

Supplementary Information

Catalytic activity of gold nanoparticles protected by quaternary ammonium salt-based gemini surfactants with different spacer structures

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S1. Material and methods

Reduction reaction of *p*-nitrophenol (*p*-NP) into *p*-aminophenol

The reaction rate v of the reduction reaction of *p*-NP is represented by Eqs. (1) and (2):

$$v = - \frac{d[p\text{-NP}]}{dt} \quad (1)$$

$$= k[p\text{-NP}][\text{NaBH}_4], \quad (2)$$

where $[p\text{-NP}]$ and $[\text{NaBH}_4]$ are the concentrations of *p*-NP and sodium borohydride, respectively, t is the time, and k is the reaction rate constant. Because the concentration of sodium borohydride is significantly higher than that of *p*-NP ($[\text{NaBH}_4] \gg [p\text{-NP}]$), the second-order reaction in Eq. (2) can be presented as a pseudo-first-order reaction (Eq. (3)):

$$v = k'[p\text{-NP}], \quad (3)$$

where k' is the pseudo-first-order reaction rate, $k' = k [\text{NaBH}_4]$. From Eqs. (1) and (3), Eq. (4) is obtained by integrating over time t and $[p\text{-NP}]$ as follows:

$$\ln[p\text{-NP}]_t = \ln[p\text{-NP}]_0 - k't, \quad (4)$$

where $[p\text{-NP}]_0$ and $[p\text{-NP}]_t$ are the concentrations of *p*-NP at time 0 and t , respectively. Using the Lambert–Beer law in Eq. (4), Eq. (5) can be obtained:

$$\ln\left(\frac{A_t}{\varepsilon l}\right) = \ln\left(\frac{A_0}{\varepsilon l}\right) - k't, \quad (5)$$

where A_0 and A_t are the absorbances of *p*-NP at times 0 and t , respectively, ε is the molar absorption coefficient, and l is the length of the cuvette (1 cm). Because ε , l , and A_0 are constants (C), Eq. (5) can be expressed as Eq. (6):

$$\ln(A_t) = -k't + C \quad (6)$$

From Eq. (6), the relationship between the logarithm of the absorbance of *p*-NP at 400 nm ($\ln A_t$, herein after referred to as $\ln A_{400}$) and the reaction time t is linear with the slope $-k'$, where k' is the apparent reaction rate constant and can be calculated from the slope. From the

value of k' , we evaluated the catalytic activity of gold nanoparticles protected by gemini surfactants for the reduction reaction of *p*-NP.

Sodium borohydride and 1,1-diphenyl-2-picrylhydrazyl (DPPH) radical scavenging reaction

The scavenging reaction of DPPH radicals (DPPH•) by the antioxidant AH is represented by Eq. (7).



The generated radical A• is stable, and therefore its side reactions with DPPH• (Eq. (8)) or itself (Eq. (9)) can be ignored [27, 28].



S2. Dynamic light scattering (DLS)

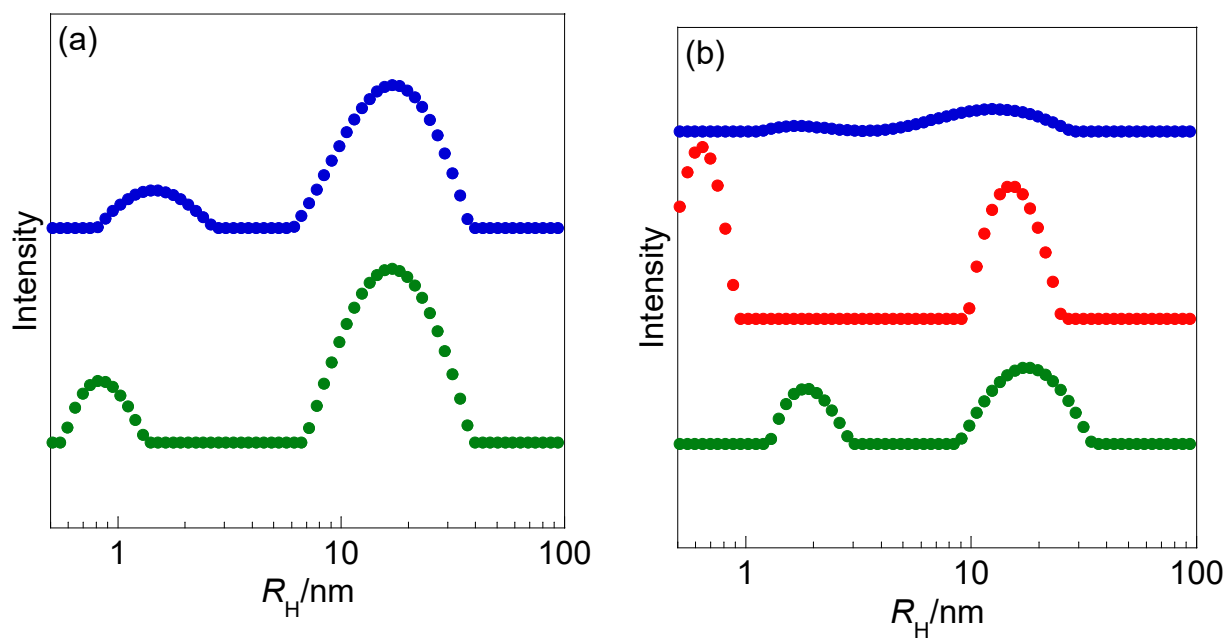


Fig. S1. Size distribution of apparent hydrodynamic radius for gold nanoparticles protected by gemini surfactants ($2C_{12}(\text{Spacer})$). (a) $[2C_{12}(\text{Spacer})]:[\text{Au}] = 1:1$, (b) $[2C_{12}(\text{Spacer})]:[\text{Au}] = 4:1$ for $2C_{12}(2/2\text{-N-}2)$ -gold nanoparticles (\bullet), $2C_{12}(2\text{-N-}2)$ -gold nanoparticles (\bullet), $2C_{12}(2\text{-O-}2)$ -gold nanoparticles (\bullet).