Supporting Information

Simple Preparation of Porous Carbon Supported Ruthenium: Propitious Catalytic Activity in the Reduction of Ferrocyanate(III) and Cationic Dye

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Catalyst Characterization. Powder X-ray diffraction (XRD) measurements were performed on the PANalytical (X’Pert PRO) instrument using a Cu Kα radiation (λ = 0.1541 nm). HRTEM observations were performed on a Philips Tecnai F20 G2 FEI-TEM electron microscope at an acceleration voltage of 200 kV. TEM samples were prepared on lacey carbon on 400 mesh copper grids. A drop of sample (5 µL) was deposited on the grid and left to air-dry. To quantify the loading of Ru, an inductively coupled plasma atomic-emission spectrometry (ICP-AES) was used. (Spectro Ciiros Vision, Germany). N₂ adsorption/desorption isotherms were measured using a physisorption apparatus (Micromeritics, ASAP 2020). Moreover, microwave heating was performed by using Milestone’ START (power 300 W) instrument. H₂ pulse chemisorption for metal dispersion of all samples was performed utilizing an Autochem-2920 instrument. The amount of H₂ uptake during the reduction was measured continuously with a thermal conductivity detector (TCD) and the corresponding Ru dispersion in each catalyst sample was derived, given an assumption of a complete Ru reduction with the stoichiometry of H/Ru₂ = 2. All Fourier-transform infrared (FT-IR) spectra were recorded by a Bruker IFS28 spectrometer in the region of 4000–400 cm⁻¹ with a spectral resolution of 2 cm⁻¹ using KBr pellet method at room temperature. Thermogravimetric and differential thermal analysis (TG-DTA) measurements were performed on a Netzsch TG-209 instrument under air atmosphere. The absorption spectra were recorded with a Thermo Scientific evolution 220 UV–visible spectrophotometer. Gas chromatography/mass spectrometry (GC/MS) analyzer (Agilent 7890B GC system) equipped with a DB-5MS capillary column (30 m, 0.25 mm i.d., 0.25 µm-phase thickness; Agilent J&W Scientific), connected to an Agilent 5977A Mass Spectrometer was carried out.

Ruthenium Dispersion Measurements. Approximately, a 100 mg of catalyst was placed in a U-shaped quartz tube along with a thermocouple in a temperature-controlled furnace. The Ru dispersions of Ru@PDC sample was measured by hydrogen chemisorption. Prior to each measurement, the sample was pretreated by argon gas with a flow rate of 30 mL min⁻¹ at 623 K for 2 h to remove impurities. Then, the system was cooled to room temperature. At first H₂ adsorption isotherm (flow rate: 10% H₂/Ar gas mixture and a heating rate of 10 °C min⁻¹) was measured after the sample was cooled to 323 K, followed by outgassing for one hour to obtain a second H₂ adsorption isotherm under the same conditions.
The metal dispersion can be calculated based on monolayer coverage of H\(_2\) chemisorption as given in eqn (1)\(^{S1}\)

\[
D = \left( \frac{V_m}{22414} \right) \times S \times M_w \times \left( \frac{100}{X_m} \right)
\]  

(1)

In which \(D\) is the dispersion in \%, \(V_m\) the mono-layer coverage in cm\(^3\) g\(^{-1}\), \(S\) the stoichiometric factor of H\(_2\) to Ru atoms (S=2), \(M_w\) the molar weight of ruthenium (101.07 g mol\(^{-1}\)), and \(X_m\) the weight fraction of metal on the catalyst. So, a value of \(D = 6.01\%\) was calculated for the dispersion of Ru in the 4.01% wt. Ru@PDC sample.

