



Universiteit  
Leiden  
The Netherlands

## Heterogenized molecular (pre)catalysts for water oxidation and oxygen reduction

Ham, C.J.M. van der

### Citation

Ham, C. J. M. van der. (2019, October 10). *Heterogenized molecular (pre)catalysts for water oxidation and oxygen reduction*. Retrieved from <https://hdl.handle.net/1887/79257>

Version: Publisher's Version

License: [Licence agreement concerning inclusion of doctoral thesis in the Institutional Repository of the University of Leiden](#)

Downloaded from: <https://hdl.handle.net/1887/79257>

**Note:** To cite this publication please use the final published version (if applicable).

Cover Page



Universiteit Leiden



The handle <http://hdl.handle.net/1887/79257> holds various files of this Leiden University dissertation.

**Author:** Ham, C.J.M. van der

**Title:** Heterogenized molecular (pre)catalysts for water oxidation and oxygen reduction

**Issue Date:** 2019-10-10

# **Heterogenized molecular (pre)catalysts for water oxidation and oxygen reduction**

## **Proefschrift**

ter verkrijging van  
de graad van Doctor aan de Universiteit Leiden,  
op gezag van Rector Magnificus prof. mr. C.J.J.M. Stolker  
volgens besluit van het College voor Promoties  
te verdedigen op donderdag 10 oktober 2019  
klokke 13:45 uur

door

**Cornelis Jozef Maria van der Ham**

geboren te Gouda in 1989

## **Promotiecommissie:**

**Promotor:** Prof. dr. M.T.M. Koper

**Co-promotor:** Dr. D.G.H. Hetterscheid

**Overige leden:** Prof. dr. E. Bouwman

Prof. dr. M. Ubbink

Dr. S. Bonnet

Prof. dr. M. Albrecht (Universität Bern, Switzerland)

Dr. J.P. Hofmann (TU Eindhoven, The Netherlands)

ISBN: 978-90-830276-2-3

Printing: Print Service Ede

Cover illustration: starline / Freepik

Voor moeders

# Table of Contents

<b>1</b>	<b>Introduction</b>	<b>3</b>
1.1	Renewable energy and its storage . . . . .	4
1.2	The thin line between homogeneous and heterogeneous catalysis . . . . .	12
1.3	Homogeneous <i>versus</i> heterogeneous electrochemical water oxidation and oxygen reduction catalysis concerning molecular (pre)catalysts . . . . .	19
1.4	References . . . . .	21
<b>2</b>	<b>Structure dependence on the activation of molecular iridium precatalysts for the water oxidation reaction</b>	<b>27</b>
2.1	Introduction . . . . .	28
2.2	Experimental . . . . .	31
2.3	Results . . . . .	36
2.4	Discussion . . . . .	46
2.5	Conclusions . . . . .	52
2.6	References . . . . .	52
<b>3</b>	<b>Activation pathways taking place at molecular copper precatalysts for the oxygen evolution reaction</b>	<b>57</b>
3.1	Introduction . . . . .	58
3.2	Experimental . . . . .	59
3.3	Results . . . . .	63
3.4	Conclusions . . . . .	69
<b>4</b>	<b><i>In situ</i> generated copper-phenanthroline complexes as catalysts for the oxygen reduction reaction</b>	<b>75</b>
4.1	Introduction . . . . .	76

4.2	Experimental . . . . .	78
4.3	Results . . . . .	80
4.4	Discussion . . . . .	88
4.5	Conclusion . . . . .	92
4.6	References . . . . .	92
<b>5</b>	<b>Phenanthroline immobilized on Au electrodes as ligand in copper-mediated oxygen reduction</b>	<b>95</b>
5.1	Introduction . . . . .	96
5.2	Experimental . . . . .	98
5.3	Results and discussion . . . . .	100
5.4	Conclusion . . . . .	119
5.5	References . . . . .	119
<b>6</b>	<b>Summary</b>	<b>121</b>