Supporting Information

Mechanistic Study of Copper-Catalyzed Decarboxylative C-N Cross-Coupling with Hypervalent Iodine Oxidant

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Gibbs free energy of all pathways:

Gibbs free energy of Scheme 3 in article:





Gibbs free energy of Path 1 (Figure 1 in article):



Figure S1. Gibbs free energy for Path 1 (kcal/mol)

Gibbs free energy of Path 2 (Scheme 4 in article):





Gibbs free energy of Path 3 (Figure 2 in article):



Figure S2. Gibbs free energy for Path 3 (kcal/mol)

Gibbs free energy of Path 4 (Figure 4 in article):



Figure S3. Gibbs free energy for Path 4 (kcal/mol)

Gibbs free energy and corrected Gibbs free energy used in the article have all been calculated here as reference (as shown in **Figure S1-3**, **Scheme S1-2**). According to these calculation, ⁺HDMAP-assisted RCOO-I bond heterolytic cleavage (in Path3) is the most favorable pathway for the I-O cleavage. This conclusion is in accordance with the enthalpy calculation results used in the article. However, due to overestimation of entropy in solution, the Gibbs energy change in the I-O bond dissociation step (process of $A \rightarrow B+C$) is much lower than the enthalpy change.

Free Cu(I) & Cu(II) species in solution (Ref 24)

ΔH _{sol} (ΔG _{sol}) (ΔG _{corr-sol})	[TfO-Cu ^I L] ← → +6.9 (+5.7) (+6.7)	[Cu ^I L ₂] 0.0 (0.0) (0.0)	<>	[Cu ^I L ₃] +0.03 (+9.8) (+13.0)
L=DMAP	[TfO-Cu ^{II} L ₃] +0.01 (-3.7) (-1.0)	► [Cu ^{ll} L ₄] 0.0 (0.0) (0.0)	<>	[Cu ^{II} L ₃] +13.7 (-1.1) (-1.3)

Scheme S3. Equilibrium of different Cu(I) & Cu(II) catalysts in solution

We investigated the free Cu(I) and Cu(II) species mentioned in **Scheme 2** at the beginning of our research. For both Cu(I) and Cu(II) catalysts, DMAP is a better ligand than OTf in solution. In addition, Cu(I)L₂ and Cu(II)L₄ are the most thermodynamically stable species respectively for Cu(I) and Cu(II) catalysts. Therefore, Cu(I)L₂ and Cu(II)L₄ were taken into consideration in **Scheme 3**.

Energy change of the disproportionation process (Ref 23)

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Scheme S4. The disproportionation process of Cu(OTf)<sub>2</sub>
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According to reference [23], the active Cu(I) can be initially produced either through the disproportionation of Cu(II) or via the reduction of Cu(II) by a nucleophile. To validate the disproportionation process from Cu(OTf)₂ to Cu(I)L₂, extra calculations were performed in **Scheme S4**. Cu(OTf)₂ was first coordinated by two DMAP ligand to generate a more stable Cu(II)(OTf)₂L₂, and the latter one could then disproportionate into Cu(I) and Cu(III) species with a reasonable enthalpy change of +23.9kcal/mol.

Complete transformations of Path 1



The complete transformations of Path 1 have been shown in **Figure S4**. We also considered the possibility proposed in our previous experimental work (*J. Am. Chem. Soc.* **2016**, 138, 9714-9719) (as shown in red part). Calculation results shows that the SET process between Cu(I) species and

oxygen radical species is even more unfavorable.

Complete transformations of Path 2



Figure S5. Enthalpy profile for Path 2

Potential energy scan of I-O bond in Int13



Figure S6. The potential energy scan of I-O bond in Int13.

Potential energy scan of Cu-N(DMAP) bond in Int18



Figure S7. The potential energy scan of Cu-N(DMAP) bond in Int18.

Another concerted metalation deprotonation process in Figure 2



Scheme S5. Another concerted metalation deprotonation process

In this work, another concerted metalation deprotonation transition state like **TS-CMD** in Scheme S5 was also considered. However, the optimized structure of the proposed CMD transition state **TS-CMD** always converged at **TS19-9**. This might be ascribed to the significant steric hindrance and distortion in **TS-CMD**. Therefore, the stepwise deprotonation process proposed in the manuscript is more reliable.

The formation of ⁺HDMAP

Scheme S6. The formation of ⁺HDMAP in some equilibriums



The prontonated base (⁺HDMAP) is not only generated during the deprotonation process, but also gets formed in acid-base equilibriums (as shown in **Scheme S6**). As long as trace amount of ⁺HDMAP is formed and then participates in the first catalytic cycle of reaction, equivalent amount of ⁺HDMAP can be subsequently formed in deprotonation process (**Int19→Int9** in Figure 2) to drive the whole reaction moving forward.