**Table S1.** Dispersion and average crystallite size for Ru-based catalysts based on H\(_2\) chemisorption analysis.

| Catalyst               | Ru content (wt.%) | Size (nm) | H\(_2\) uptake (\(\mu\)mol g\(^{-1}\)) | Dispersion\(^a\) (H/Ru) | Ref     |
|------------------------|-------------------|-----------|----------------------------------------|--------------------------|---------|
| Ru/Carbon black        | 4.7               | 4.4       | 47                                     | 4.6                      | S2      |
| Ru/\(\gamma\)-Al\(_2\)O\(_3\) | 5.0               | 6.3       | 26                                     | 11.8                     | S3      |
| Ru/\(\gamma\)-Al\(_2\)O\(_3\) | 1.5               | NR\(^b\)  | 39.0\(\pm\)1.5                        | NR                       | S4      |
| Colloidal Ru/\(\gamma\)-Al\(_2\)O\(_3\) | 5.1               | 2.2       | 70                                     | 0.28                     | S5      |
| Ru/ACC                 | 3.0               | 2.5       | NR                                     | 32.0                     | S6      |
| Ru/MOC-900             | 1.5               | 3.0       | NR                                     | 3.1                      | S7      |
| Ru/CeO\(_2\)           | 1.0               | 1.9       | 14.9                                   | 0.15                     | S8      |
| Ru/TiO\(_2\)           | 4.8               | NR        | NR                                     | 0.26                     | S9      |
| Ru-K/AC                | 4.0               | 5.9       | 42.4                                   | 21.4                     | S10\(^c\) |
| Ru@PDC                 | 4.01              | 5 \(\pm\) 0.2 | 63.2                             | 6.01                     | This work |

\(^a\)Calculated from equation (1). \(^b\)Not reported. \(^c\)At 400\(^\circ\)C and 3.0 MPa.

**Inductively Coupled Plasma Atomic-Emission Spectrometry (ICP-AES).** The ruthenium content was quantitatively estimated by inductively coupled plasma atomic-emission spectrometry (ICP-AES). Typically, a 10 mg of Ru@PDC was treated with aqua-regia by evaporating to dryness. The process was repeated at least for 5 times, and the final 50 mL solution was made in dil. HCl medium. Similarly, another two sets were prepared. The average
concentration of Ru was estimated from these three set of solutions. The average Ru content (4.01wt%) was then calculated.

Figure S1. The pore-size distributions for as-prepared samples.

Figure S2. Typical SEM images of (a-f) the pristine PDC-800 sample with different magnifications.
**Figure S3.** Typical FE-TEM images of pristine PDC-600, (a,b) and PDC-700 samples (c,d) with different magnifications.

**Figure S4.** Histogram of particle size distribution for Ru NPs in Ru@PDC catalyst.

**Figure S5.** EDS analysis of Ru@PDC catalyst.
Figure S6. (a) FT-IR spectra of waste plastic derived carbons at different temperatures (PDC-600, PDC-700 and PDC-800) and Ru@PDC samples, and (b) Ru@PDC catalyst dispersed in DI water.

Figure S7. FE-SEM images of carbon spheres produced from various carbon sources, (a) HDPE, (b) LDPE, (c) PC and (d) PET carbonization at 800 °C under same experimental conditions.
Figure S8. TEM images of carbon spheres produced from various carbon sources, (a,b) HDPE, (c,d) LDPE, and (e-h) PC carbonization at 800 °C under same experimental conditions.

Figure S9. XRD patterns of carbon produced from various carbon sources, (a) HDPE, (b) LDPE, and (c) PC carbonization at 800 °C.

Figure S10. UV-Visible absorption spectra of $\text{K}_3[\text{Fe(CN)}_6]$ in the absence of (a) $\text{NaBH}_4$ and (b) Ru@PDC catalyst.
Figure S11. UV-Visible absorption spectra of K₃[Fe(CN)₆] in the (a) absence of catalyst, (b) presence of 1.0 mg of Ru@PDC catalyst, and (c) presence of 2.0 mg of Ru@PDC catalyst by Na₂S₂O₃.

Figure S12. Plot of rate constant against different amounts of Ru@PDC catalyst under same experimental conditions.

**Carbon Yield Calculation.** The mass yield of the carbon is defined as the ratio of the mass of the resultant carbon to that of the mass of the precursor plastics taken, with both masses being measured on a dry basis and expressed in percentage (%) using equation (2) as follows:

\[
\text{Yield of carbonization (\%)} = \frac{M_2}{M_0} \times 100 \quad (2)
\]

where \( M_0 \) is the mass of the precursor waste plastics and \( M_2 \) is the mass of the carbon on a dry basis.
Chemical and Elemental Composition Analyses. We quantify chemical composition by gas chromatography/mass spectrometry (GC/MS) analyzer (Agilent 7890B GC system) equipped with a DB-5MS capillary column (30 m, 0.25 mm i.d., 0.25 µm-phase thickness; Agilent J&W Scientific), connected to an Agilent 5977A Mass Spectrometer. The elemental analysis results showed that PET contains more carbon, nitrogen and hydrogen, but less sulphur than those of other samples (Table S2). All chemical intermediates were identified by comparing with authentic samples while using biphenyl as an internal standard, to understand the reaction pathway. In addition, the elemental composition of PDC derived from waste PET plastic bottles at different temperatures was examined by CHN/O analysis, as shown in Table S3 and S4. This analysis was done using the Elemental Analyzer (Perkin Elmer, Series II 2400) to evaluate the percentage of carbon, hydrogen, and oxygen value, determined by difference, according to previous literature.511

