or superiorm (10.2022, 28(9), 2214002 (9 of 11)

 Four-electron or superiorm (10.2022, 28(9), 2214002 (9 of 11)

 Four-electron cobalt and triang Z Z, Zhang W, Cao R. Significantly the *C*²² (*L Electrochem.*) 2022, 28(9), 2214002 (9 of 11)

Jin X T, Zhang Q X, Zhang W, Long R, Xiong Y J, Apfel

U P, Cao R. Controlling oxygen reduction selectivity

the content of through steric effects: Electro 12746. [19] Hong Y H, Han J W, Jung J, Nakagawa T, Lee Y M, Nam $\frac{\text{d}E}{\text{d}E}$ (*Kleetrochem.*) 2022, 28(9), 2214002 (9 of 11)

Jin X T, Zhang Q X, Zhang W, Xiong Y J, Apfel

U P, Cao R. Controlling oxygen reduction selective is the controlling to the controlling oxygen reduction With a cobalt porphyrin complex using water as an oxy-

With X , The Cobalt porphyrin complement of the studying With complement of the studying water of the studying water reflects: Pleterocatalytic two-electron and
 He (E²² (*L Electrochem*,) 2022, 28(9), 2214002 (9 of 11)

Jin X T, Zhang V, Xhang W, Long R, Xiong Y J, Apfel

U P, Cao R. Controlling oxygen reduction selectivity

through sierie effective are detrocontally is two-el $\label{eq:21} \frac{\text{tR} \# (J. Electrochen.) 2022, 28(9), 2214002 (9 of 11)}{\text{Bin X T, Zhang Q X, Zhang W, Long R, Xiong Y J, Apfel} \quad\text{Liang Z Z, Zhang W, Cao R. Significantly U P, Gao R. Controlling oxygen reduction selectivity from the image of the image.}$

Sour-electron oxygen reduction electrivity gene electrocatalysis with cooperation between

through [20] Li X L, Lei H T, Xie L S, Wang N, Zhang W, Cao R. **HETALLOPORTIVAL EXAMPLE 1902**, 28(9), 2214002 (9 of 11)

The XT, Zhang Q X, Zhang W, Long L X, Zhang V, Long L X, Zhang W, Gook Significantly boostd oxy-

U.P., Cao R. Controlling oxygen reduction selectivity

durage as $\frac{\ln(R\ H_L\ (L\ Heronechem, 2022, 28(9), 2214002 (9 of 11))}{\ln X T, Zhung Q X, Zhung W, Long R, Xiong Y 1, Apfel
Unwayk series (Electrocullyite) coverage reduction selection and
through stere effects. Electrocultyite (we-electron and
through stere effects). Electrocultyite (we-electron and
through stere effects). Electrocultyite (we-electron and
proportingly. Augew. Chen, Int. Ed., 2021, 60(25) 12742-
topionscept [J, Augew. Chen, Int. Ed., 2021, 60(25) 12742-
12$ $\begin{align*} \end{align*} \begin{tabular}{ll} \text{H$_2$} & \text$ [21] Zhang R, Warren J J. Recent developments in metallopo- $\frac{4E}{2746}$ Fig. 2. Electrochem.) 2022, 28(9), 2214002 (9 of 11)

1) m X T, Zhang Q X, Zhang W, Long R, Xiong Y J, Apfel

11. ang Z Z, Zhang W, Cao R. Significantly hoosted ory

10. P, Cao R. Controlling corporation sel Jin X T, Zhang Q X, Zhang W, Long R, Xiong Y J, Apfel

U P, Cao R. Controlling exygen reduction selectrivity

through strategies first effects Electron and ion poplyinis dagget[1]. Dalton Trans., 2021, 50(15):

futurells Jin X T, Zhung Q X, Zhung W, Long R, Xiong Y J, Apfel Laing Z Z, Zhung W, Cao R. Significantly boosted oxy-

U P, Cao R. Controlling oxygen reduction selective and through starting towers erobat and through starting to

t

- 12746.

12746. In J. Cao R. Significandy improved ebettocatalytic

1919 Hengy YH, Hand W, Hinley, Nokagawa T, Lee Y M, Nam

1679 Forekazimi of condital particular parametimical parametimical particular parametimical param
-
-
- 1331.
-
- with a cobalt porphyrin complex using water as an oxy-

gas so coidar as on coidar as an oxidad Soc, 2019, 141(23): 9155-9159.

Soc, 2019, 141(23): 9155-9159.

2012 Li Li T, Xie Li B, Wing W, Xie angly (200 R. Lei B T, Xi Li X L, Lei H T, Xie L S, Wang N, Zhang W, Cao R. catalysis[J]. J. Am. Chem.

Metalloporphyrins as catalyis models for studying hy-

drogen and oxygen evolution and oxygen reduction reac-

from Eng. 2022, 55(6): 878-892.
 drogen and oxygen evolution and oxygen reduction reac-

[25] Lines 2. (256): 878-8221, 256(3): 878-822, 256(3): 878-822, 256(3): 878-822, 250, 26(4): 2524-3234, 1

[25] Lines *Z*, Conce H B, Zhou G J, Guo K, Wang B, Lei H
 phyrin electrocatalysts for reduction of small molecules: T, Zhang W, Zheng H Q, Apfel U P, Cao R.
Strategies for managing electron and proton transfer reac-

Strategies for managing electron and proton transfer reac-

for Strutegies for managing electron and proton transfer reac-

ganic-framework-supported molecular electrocatalysis

1261) (Amela D, Schu, P. (Nov. 2013, 402, 100) (1) 203-302.

126, 000158, 8472.8476.

