

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 \cdot) by the antioxidant AH is represented by Eq. (7).



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



S2. Dynamic light scattering (DLS)

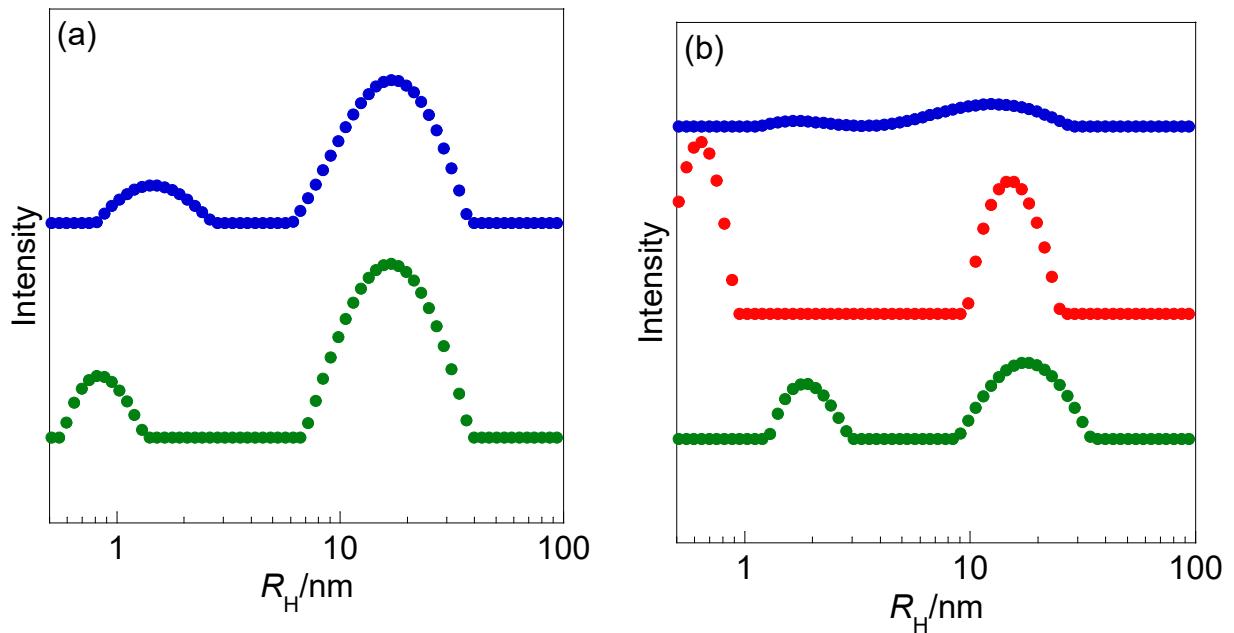


Fig. S1. Size distribution of apparent hydrodynamic radius for gold nanoparticles protected by gemini surfactants (2C₁₂(Spacer)). (a) [2C₁₂(Spacer)]:[Au] = 1:1, (b) [2C₁₂(Spacer)]:[Au] = 4:1 for 2C₁₂(2/2-N-2)-gold nanoparticles (●), 2C₁₂(2-N-2)-gold nanoparticles (●), 2C₁₂(2-O-2)-gold nanoparticles (●).