Table S2. Chemical Composition of Waste Plastics.

| Chemical name | LDPE<sup>a</sup> | HDPE<sup>b</sup> | PC<sup>c</sup> | PET<sup>d</sup> |
|---------------|-----------------|-----------------|-------------|----------------|
| Toluene       | 34.18           | 44.02           | 44.02       | 46.43         |
| Naphthalene   | 3.82            | 7.28            | 15.82       | 26.76         |
| Anthracene    | 20.49           | 20.41           | 7.24        | 11.14         |
| Pyrene        | 9.26            | 7.21            | 5.64        | 6.84          |
| Biphenyl      | 7.93            | 6.65            | 6.51        | 7.32          |
| Fluorene      | 1.15            | 1.06            | 1.12        | 1.63          |
| Others        | n/d<sup>e</sup> | n/d             | n/d         | n/d           |

<sup>a</sup>Low-density polyethylene. <sup>b</sup>High-density polyethylene. <sup>c</sup>Polyacrylate. <sup>d</sup>Polyethylene terephthalate. <sup>e</sup>Not detected.

Table S3. Elemental Composition of Carbon Products Prepared Using Waste Plastics.

| Type of plastic | Elemental composition (%) |
|-----------------|--------------------------|
|                 | C  | H  | O  | N  | S  | Cl | Others |
| LDPE<sup>a</sup> | 68.910 | 12.370 | 12.431 | 0.480 | 1.922 | 0.980 | n/d<sup>e</sup> |
| HDPE<sup>b</sup> | 68.891 | 9.131 | 14.612 | 0.821 | 1.290 | 1.242 | n/d |
| PC<sup>c</sup>  | 67.561 | 4.940 | 23.012 | 0.422 | 0.713 | 2.121 | n/d |
| PET<sup>d</sup> | 69.920 | 4.041 | 23.491 | 0.613 | 0.731 | 0.232 | n/d |

<sup>a</sup>Low-density polyethylene. <sup>b</sup>High-density polyethylene. <sup>c</sup>Polyacrylate. <sup>d</sup>Polyethylene terephthalate. <sup>e</sup>Not detected.
Table S4. Elemental Analysis of PDCs and Ru@PDC Samples.

| Sample     | Elemental composition (%) |  |  |  |  |  | Ru (wt%) |
|------------|---------------------------|---|---|---|---|---|----------|
| Char       | 70.010                    | 4.101 | 2.140 | 23.201 | 0.424 | n/d  | n/d  |
| PDC-600b   | 69.001                    | 4.062 | 2.061 | 23.110 | n/d  | n/d  | n/d  |
| PDC-700b   | 69.689                    | 3.311 | 1.129 | 23.061 | n/d  | n/d  | n/d  |
| PDC-800b   | 69.407                    | 3.161 | 1.077 | 22.291 | n/d  | n/d  | n/d  |
| Ru@PDCb    | 69.321                    | 2.124 | 0.965 | 22.145 | n/d  | n/d  | 4.01  |

*a Before activation. b After activation. c Not detected. d Ru content was calculated using ICP-AES technique.

Table S5. Effect of Carbonization Temperature and Yield of Carbon Using Waste Plastics.

| Samples | Carbonization temperature ($T_c, °C$) | Yield (%)a | Activation temperature ($T_a, °C$) | Yield (%)b | $S_{BET}^c$ (m² g⁻¹) |
|---------|---------------------------------------|------------|------------------------------------|------------|----------------------|
| PDC-600 | 300                                   | 71.6       | 600                                | 63.7       | 97.6                 |
| PDC-700 | 300                                   | 67.2       | 700                                | 58.1       | 294.2                |
| PDC-800 | 300                                   | 64.5       | 800                                | 54.8       | 466.7                |

*a Yield was calculated after ZnCl₂ carbonization. b Yield was calculated after CO₂ activation. c Surface area determined after CO₂ activation.