126, 000158, 8472.847 of oxygen by iron porphyrin enabled with 2nd sphere re-

and Crawky M R, Zhang D Y, Oldacee A N, Beavers

don sative ferrocenes[I]. Chin. J. Catal., 2021, 42(8): 1327-

1231, and Complying Distant S H, Cook T R. Tuning the don extire ferrocens(I). Chin. J. Canl. 2021, 42(2): 1327-

1331. Simulation to fail completing prison for ougher particular and the completing prison for ougher and the completing production to fail and the production of anism of catalytic oxygenation of alkanes by halogenated 1098-1106.

iron pophyrins[J]. Science, 1994, 264(5163): 131-11313.

Zagal J H, Recio F J, Gutierez C A, Zunige, P. Pacz M

A, Caro C A. Towards a unified way of com iron peoplyrins[J], Science, 1994, 2645(35): 1311-1313. [25] Wan H, Jossemas V, Escudent-Becchinon M, Rossmesis J.

[24] Zagal J H, Rocio 1/, Giudirex C A, Zaniga C, Paez M

electrocatalysts in the coupon relation reactio Zagal J H, Recio F J, Gutierrez C A, Zuniga C, Paez M

Insights in the oxygen reduction

A, Caro C A. Towards a unified way of comparing the

electrochantylic activity MN, mareorcyclic retation and tanking the

electrocha
-
-
-
-
-

(a), 2214002 (9 of 11)

Liang Z Z, Zhang W, Cao R. Significantly boosted oxy-

gen electrocatalysis with cooperation between cobalt and

iron porphyrins dagger[J]. Dalton Trans., 2021, 50(15):

5120-5123.

Liu Y J, Zhou G (exp. 2214002 (9 of 11)
Liang Z Z, Zhang W, Cao R. Significantly boosted oxy-
gen electrocatalysis with cooperation between cobalt and
iron porphyrins dagger[J]. Dalton Trans., 2021, 50(15):
5120-5123.
Liu Y J, Zhou G J, Z iang Z Z, Zhang W, Cao R. Significantly boosted oxy-

gen electrocatalysis with cooperation between cobalt and

iron porphyrins dagger[J]. Dalton Trans., 2021, 50(15):

5120-5123.

Liu Y J, Zhou G J, Zhang Z Y, Lei H T, Ya 5120-5123. 电化学(*J. Electrochem.*) 2022, 28(9), 2214002 (9 of 11)

Long R, Xiong Y J, Apfel Liang Z Z, Zhang W, Cao R. Significantly boosted oxy-

gen reduction selectivity en electrocatalysis with cooperation between cobalt and

ata

- 11 P, Can R. Controlling oxygen reduction selectivotis in gene electrocatallysis with cooperation between cochlat and
through state Helercton experiment of the prophyrin at-

in 23.26.3123.

123.46. Non-Section oxygen red through steric effects: Electrocatalytic two-electron and

four porphyrins dagger[7]. Dalton Trans., 2021, 90(15):

foreignetrical cygen reduction with coball porphyrin al-

foreignetrical particular porphyrin enables por four-electron oxygen reduction with cobalt porphyrin at-

1920-5123. [30]. Liu Y, Zhou G, Zhang Z Y, Lei H T, Yao Z, Li J F,

1920-66.

1920-66.

1920-6.

1920-6.

W, Intan Jw, Jung J, Nakagama'1, Les V M, Nam Demos

W, Fi (30), 2214002 (9 of 11)

Liang Z Z, Zhang W, Cao R. Significantly boosted oxy-

gen electrocatalysis with cooperation between cobalt and

iron porphyrins dagger[J]. Dalton Trans., 2021, 50(15):

5120-5123.

[30] Liu Y J, Z (e), 2214002 (9 of 11)

Liang Z Z, Zhang W, Cao R. Significantly boosted oxy-

gen electrocatalysis with cooperation between cobalt and

iron porphyrins dagger[J]. Dalton Trans., 2021, 50(15):

5120-5123.

Liu Y J, Zhou G oxylet 2002 (9 of 11)

Liang Z Z, Zhang W, Cao R. Significantly boosted oxy-

gen electrocatalysis with cooperation between cobalt and

iron porphyrins dagger[J]. Dalton Trans., 2021, 50(15):

5120-5123.

Liu Y J, Zhou G J (11), 2214002 (9 of 11)

Liang Z Z, Zhang W, Cao R. Significantly boosted oxy-

gen electrocatalysis with cooperation between cobalt and

iron porphyrins dagger[J]. Dalton Trans., 2021, 50(15):

5120-5123.

Liu Y J, Zhou G (exp. 214002 (9 of 11)

1. Liang Z Z, Zhang W, Cao R. Significantly boosted oxy-

gen electrocatalysis with cooperation between cobalt and

iron porphyrins dagger[J]. Dalton Trans., 2021, 50(15):

5120-5123.

Liu Y J, Zhou (329) , 2214002 (9 of 11)
Liang Z Z, Zhang W, Cao R. Significantly boosted oxy-
gen electrocatalysis with cooperation between cobalt and
iron porphyrins dagger[J]. Dalton Trans., 2021, 50(15):
5120-5123.
Lin J, Cao R. (a), 2214002 (9 of 11)

Liang Z Z, Zhang W, Cao R. Significantly boosted oxy-

gen electrocatalysis with cooperation between cobalt and

iron porphyrins dagger[J]. Dalton Trans., 2021, 50(15):

5120-5123.

Liu Y J, Zhou G (exceedingly), 2214002 (9 of 11)

Liang Z Z, Zhang W, Cao R. Significantly boosted oxy-

ear electrocatalysis with cooperation between cobalt and

earn electrocatalysis with cooperation between cobalt and

iron porphyrins (9), 2214002 (9 of 11)

Liang Z Z, Zhang W, Cao R. Significantly boosted oxy-

gen electrocatalysis with cooperation between cobalt and

iron porphyrins dagger[J]. Dalton Trans., 2021, 50(15):

5120-5123.