An alternative oxidative mechanism of carboxylate

Scheme S7. Energy change of an alternative oxidative mechanism of RCOO-



Herein, we also considered the possibility of the decarboxylation of carboxylate. The carboxylate (Int1-H) can be formed in the presence of the base DMAP. Then, Cu(III)/Cu(II)/PhIO species were considered as the oxidant respectively to oxidize the carboxylate and the carboxyl radical (Int4) could then be generated. Comparing to the exothermic combination process (Int1 \rightarrow Int3, Δ H= -24.9 kcal/mol) proposed in the manuscript, the oxidation of carboxylate is obviously an endothermic process (Int1 \rightarrow Int1-H \rightarrow 4, Δ H^{\pm} > +20 kcal/mol), which is indeed unfavorable.

Electronic energies and thermal corrections of related intermediates and transition states

	Electronic Energy	Thermal Correction of	Thermal Correction of
	(Hartree)	Gibbs Free Energy	Enthalpy(Hartree)
		(Hartree)	
Intl	-763.0712973	0.197678	0.261169
Int1-(PhIO) ₂	-1399.602186	0.351131	0.464439
TS1-2	-1399.602007	0.349213	0.460962
Int2	-1399.603554	0.352561	0.464854
Int3	-1399.620326	0.35467	0.465459
Int3-t	-1399.575711	0.341817	0.464216
Int4	-762.3911035	0.183993	0.247671
TS4-5	-762.3908601	0.181611	0.245753
Int5	-573.7585121	0.172281	0.228911
Int6	-1153.419712	0.328785	0.408351
Int7-t	-1547.476407	0.414995	0.525379
Int8-t	-1152.78244816	0.313157	0.394406
Int9	-1152.81915325	0.321776	0.397132
TS9-TM	-1152.800038	0.318998	0.395507
TM	-573.2028513	0.1714	0.221013
Int10	-1782.476771	0.516133	0.653266
Int11	-1005.311194	0.267791	0.34815
Int12	-1005.525891	0.260887	0.347048
Int13	-1782.474697	0.516717	0.654075
1-H	-762.5866285	0.186414	0.248145

Table S1. Electronic energies and thermal corrections (in solution)

Int14	-636.9911977	0.146572	0.214846
Int15	-637.1775577	0.139915	0.213958
Int16	-1157.126639	0.283684	0.3787
TS16-4	-1157.111626	0.281786	0.373662
Int17	-1918.040256	0.63479	0.760503
Int18	-1535.63186154	0.487490	0.585861
Int19	-1535.629417	0.483697	0.583822
TS19-9	-1535.62966719	0.481138	0.579663
Int20	-1979.282701	0.503129	0.643983
Int20-t	-1979.267912	0.494853	0.643245
Int21	-1342.089015	0.338131	0.42737
Int22	-1724.50542961	0.486729	0.601945
Int23	-1342.087276	0.343992	0.428189
Int24-t	-1736.145674	0.430517	0.54507
TS24-25-t	-1736.13583096	0.430138	0.539217
Int25-t	-1341.425931	0.330296	0.41409
Int25-s	-1341.433148	0.333762	0.415261
TS25-26-t	-1341.407651	0.325019	0.410961
Int26-t	-1152.78469034	0.315546	0.394687
Cu(I)L ₂	-962.0533138	0.277861	0.35083
Cu(I)L ₃	-1344.432139	0.424619	0.524813
TfO-Cu(I)L	-1541.46605045	0.139574	0.212608
1-Cu(I)	-1342.73152445	0.347565	0.439745
Cu(II)L ₃	-1344.25678621	0.429995	0.525999
Cu(II)L ₄	-1726.65889272	0.586083	0.701459

TfO-Cu(II)L ₃	-2306.08195855	0.443218	0.562576
1-Cu(II)-a	-1724.93082431	0.503648	0.615487
1-Cu(II)-b	-1724.95201100	0.505465	0.616332
1-Cu(II)-c	-1342.52033317	0.359855	0.441771
1-Cu(II)-a-H	-1724.49767684	0.487555	0.601469
1-Cu(II)-d-H	-1724.49724236	0.488770	0.602473
L	-382.3768738	0.129148	0.171992
⁺ HL	-382.8414665	0.143985	0.185102
PhI	-243.1277969	0.058215	0.096832
(PhIO) ₂	-636.5083991	0.133793	0.202763
CO ₂	-188.6461058	-0.009272	0.015043
НОХ	-394.7309822	0.080961	0.127329
XO-radical	-394.0490045	0.068042	0.115101
XO-anion	-394.213323	0.067464	0.11421