The carbon yields under different carbonization conditions are summarized in Table S5. It can be seen that the yields are very different after ZnCl₂ carbonization. The largest yield is 71.6% for PDC-600 and the smallest yield is 64.5% for PDC-800. Compared to ZnCl₂ carbonization (data not shown), CO₂ activation generally results in larger surface areas and micropore volumes (determined by N₂ adsorption). However, a slight decrease in yield is observed for PDC-800 carbon sample. It is expected that at the carbonization temperature of 600 °C and above, the extensive growth of graphene layers occurs mainly due to the intermolecular crosslinking of polymer chains containing highly organized aromatic rings. Consequently, the decrease in yield is observed due to the formation of simple organic moieties, which are easily volatile during the carbonization at high temperature conditions. In addition, CO₂ activations also result in the large surface area, high porosity and thickening of the graphene planes. The formation of such structures allows for more graphene planes, which eventually enhance the catalytic active...
properties of the resultant PDCs. In other words, it can be inferred that a fast heating rate and slow CO\textsubscript{2} flow rate are appropriate to produce high surface area carbons yield.\textsuperscript{S13}

**Carbon Supported Other Heterogeneous Catalysts.** The results for the various supported metal catalysts are shown in Table S7. To prove the competence of the catalytic activity of Ru@PDC, the reduction of Fe(CN)\textsubscript{6}\textsuperscript{3−} was performed using various carbon supported heterogeneous metal catalysts, such as Fe\textsubscript{3}O\textsubscript{4}@PDC, Co\textsubscript{3}O\textsubscript{4}@PDC, NiO@PDC, MnO\textsubscript{2}@PDC and CuO@PDC, under identical conditions. The average crystal size of the metal nanoparticles was calculated by the Scherrer formula, and determined by XRD spectra (data not shown). The performance of other catalyst results is listed in Table S7. Among them, Fe\textsubscript{3}O\textsubscript{4}@PDC, Co\textsubscript{3}O\textsubscript{4}@PDC and MnO\textsubscript{2}@PDC (Table S7, entry 1 and 2) showed a very poor catalytic activity with a lower conversion, whereas the other catalysts (Table S7, entry 3–5) are less active compared to Ru@PDC catalyst in the Fe(CN)\textsubscript{6}\textsuperscript{3−} reduction. Based on these observations, we inferred that the presence of an active small Ru NPs (5 ± 0.2 nm) on PDC support (Ru@PDC) are responsible for the high catalytic activity in the presence of the NaBH\textsubscript{4} at room temperature.

**Table S6.** Different Catalysts in the Reduction of K\textsubscript{3}[Fe(CN)\textsubscript{6}].

| entry | catalyst       | size (nm)\textsuperscript{a} | time (s) | reductant | k (s\textsuperscript{-1}) | TOF (s\textsuperscript{-1}) | Conversion (%) |
|-------|----------------|-------------------------------|----------|-----------|--------------------------|-----------------------------|----------------|
| 1     | Fe\textsubscript{3}O\textsubscript{4}@PDC | 25-35                         | 50       | NaBH\textsubscript{4} | 0.018                    | 6.0 × 10\textsuperscript{-5} | 28             |
| 2     | Co\textsubscript{3}O\textsubscript{4}@PDC | 33-35                         | 50       | NaBH\textsubscript{4} | 0.021                    | 6.0 × 10\textsuperscript{-5} | 33             |
| 3     | NiO@PDC       | 34.5                          | 45       | NaBH\textsubscript{4} | 0.046                    | 6.66 × 10\textsuperscript{-5} | 41             |
| 4     | MnO\textsubscript{2}@PDC | 23-26                         | 41       | NaBH\textsubscript{4} | 0.056                    | 7.31 × 10\textsuperscript{-5} | 47             |
| 5     | CuO@PDC      | 22-24                         | 45       | NaBH\textsubscript{4} | 0.061                    | 6.66 × 10\textsuperscript{-5} | 55             |
| 6     | Ru@PDC       | 5 ± 0.2                       | 30       | NaBH\textsubscript{4} | 0.1011                   | 5.0 × 10\textsuperscript{-5} | 98             |