[30] Liu Y J, Zh porphyrin Fanalized Carbon Content Carbon Nighter State of Orientally
game electrocatalysis with cooperation between cobalt and
iron porphyrins dagger[J]. Dalton Trans., 2021, 50(15):
5120-5123.
Liu Y J, Zhou G J, Zhang Z 9), 2214002 (9 of 11)
Liang Z Z, Zhang W, Cao R. Significantly boosted oxy-
gen electrocatalysis with cooperation between cobalt and
iron porphyrins dagger[J]. Dalton Trans., 2021, 50(15):
5120-5123.
Liu Y J, Zhou G J, Zha (389) , 2214002 (9 of 11)
Liang Z Z, Zhang W, Cao R. Significantly boosted oxy-
gen electrocatalysis with cooperation between cobalt and
ion porphyrins dagger[J]. Dalton Trans., 2021, 50(15):
5120-5123.
[30] Liu Y J, Z (a), 2214002 (9 of 11)

Liang Z Z, Zhang W, Cao R. Significantly boosted oxy-

gen electrocatalysis with cooperation between cobalt and

iron porphyins dagger[J]. Dalton Trans., 2021, 50(15):

5120-5123.

Liu Y J, Zhou G J Liang Z Z, Zhang W, Cao R. Significantly boosted oxy-
gen electrocatalysis with cooperation between cobalt and
iron porphyrins dagger[J]. Dalton Trans., 2021, 50(15):
5120-5123.
17. Zhou G J, Zhang Z Y, Lei H T, Yao Z, Li Liang Z Z, Zhang W, Cao R. Significantly boosted oxy-
gen electrocatalysis with cooperation between cobalt and
iron porphyrins dagger[J]. Dalton Trans., 2021, 50(15):
5120-5123.
Liu Y J, Zhou G J, Zhang Z Y, Lei H T, Yao Z gen electrocatalysis with cooperation between cobalt and
iron porphyrins dagger[J]. Dalton Trans., 2021, 50(15):
5120-5123.
Liu Y J, Zhou G J, Zhang Z Y, Lei H T, Yao Z, Li J F,
Lin J, Cao R. Significantly improved electro ion porphyrins dagger[J]. Dalton Trans., 2021, 50(15):

5120-5123.

[30] Liu Y J, Zhou G J, Zhang Z Y, Lei H T, Yao Z, Li J F,

Lin J, Cao R. Significantly improved electrocatalytic

oxygen reduction by an asymmetrical pae 5120-5123.

Liu Y J, Zhou G J, Zhang Z Y, Lei H T, Yao Z, Li J F,

Lin J, Cao R. Significantly improved electrocatalytic

exygen reduction by an asymmetrical paeman dinuelear

cobalt[(I) porphyrin-porphyrin dyad[J]. Chem. Liu Y J, Zhou G J, Zhang Z Y, Lei H T, Yao Z, Li J F,
Lin J, Cao R. Significantly improved electrocatalytic
oxygen reduction by an asymmetrical paeman dinuclear
cobalt(II) porphyrin-porphyrin dyad[J]. Chem. Sci., 2020,
11(
	-
	-
	- Ilong Y II, Ilm J W, Jung J, Nakagawa T, Lee Y M, Nam

	(with an cohicentalytic overgenation reactions by an asymmetrical parama dinuclear

	with a colshi popphyrin complex using water as an oxy

	with a colshi popphyrin com Vi, Fukuzumi S. Photocatalytic oxygenation reactions

	with a cobalt porphyrin-porphyrin chorolly Chem. Sei, 2020,

	gen source and loosygen us an oxidant[1]. J. Am. Chem. [31] Oldare A N, Friedman A E, Cook T R. A self-asse gen source and dioxygen as a oxidant[1]. 1. Am, Chem. [31] Oldace A N, Friedman A F, Cook T R. A self-assembled

	Soc., 2017, 141(23): 9155-9159.

	Meallipopentying is eculations consisting the exaction comparisons a unalyti Soc., 2019, 141(23): 9155-9159.

	Li XL, Lei H T, Xie Ls, Wung W, Cao R.

	Li XL, Lei H T, Xie Ls, Wung N, Zhang W, Cao R.

	Cetality Schich and oxygen are reduction recessors are reduction recessors and oxygen at consider ac Lin J, Cao R. Significantly improved electrocatalytic
oxygen reduction by an asymmetrical paeman dinuclear
cobalt(II) porphyrin-porphyrin dyad[J]. Chem. Sci., 2020,
11(1): 87-96.
Oldacre A N, Friedman A E, Cook T R. A self colati(II) porphyrin-porphyrin dyad[J]. Chem. Sci., 2020,

	11(1): 87-96.

	(31) Oldacre A N, Friedman A E, Cook T R. A self-assembled

	cofacial cobalt porphyrin prism for oxygen reduction

	catalysis[J]. J. Am. Chem. Soc., 2 11(1): 87-96.

	Oldaere A N, Friedman A E, Cook T R. A self-assembled

	cofacial cobalt porphyrin prism for oxygen reduction

	catalysis[J]. J. Am. Chem. Soc., 2017, 139(4): 1424-1427.

	Zhang W, Shaikh A U, Tsui E Y, Swager T Oldacre A N, Friedman A E, Cook T R. A self-assembled
cofacial cobalt porphyrin prism for oxygen reduction
catalysis[J]. J. Am. Chem. Soc., 2017, 139(4): 1424-1427.
Zhang W, Shaikh A U, Tsui E Y, Swager T M. Cobalt
porphyr cofacial cobalt porphyrin prism for oxygen reduction
catalysis[J]. J. Am. Chem. Soc., 2017, 139(4): 1424-1427.
Zhang W, Shaikh A U, Tsui E Y, Swager T M. Cobalt
porphyrin functionalized carbon nanotubes for oxygen
reductio
		- 1098-1106.
		-
- r, Lei H T, Xie L S, Wang N, Zhang W, Gao R,

contryistin as catalyzis (J.J. Am. Chem. Soc., 2017, 139(4): 1424-1427.

and oxygen evolution and oxygen reduction reac-

and oxygen evolution and oxygen reduction reac-

po Metalloporybyins as catalytic modes for studying by-

drogen and oxygen colution and oxygen colution and oxygen colution and oxygen and oxygen of the communication and oxygen colution and oxygen colution and the communicat tions[J]. Acc. Chem. Res., 2022, 55(6): 878-892.