\textsuperscript{a}Reaction conditions: [K\textsubscript{3}Fe(CN)\textsubscript{6}] (3 × 10\textsuperscript{-3} M; 3 mL), catalyst (1.0 mg), NaBH\textsubscript{4} (0.04 M; 0.2 mL), RT. \textsuperscript{b}The average crystallite size was estimated from Scherrer’s equation.
| catalyst                  | size      | catalyst     | time | reductant | rate constant (k) | TOF (min\(^{-1}\)) | ref  |
|---------------------------|-----------|--------------|------|-----------|-------------------|---------------------|------|
| Au NPs\(^{a}\)            | 3 ± 4     | 50–150 µL    | 18   | NaBH\(_4\) | 0.24              | 0.72                | S14  |
| Pt NNs\(^{b}\)            | 60–100    | 50           | 60   | Na\(_2\)S\(_2\)O\(_3\) | 9.1 ± 0.7 × 10\(^{-3}\) | 1 × 10\(^{-2}\) | S15  |
| Pt NBs\(^{c}\)            | 60–100    | 50           | 60   | Na\(_2\)S\(_2\)O\(_3\) | 16.9 ± 0.6 × 10\(^{-2}\) | 1 × 10\(^{-2}\) | S15  |
| Pd/GPDA\(^{d}\)           | 2         | 5 µg         | 75 s | NaBH\(_4\) | 2.330 × 10\(^{-2}\) s\(^{-1}\) | 7.8 × 10\(^{8}\) s\(^{-1}\) | S16  |
| Au@Boehmite               | 15–40     | 1 cm\(^2\) × 1.9 µm | 32    | NaBH\(_4\) | 0.103            | NR                  | S18  |
| Au/Boehmite               | 15–40     | 1 cm\(^2\) × 1.9 µm | 70    | Na\(_2\)S\(_2\)O\(_3\) | 3.12 × 10\(^{-3}\) | NR                  | S18  |
| Spherical Au NPs          | 15.2 ± 2.5| 2.28 × 10\(^{-10}\) M | 60 s  | NaBH\(_4\) | 9.22 × 10\(^{-2}\) s\(^{-1}\) | 1.36 × 10\(^{5}\) s\(^{-1}\) | S19  |
| ce-MoS\(_2\)\(^{f}\)     | >100      | 22 µM        | 30   | NaBH\(_4\) | 53 ± 7 × 10\(^{-2}\) s\(^{-1}\) | 392 ± 32           | S20  |
| Fe\(_3\)O\(_4\)@Au NS\(^{h}\) | 5        | 2.8         | 240  | NaBH\(_4\) | 18.65 × 10\(^{-3}\) s\(^{-1}\) | 1.1 × 10\(^{-2}\) | S21  |
| Fe\(_3\)O\(_4\)@Au HS\(^{i}\) | 25–30    | 2.8         | 150  | NaBH\(_4\) | 36.55 × 10\(^{-3}\) s\(^{-1}\) | 7.14 × 10\(^{-3}\) | S21  |
| Au@(NIPAM-Am)             | 36 ± 5    | 1.8 × 10\(^{15}\) Au-atom mL\(^{-1}\) | 40    | NaBH\(_4\) | 1.9 × 10\(^{-2}\) | 0.1                | S22  |
| G\(^{j}\)-Pd              | 18.8      | 1.0          | 5    | NaBH\(_4\) | 9.5 × 10\(^{-3}\) s\(^{-1}\) | 4 × 10\(^{-2}\)   | S23  |
| G-Pt                      | 2.5       | 1.0          | 5    | NaBH\(_4\) | 2.1 × 10\(^{-2}\) s\(^{-1}\) | 2 × 10\(^{-2}\)   | S23  |
| G-Au                      | 15.6      | 1.0          | 5    | NaBH\(_4\) | 1.2 × 10\(^{-2}\) s\(^{-1}\) | 3.6 × 10\(^{-2}\) | S23  |
| G-Ag                      | 48.2      | 1.0          | 5    | NaBH\(_4\) | 2.6 × 10\(^{-2}\) s\(^{-1}\) | 1.6 × 10\(^{-2}\) | S23  |
| CNT\(^{k}\)/Pt\(_{x}\) hybrid | 3       | 0.40        | 60   | NaBH\(_4\) | 0.0820 s\(^{-1}\) | 1.35 × 10\(^{-3}\) | S24  |