The properties cheopenes in metallopo-

The properties cheopenes in the state and processes of the state and the state and the properties for managing electron and proton m Y, Zhang W, Cao R. Bioinspired N₄-metallomacrocycles ferrocene-substituted cobalt porphyrins[J]. Inorg. Chem., Zhumg R, Warren J J. Recent developments in metallopo-

133) Liang Z Z, Guo II B, Zhou G J, Guo K, Weng B, Lei H

organize dectrocordalytis for reduction of small molecules:

15. Them SK Zhou II P, Coordinal Chemisforchie origit). Chemis inc. 2021, 14(1): 293-302.

Monda B. Sen P., Dey, A. Proton reduction in the possence of oxygen reduction film. And the possence of oxygen by inco prophyrin catalod with 2nd sphere rs-

of oxygen by inco pr Mondal B, Sen P, Dey A. Proton reduction in the presence

Ed. 2021, 60(15): 8472-8476.

of expgen by ion populyin enshed with 2nd sphere to-

dox active fermoence[J]. Unin. 1. Catal, 2021, 42(8): 1327-

intermal A F, Cook 1331.

teind porphyrin prisms for oxygen reduction using modu-

tion metallyite oxygenation of allanes by halogenated

intensity of the milding blocks[1]. J. Am. Chem. Soc., 2021, 143(2):

iron porphyrins JS: pore, 1994, Crimsaff M W, Hill M G, Labinger J A, Gray H H. Mech-

mais of easting the same of Schar and M, Research in the eio F J, Guiterrez C A, Zuniga C, Paez M

1. Towards a unified way of comparing the exygen reduction reaction: From rowards a unified way of comparing the sectecterial six to diporphyrins[J]. ACS Catal., 2

ic activity MN : C A, Zuniga C, Paez M

issights in the oxygen reduction reaction: From metallie

of vary of comparing the

electrocealists to diporphyrins [J]. ACS Catal., 2020, 10

sencopylic metal catalysts

(11): 5979-5989.

the rev A, Caro C. A. Towards a unified way of comparing the electrocallysts to diporphyrins [J]. ACS Catal., 2020, 10

electrocalistic activity MN, materocyclic media could substac (11). 5979-5899.

for O, reduction on the basis electrocatalytic activity MN_i macrocyclic metal catalysts (11): 5979-5989.

Cata Cata Cata Constate action on the basis of the revestible potential of E96 [Sm B, Ou 2 P, Memykin V N, Kadish K M.

Li Y L, Wang N, Lei H T, for O, eclustion on the basis of the reversible potantial of

the reaction (1961) Sun B, Ou Z P, Mengite Y V, Nearting A, 2014

129] Li Y L, Wang N, Li H T, Li X L, Zhang H O, Wang H

129] Li Y L, Wang W, Casimis Pierry M catalysis[J]. J. Am. Chem. Soc., 2017, 139(4): 1424-1427.

[32] Zhang W, Shaikh A U, Tsui E Y, Swager T M. Cobalt

reputcinof[J]. Chem. Mater., 2009, 21(14): 3234-3241.

1331 Liang Z Z, Guo H B, Zhou G J, Guo K, Wang B, Le Zhang W, Shaikh A U, Tsui E Y, Swager T M. Cobalt
porphyrin functionalized carbon nanotubes for oxygen
reduction[J]. Chem. Mater., 2009, 21(14): 3234-3241.
Liang Z Z, Guo H B, Zhou G J, Guo K, Wang B, Lei H
T, Zhang W, Zhe porphyrin functionalized carbon nanotubes for oxygen
reduction[J]. Chem. Mater., 2009, 21(14): 3234-3241.
Liang Z Z, Guo H B, Zhou G J, Guo K, Wang B, Lei H
T, Zhang W, Zheng H Q, Apfel U P, Cao R. Metal-or-
ganic-framewor reduction[J]. Chem. Mater., 2009, 21(14): 3234-3241.

Liang Z Z, Guo H B, Zhou G J, Guo K, Wang B, Lei H

T, Zhang W, Zheng H Q, Apfel U P, Cao R. Metal-or-

ganic-framework-supported molecular electrocatalysis

for the ox Liang Z Z, Guo H B, Zhou G J, Guo K, Wang B, Lei H
T, Zhang W, Zheng H Q, Apfel U P, Cao R. Metal-or-
ganic-framework-supported molecular electrocatalysis
for the oxygen reduction reaction[J]. Angew. Chem. Int.
Ed., 2021, T, Zhang W, Zheng H Q, Apfel U P, Cao R. Metal-or-
ganic-framework-supported molecular electrocatalysis
for the oxygen reduction reaction [J]. Angew. Chem. Int.
Ed., 2021, 60(15): 8472-8476.
[34] Crawley M R, Zhang D Y, Ol ganic-framework-supported molecular electrocatalysis
for the oxygen reduction reaction [J]. Angew. Chem. Int.
Ed., 2021, 60(15): 8472-8476.
Crawley M R, Zhang D Y, Oldacre A N, Beavers C M,
Friedman A E, Cook T R. Tuning t for the oxygen reduction reaction [J]. Angew. Chem. Int.
Ed., 2021, 60(15): 8472-8476.
Crawley M R, Zhang D Y, Oldacre A N, Beavers C M,
Friedman A E, Cook T R. Tuning the reactivity of cofa-
cial porphyrin prisms for oxyg Ed., 2021, 60(15): 8472-8476.
Crawley M R, Zhang D Y, Oldacre A N, Beavers C M.
Friedman A E, Cook T R. Tuning the reactivity of cofa-
cial porphyrin prisms for oxygen reduction using modu-
lar building blocks[J]. J. Am. C Crawley M R, Zhang D Y, Oldacre A N, Beavers C M,
Friedman A E, Cook T R. Tuning the reactivity of cofa-
cial porphyrin prisms for oxygen reduction using modu-
lar building blocks[J]. J. Am. Chem. Soc., 2021, 143(2):
1098-Friedman A E, Cook T R. Tuning the reactivity of cofacial porphyrin prisms for oxygen reduction using modular building blocks[J]. J. Am. Chem. Soc., 2021, 143(2): 1098-1106.