| CNT/Pt\(_{x}\) hybrid     | 20        | 2.4          | 70   | NaBH\(_4\) | 0.0580 s\(^{-1}\) | 2.62 × 10\(^{4}\) | S24  |
| Fe\(_3\)O\(_4\)@GNS\(^{l}\) | 2        | 0.3 mL      | 1    | NaBH\(_4\) | NR               | NR                  | S25  |
| Stock Numbers | Material | Concentration | Activity | Contact Time | Active Mass | Discharge | Voltage |
|---------------|----------|---------------|----------|--------------|-------------|-----------|---------|
| GHNSs"        |          | 20–25         | 1.0      | 225 s        | NaBH₄       | 17.66 × 10⁻³ s⁻¹ | 6.664 × 10⁻³ | S26 |
| Pt-HPNTs"     |          | >100          | 2.0 g L⁻¹| 7.5          | NaBH₄       | NR        | 3.75 × 10⁻² | S27 |
| PDCA"--AuNPs  |          | 4.5 ± 0.6     | 10µL     | 3            | NaBH₄       | NR        | 7.5 × 10⁻³ | S28 |
| NiWO₄" NPs    |          | 20 ± 5        | 250      | 240          | Na₂S₂O₃     | 0.0064    | 9.6 × 10⁻⁴ | S29 |
| Au@pNIPAM"    |          | 58.2 ± 4.6    | 1.34 × 10⁻¹² M | 80s        | NaBH₄       | 0.08 s⁻¹ | NR      | S30 |
| Fe₃O₄@Pd NPs  |          | 20            | 25 µL    | 150          | NaBH₄       | 22.50 × 10⁻³ s⁻¹ | 3.28 × 10⁻² s⁻¹ | S31 |
| Fe₃O₄@Au--Pd NPs |        | 25–30         | 25 µL    | 90s          | NaBH₄       | 36.06 × 10⁻³ s⁻¹ | 8.78 × 10⁻² s⁻¹ | S31 |
| PEGDMA"@AuNP  |          | 8–10          | 0.1      | 20           | NaBH₄       | 0.837     | 3.0      | S32 |
| Ni(P₄Mo₆O₃₁)₂ |          | NR            | 3.16 × 10⁻⁶ M | 180        | Na₂S₂O₃     | 6.35 × 10⁻³ | 2.49 × 10⁻³ s⁻¹ | S33 |
| Cd(P₂Mo₆O₃₁)₂ |          | NR            | 3.22 × 10⁻⁶ M | 150        | Na₂S₂O₃     | 13.16 × 10⁻³ | 3.52 × 10⁻³ s⁻¹ | S33 |
| Cd₄(Cd(P₂Mo₆O₃₁)₂ |   | NR            | 5.53 × 10⁻⁶ M | 180        | Na₂S₂O₃     | 9.43 × 10⁻³ | 1.46 × 10⁻³ s⁻¹ | S33 |
| Mn-Phosphomolybate | | NR            | 20        | 150       | Na₂S₂O₃     | 1.5 × 10⁻³ | 7.5 × 10⁻³ | S34 |
| RuNPs         |          | NR            | 1.0      | 45s         | NaBH₄       | 0.0612 s⁻¹ | 6.66 × 10⁻⁵ s⁻¹ | this work |
| Ru/C          |          | NR            | 1.0      | 45s         | NaBH₄       | 0.021 s⁻¹ | 6.66 × 10⁻⁵ s⁻¹ | this work |
| Ru@PDC        |          | 5 ± 0.2       | 1.0      | 30s         | NaBH₄       | 0.0842 s⁻¹ | 1.0 × 10⁻⁴ s⁻¹ | this work |
| Ru@PDC        |          | 5 ± 0.2       | 2.0      | 30s         | NaBH₄       | 0.1011 s⁻¹ | 5.0 × 10⁻⁵ s⁻¹ | this work |
| Ru@PDC        |          | 5 ± 0.2       | 1.0      | 30s         | Na₂S₂O₃     | 0.0932 s⁻¹ | 1.0 × 10⁻⁴ s⁻¹ | this work |
| Ru@PDC        |          | 5 ± 0.2       | 2.0      | 30s         | Na₂S₂O₃     | 0.1164 s⁻¹ | 5.0 × 10⁻⁵ s⁻¹ | this work |