1098-1106.

1098-1106.

Insights in the oxygen cial porphyrin prisms for oxygen reduction using modular building blocks[J]. J. Am. Chem. Soc., 2021, 143(2):
1098-1106.
Wan H, Jensen A W, Escudero-Escribano M, Rossmeisl J.
Insights in the oxygen reduction reaction: From lar building blocks[J], J. Am. Chem. Soc., 2021, 143(2):
1098-1106.
Wan H, Jensen A W, Escudero-Escribano M, Rossmeisl J.
Insights in the oxygen reduction reaction: From metallic
electrocatalysts to diporphyrins[J]. ACS Ca [J. J. Am. Chem. Soc., 2021, 143(2):

Escudero-Escribano M, Rossmeisl J.

en reduction reaction: From metallic

iporphyrins[J]. ACS Catal., 2020, 10

g D Y, Fang Y Y, Song Y, Zhu W H,

kin V N, Kadish K M. Electrochem-

op 1098-1106.

Wan H, Jensen A W, Escudero-Escribano M, Rossmeisl J.

Insights in the oxygen reduction reaction: From metallic

electrocatalysts to diporphyrins[J]. ACS Catal., 2020, 10

(11): 5979-5989.

2P, Meng D Y, Fang Y [35] Wan H, Jensen A W, Escudero-Escribano M, Rossmeisl J.

Insights in the oxygen reduction reaction: From metallic

electrocatalysts to diporphyrins[J]. ACS Catal., 2020, 10

(11): 5979-5989.

[36] Sun B, Ou Z P, Meng D Insights in the oxygen reduction reaction: From metallic
electrocatalysts to diporphyrins[J]. ACS Catal., 2020, 10
(11): 5979-5989.
Sun B, Ou Z P, Meng D Y, Fang Y Y, Song Y, Zhu W H,
Solntsev P V, Nemykin V N, Kadish K M. electrocatalysts to diporphyrins [J]. ACS Catal., 2020, 10
(11): 5979-5989.
Sun B, Ou Z P, Meng D Y, Fang Y Y, Song Y, Zhu W H,
Solntsev P V, Nemykin V N, Kadish K M. Electrochem-
istry and catalytic properties for dioxyge (11): 5979-5989.

Sun B, Ou Z P, Meng D Y, Fang Y Y, Song Y, Zhu W H,

Solntsev P V, Nemykin V N, Kadish K M. Electrochem-

istry and catalytic properties for dioxygen reduction using

ferrocene-substituted cobalt porphyr [36] Sun B, Ou Z P, Meng D Y, Fang Y Y, Song Y, Zhu W H,

Solntsev P V, Nemykin V N, Kadish K M. Electrochem-

istry and catalytic properties for dioxygen reduction using

ferrocen-substituted cobalt porphyrins [J]. Inorg
	-
	-
	-
	-

electrocatalytic oxygen reduction activity and selectivity with a cobalt corrole appended with multiple positively the *R*²²(*J. Electrochem.*) 2022, 28(9), 2214002 (10 of 11)

electrocatalytic oxygen reduction activity and selectivity ing and absorption, version 2008/1. University of Göttin-

with a cobalt corrole appended with mul

- (45): 24805-24813. $\pm \frac{1}{2} \left\{ \frac{1}{2} \left(\frac{1}{2} \right) \frac{1}{2} \left(\frac{1}{2} \right) \frac{1}{2} \left(\frac{1}{2} \right) \frac{1}{2} \frac{1}{2} \left(\frac{1}{2} \right) \frac{1}{2} \frac{1}{2}$ (b) *Comparing Comparing the changed proton relay sites[J]. J* the *C*²² (*Electrochem.*) 2022, 28(9), 2214002 (10 of 11)

electrocatalytic oxygen reduction activity and selectivity ing and absorption, version 2008/1. University of Göttim-

with a cobalt corrole appended with multi **EVE SECTION (EXECTION ASSAUTE 1000** (10 of 11)
 Electrocatalytic oxygen reduction activity and selectivity ing and absorption, version 2008/1. University of Göttin-

with a cobalt corrole appended with multiple positi the (*k²²*): *Electrochem.*) 2022, 28(9), 2214002 (10 of 11)

electrocatalytic oxygen reduction activity and selectivity ing and absorption, version 2008/1.