"Gold nanoparticles. "Platinum nanonets. "Platinum nanoballs. "Graphene-polydopamine. "Imidazole and institute of functional material chemistry. "Chemically exfoliated molybdenum disulfide. "Iron oxide. "Gold nanoseeds. "Gold hollow sphere. "Graphene. "Carbon nanotubes. "Graphene nanosheets. "Gold hollow nanospheres. "Hollow porous nanotubes. "2,6-Pyridinedicarboxylic acid. "Nickel tungstate. "Poly(N-isopropylacrylamide). "Poly(ethylene glycol dimethacrylate). "NR = Not reported
**Order of the Reaction.** Chen et al. reported that the order of the reaction can be expressed as follows:

\[-dC_A/dt = k^s(K_AC_A)^m/1+(K_AC_A)^m = kC_A^n\]  \hspace{1cm} (3)

where \(n\) refers to the apparent order of reaction with respect to the \([K_3Fe(CN)_6]\), and \(k\) can be defined as:

\[k = k^sK_AC_A^{m-n}/1+(K_AC_A)^m\]  \hspace{1cm} (4)

When \(n \neq 1\), the definite integration of the differential equation (eq (4)) yields eq (5), where \(C_{A0}\) is the initial concentration of the reactant \([K_3Fe(CN)_6]\).

\[C_A^{1-n} = (n-1)k + C_{A0}^{1-n}\]  \hspace{1cm} (5)

Importantly, eqn (5) can be used to quantitatively fit the curve \(C_A vs. t\) data, then the apparent reaction order, \(n\), and the apparent rate constant, \(k\), can be obtained.

**Table S8.** Kinetic Parameters for Ru@PDC Catalyst at Different Dosages.

| catalyst (mg) | reaction time (s) | \(R_{ave}^{a}\) (mol s\(^{-1}\)) | rate constant \((k, s\(^{-1}\))^{d}\) | \(n^{b}\) | TOF\(^{c}\) (mol mol\(^{-1}\) s\(^{-1}\)) | correlation coefficient \((R^2)\) |
|-------------|------------------|-----------------|----------------|---------|-----------------|-----------------|
| 0.25        | 30               | \(1 \times 10^4\) | 0.0686         | 0.90182 | \(4.0 \times 10^4\) | 0.9897          |
| 0.5         | 30               | \(1 \times 10^4\) | 0.0798         | 1.0672  | \(2.0 \times 10^4\) | 0.9864          |
| 1.0         | 30               | \(1 \times 10^4\) | 0.0942         | 1.3448  | \(1.0 \times 10^4\) | 0.9965          |
| 1.5         | 30               | \(1 \times 10^4\) | 0.1002         | 1.4388  | \(6.66 \times 10^5\) | 0.9981          |
| 2.0         | 30               | \(1 \times 10^4\) | 0.1011         | 2.5608  | \(5.0 \times 10^5\) | 0.9999          |
| 2.5         | 18               | \(1.66 \times 10^4\) | 0.1231         | 2.6438  | \(6.66 \times 10^5\) | 0.9977          |
| 3.0         | 15               | \(2.0 \times 10^4\) | 0.1335         | 2.6959  | \(6.66 \times 10^5\) | 0.9990          |

\(^{a}\)\(R_{ave}\) is defined by the initial moles of \([K_3Fe(CN)_6]\) over the overall reaction time. \(^{b}\)\(n\) is defined by the apparent order of reaction. \(^{c}\)TOF is the turnover frequency defined by the ratio of mole of \([K_3Fe(CN)_6]\) per mole of Ru@PDC catalyst in per second. \(^{d}\)\(k\) is defined by the rate constant.
**Table S9.** Chemical structure and some properties of NF dye

| Property                        | Value                                                                                                                                 |
|---------------------------------|---------------------------------------------------------------------------------------------------------------------------------------|
| Common name                     | New fuchsin, basic violet 2, magenta III, new magenta, fuchsin NB                                                                 |
| IUPAC name                      | 4-[(4-amino-m-tolyl)(4-imino-3-methylcyclohexa-2,5-dien-1-ylidene)methyl]-o-toluidine monohydrochloride                                    |
| Class                           | Triarylmethane                                                                                                                                 |
| Appearance                      | Green powder                                                                                                                                 |
| Empirical formula               | C\(_{22}\)H\(_{24}\)N\(_{4}\)Cl                                                                                                          |
| Solubility in water             | 1.13%                                                                                                                                 |
| Solubility in ethanol           | 3.2%                                                                                                                                 |
| Molecular weight (g mol\(^{-1}\)) | 365.90                                                                                                                                    |
| Color in water                  | Red                                                                                                                                 |
| \(\lambda_{\text{max}}\) (nm)  | 553 nm                                                                                                                                 |
| Molecular structure             | ![Molecular structure](image)                                                                                                             |

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