with a cobalt corrole appended with multiple positively gen, $\text{#L}(E*@{f.} \text{Electroculhytic oxygen reduction activity and selectivity} \text{ing and absorption, version 2008/1. University of Gatim-
with a cobalt corrole appeared with multiple positively
charge proton cells (1). Phys. Chen. C, 2021, 125 [380] Schelchic & M. These annealing in SHELX>00: Diver
charge proton cells (1). Phys. Chen. C, 2021, 125 [380] Schelchic & M. Phase annealing in SHELX>00: Diver
451 [300a² P. Krakaash K, Yadav M., Ganesan V, Sankar M, 467-473. \nGraph$ He E²²(*L Electrochem*,) 2022, 28(9), 2214002 (10 of 11)

electrocaulytic exygen reduction activity and selectivity of mg and absorption, version 2008/1. University of Gottin-

with a cobalc corrole appended with mu Fig. Fig. 2013, Electrocal porto (13): 2021, 2021, 2021, 2021, 2010, 2021, 2010, 2011, 2011, 2011, 2016, 20 $\begin{tabular}{l|c|c|c|c|c|c|c} \hline &\textbf{ft} &\textbf{ft$ (*b*₍*C*²²(*L Electrochem, 2022, 28(9), 2214002 (10 of 11)

electrocatalytic oxygen reduction activity and selectrivity ing and absorption, version 2008/1. University of Gittin-

with a cobalc correlaty steel(<i>J*) the the matterial mat $\begin{tabular}{ll} \textbf{#14} \# \# \# \textbf{#} \textbf{H} \textbf{H} \textbf{H} \textbf{H} \textbf{H} \textbf{H$
- 411-414.
-
- electrocatalytic oxygen reduction activity and selectivity wing and absorption, version 2008/1. University of Givilinum with a cobalt corole appended with multiple positively gent, Germany, 2008.

changed proton relay sin electrocatalytic oxygen reduction activity and selectivity

with a coloche conveloperation with multiple positive changes, 2008.

then a coloche coloche standard with multiple positive changes are corresponded with multipl with a cobalt corrole appended with multiple positively

dragod proton estis effect (M). Phys. Chem. C, 2021, 125 [90] Sheldrick G M. Phase annealing in SHELX-90: Direct

d45): 24805-24813.

Supported (A): Vadia-M, Cardian charged proton relay sites[I]. J. Phys. Chem. C, 2021, 125 [50] Sheldrick G M. Phase amealing in SHELX-90: Direct (45): 24860-24813.

Similar P. K., Praksa K, Yadav M, Ganesan V, Sankar M, and the larger structures [J]. Ac (45): 24805-24813.

(46): 24805-24813.

Sonks. PK, Pradav M, Gamesan V, Sankar M, 467473 .

Sonks. Rigger and Constant PK, Pradav M, Gamesan V, Sankar M, 467473 .

Ciopa R, Yradav D.K. Co(II)-porphyrin-decorated earbon [[41] Sonkar PK, Prakash K, Yodav M, Ganesam V, Sunkar M, $467-473$.

(mpm R, Yadav M) K. Co(Il)-porphyind-decorated carbon [51] Sheldrek G M. Crystal structure refinement with SHEL

unproduction start declinary

sumpsised Gupta R, Yadav D K. Co(III)-porphyrin-decorated carbon [51] Sheldrick G M. Crystal structure retimement with SHEL
nanombes as cantayst for oxygen reduction reactions: An 2(32) Aria + Y, Yan V, 11 N, Wa H R, Lou X W, Wang X Anarchubes as eatalysts for oxygen reduction reactions: An

2Chem. A_N Xin B J.Con X W, Wu H B, Lou X W, Weyn H B, Lou X W, Weyn H B, Lou X W, The H B, Lou X W, The H B, Lou X W, The H B, D. 2017, 5(13): 6263-6276.

2017,
-
- approach for find cell improvement(J1, J. Mater. Chem. A, $[52]$ Xii. B Y, Yun Y, Li N, Wu H B, Lou X W, Wung X. A
 $[42]$ DACuire R, Dogutan D K, Tees T S, Sumivich J, Shaudele eranconiclogiste framewoolcole diffunctiona 2017, 5(13): 6(263-6276.

McGuire R, Doguan D K, Teets T S, Suntivich J, Shuo-

Henn Y, Nocean D K, Teets T S, Suntivich J, Shuo-

Henn Y, Nocean D K, Teets T S, Suntivich J, Shuo-

conbul(I) hungman perphyrim [J]. Chem. S McGuire R, Dogutan D K, Test 1'S, Suntivido J, Shao-

Section and Hy-IT means of \sim 100 (S1) Friesh M.A, Thuse G W, Solishgel H B, Souscini G E,

Hom N, New 11. (active simulation reactivity of [53] Friesh M.A, Choesema Hom Y, Noecra D G. Oxygen reduction reactivity of [53] Frisch M J, Trucks G W, Schlogel H B, Scussria G E,

and A. Chessens at P, Rev D L Giussian (6 Evi-

diality and T M, Extens and R, N. Chessens at P, Rev D L Giussian cobalt(II) hangman porphyrins[J]. Chem. Sci., 2010, 1(3):

Hall 41-14.

411-14.

41-14.

41-14.

41-ning 2, Wang H Y, Zheng H Q, Zhang W, Cao R. Por-

15. Given indiversel free cost A. O. (19): (Higherd, C. Costingstin nea 411-414, 22 (Wellingford, Ct Giaussian hac.) 2016.

44 (43) Linag X, Nang H Q, Zhang W, Cao R. Por-

45 (Fand Onicon in dispersion corrected density functions theodomy

45 (points in Georgia L. Effect of the damping

47 (tiang χ , Wang H χ , Zheng H Q, Zhang W, Cao R. Por-

phyrin-based frameworks for evoygen electrocatalytis and

metal pore catalytic frameworks for evo-gene electrocates of experimental

catalytic character density fu phyrin-based frameworks for oxygen electrocatalysis and

catalytic reduction of criation and inferior control in dispersion corrected density (meticanal heavey

2021, 50(4): 2450-1465.

2021, 50(4): 2450-1465.

2021, 51(4 otalytic reduction of carbon dioxide[J]. Chem, Soc. Rev. [J], J. Comp. Chem, 2011, 32(7): 1456-1465.

2021, 50(1, 50(1, 504). 2503. [55] Recke A D. Density-functional exchuance is the matter of the colleges and continuous 2021, 50(4): 2340-2581.

[44] Qin II N, Wang P, T, Xwang P, Duan X G, Lei H T,

[44] Qin II N, Wang P, Z, Wang P, Duan X G, Lei H T,

2008. 3100.

2008. 3100.

2008. 2100.

2008. 2100.

phyrins supported on carbon nanotub (44) Qin H N, Wang Y Z, Wang H, Dann X G, Lei H T, mainton with correct asymptotic behaviorf)]. Phys. Rev. A, Zhung W R (2018) (N Zhung W. Can C Cohin part and Dylis are Choren anothes as model can-
bytims supported on ea
-
-
-

- ing and absorption, version 2008/1. University of Göttingen, Germany, 2008.
Sheldrick G M. Phase annealing in SHELX-90: Direct methods for larger structures[J]. Acta Cryst., 1990, 46: 467-473. (10 of 11)
ing and absorption, version 2008/1. University of Göttin-
gen, Germany, 2008.
Sheldrick G M. Phase annealing in SHELX-90: Direct
methods for larger structures[J]. Acta Cryst., 1990, 46:
467-473.
Sheldrick G M. C 28(9), 2214002 (10 of 11)

ing and absorption, version 2008/1. University of Göttin-

gen, Germany, 2008.

[50] Sheldrick G M. Phase annealing in SHELX-90: Direct

methods for larger structures [J]. Acta Cryst., 1990, 46:
 9. 2214002 (10 of 11)

ing and absorption, version 2008/1. University of Göttin-

gen, Germany, 2008.

Sheldrick G M. Phase annealing in SHELX-90: Direct

methods for larger structures [J]. Acta Cryst., 1990, 46:

467-473. 467-473. 28(9), 2214002 (10 of 11)

ing and absorption, version 2008/1. University of Göttingen, Germany, 2008.

[50] Sheldrick G M. Phase annealing in SHELX-90: Direct

methods for larger structures[J]. Acta Cryst., 1990, 46:

467 (1002), 100 (11)

ing and absorption, version 2008/1. University of Göttingen, Germany, 2008.

Sheldrick G M. Phase annealing in SHELX-90: Direct

methods for larger structures [J]. Acta Cryst., 1990, 46:

467-473.

Sheldr 28(9), 2214002 (10 of 11)

ing and absorption, version 2008/1. University of Göttin-

gen, Germany, 2008.

[50] Sheldrick G M. Phase annealing in SHELX-90: Direct

methods for larger structures[J]. Acta Cryst., 1990, 46:
 1, 2214002 (10 of 11)

ing and absorption, version 2008/1. University of Göttin-

gen, Germany, 2008.

Sheldrick G M. Phase annealing in SHELX-90: Direct

methods for larger structures[J]. Acta Cryst., 1990, 46:

467-473.
 electrocatalyst[J]. Nat. Energy, 2016, 1: 15006.

Electrocatalystic G M. Phase annealing in SHELX-90: Direct

methods for larger structures[J]. Acta Cryst., 1990, 46:

467-473.

Sheldrick G M. Crystal structure refinement 28(9), 2214002 (10 of 11)

ing and absorption, version 2008/1. University of Göttin-

gen, Germany, 2008.

[50] Sheldrick G M. Phase annealing in SHELX-90: Direct

methods for larger structures [J]. Acta Cryst., 1990, 46:
 Robert 2002 (10 of 11)

ing and absorption, version 2008/1. University of Göttin-

gen, Germany, 2008.

Sheldrick G M. Phase annealing in SHELX-90: Direct

methods for larger structures[J]. Acta Cryst., 1990, 46:

467-473. sim and absorption, version 2008/1. University of Göttingen, Germany, 2008.

Sheldrick G M. Phase annealing in SHELX-90: Direct

methods for larger structures[J]. Acta Cryst., 1990, 46:

467-473.

Sheldrick G M. Crystal st 电化学(*J. Electrochem.*) 2022, 28(9), 2214002 (10 of 11)
on activity and selectivity ing and absorption, version 2008/1. University of Göttin-
d with multiple positively ing and absorption, version 2008/1. University of Göt
	-
	-
	-
	- 28(9), 2214002 (10 of 11)

	ing and absorption, version 2008/1. University of Göttin-

	gen, Germany, 2008.

	[50] Sheldrick G M. Phase annealing in SHELX-90: Direct

	methods for larger structures [J]. Acta Cryst., 1990, 46:
	- 1, 2214002 (10 of 11)

	ing and absorption, version 2008/1. University of Göttin-

	ing and absorption, version 2008/1. University of Göttin-

	Sheldrick G M. Phase annealing in SHELX-90: Direct

	methods for larger structures 1, 2214002 (10 of 11)

	ing and absorption, version 2008/1. University of Göttin-

	gen, Germany, 2008.

	Sheldrick G M. Phase annealing in SHELX-90: Direct

	methods for larger structures[J]. Acta Cryst., 1990, 46:

	467-473.
 28(9), 2214002 (10 of 11)

	ing and absorption, version 2008/1. University of Göttin-

	gen, Germany, 2008.

	[50] Sheldrick G M. Phase annealing in SHELX-90: Direct

	methods for larger structures[J]. Acta Cryst., 1990, 46:

	- ing and absorption, version 2008/1. University of Göttin-
gen, Germany, 2008.
Sheldrick G M. Phase annealing in SHELX-90: Direct
methods for larger structures[J]. Acta Cryst., 1990, 46:
467-473.
Sheldrick G M. Crystal stru ing and absorption, version 2008/1. University of Göttin-
gen, Germany, 2008.
Sheldrick G M. Phase annealing in SHELX-90: Direct
methods for larger structures[J]. Acta Cryst., 1990, 46:
467-473.
Sheldrick G M. Crystal stru gen, Germany, 2008.

	[50] Sheldrick G M. Phase annealing in SHELX-90: Direct

	methods for larger structures [J]. Acta Cryst., 1990, 46:

	467-473.

	[51] Sheldrick G M. Crystal structure refinement with SHEL

	XL[J]. Acta Cry Sheldrick G M. Phase annealing in SHELX-90: Direct
methods for larger structures[J]. Acta Cryst., 1990, 46:
467-473.
Sheldrick G M. Crystal structure refinement with SHEL
XL[J]. Acta Cryst., 2015, 71: 3-8.
Xia B Y, Yan Y, methods for larger structures [J]. Acta Cryst., 1990, 46:

	467-473.

	Sheldrick G M. Crystal structure refinement with SHEL

	XL[J]. Acta Cryst., 2015, 71: 3-8.

	Xia B Y, Yan Y, Li N, Wu H B, Lou X W, Wang X. A

	Xia B Y, Yan 789. [51] Sheldrick G M. Crystal structure refinement with SHEL

	XL[J]. Acta Cryst., 2015, 71: 3-8.

	[52] Xia B Y, Yan Y, Li N, Wu H B, Lou X W, Wang X. A

	metal-organic framework-derived bifunctional oxygen

	electrocatalyst[J] XL[J]. Acta Cryst., 2015, 71: 3-8.

	Xia B Y, Yan Y, Li N, Wu H B, Lou X W, Wang X. A

	metal-organic framework-derived bifunctional oxygen

	electrocatalyst[J]. Nat. Energy, 2016, 1: 15006.

	Frisch M J, Trucks G W, Schelgel
	- 5648-5652.
	- metal-organic framework-derived bifunctional oxygen
electrocatalyst[J]. Nat. Energy, 2016, 1: 15006.
[53] Frisch M A, Cheeseman JR, Fox D J. Guassian16 Revi-
Robb M A, Cheeseman JR, Fox D J. Guassian16 Revi-
sion A. 03 (Wa electrocatalyst[J]. Nat. Energy, 2016, 1: 15006.

	Frisch M J, Trucks G W, Schlegel H B, Scuseria G E,

	Robb M A, Cheeseman J R, Fox D J. Gaussian16 Revi-

	sion A. 03 (Wallingford, Ct: Gaussian Inc.), 2016.

	Grimme S, Ehrli Frisch M J, Trucks G W, Schlegel H B, Scuseria G E,
Robb M A, Cheeseman J R, Fox D J. Gaussian16 Revi-
sion A. 03 (Wallingford, Ct: Gaussian Inc.), 2016.
Grimme S, Ehrlich S, Goerigk L. Effect of the damping
function in di Robb M A, Cheeseman J R, Fox D J. Gaussian16 Revision A. 03 (Wallingford, Ct: Gaussian Inc.), 2016.

	Grimme S, Ehrlich S, Goerigk L. Effect of the damping

	function in dispersion corrected density functional theory

	[J]. J sion A. 03 (Wallingford, Ct: Gaussian Inc.), 2016.

	[54] Grimme S, Ehrlich S, Goerigk L. Effect of the damping

	function in dispersion corrected density functional theory

	[JJ. J. Comp. Chem., 2011, 32(7): 1456-1465.

	[55] Grimme S, Ehrlich S, Goerigk L. Effect of the damping
function in dispersion corrected density functional theory
[J]. J. Comp. Chem., 2011, 32(7): 1456-1465.
Becke A D. Density-functional exchange-energy approxi-
mation wi [J]. J. Comp. Chem., 2011, 32(7): 1456-1465.

	[55] Becke A D. Density-functional exchange-energy approximation with correct asymptotic behavior[J]. Phys. Rev. A,

	1988, 38(6): 3098-3100.

	[56] Lee C T, Yang W T, Parr R G. Becke A D. Density-functional exchange-energy approximation with correct asymptotic behavior[J]. Phys. Rev. A, 1988, 38(6): 3098-3100.
Lee C T, Yang W T, Parr R G. Development of the collesalvetti correlation-energy formul mation with correct asymptotic behavior [J]. Phys. Rev. A, 1988, 38(6): 3098-3100.
Lee C T, Yang W T, Parr R G. Development of the collesalvetti correlation-energy formula into a functional of
state-tion density [J]. Phys.
	- 2999-3093.
	-

吸电子和亲水性 Co-卟啉促进电催化 氧还原反应的研究 _{电化学(*J. Electrochem.*) 2022, 28(9), 2214002 (11 of 11)

·和亲水性 Co-卟啉促讲电催化}

郭鸿波#,王亚妮#,郭 凯,雷海涛,梁作中*,张学鹏*,曹 睿*
(陕西师范大学化学化工学院,应用表面与胶体化学教育部重点实验室,陕西西安 710119) **、**曹 睿*

摘要:研究影响电催化氧还原反应活性的因素对于合理设计高效的氧还原反应催化剂至关重要。调节催化剂电 子结构通常被用于精确调控电催化氧还原反应活性。然而,该反应发生在液/气/固界面,很少有报道调控分子催 化剂的亲疏水性来提高其催化活性。在此,我们报道了两种钴卟啉 NO₂-CoP(5,10,15,20-四(4-硝基苯基)钴卟啉) 和 SF-CoP(5,10,15,20-四(五氟苯基)钴卟啉)并研究了其电催化氧还原反应性能。通过同时调控 meso-位取代基 的电子结构和亲水性能,NO2-CoP 显示出比 5F-CoP 更高的电催化氧还原反应活性,其半波电位向阳极方向移 动近 60 mV^遥 NO2 -CoP 比 5F-CoP 具有更好的亲水性。理论计算表明 , NO2-CoP 比 5F-CoP 更容易有效地与 O2 分 子结合形成 Co''' O2 。这项工作提供了一个简单而有效的策略,通过使用吸电子和亲水取代基来提高钴卟啉的氧 还原反应活性。该策略对于设计和开发其他用于电催化的分子催化剂体系也具有重要的启发意义。 关键词: 分子电催化;氧还原反应;钴卟啉;亲水性;电子结构