

Accelerated Diels–Alder reaction of quinones generated *in situ* by a modified electrode in an aqueous sodium dodecyl sulfate micellar system

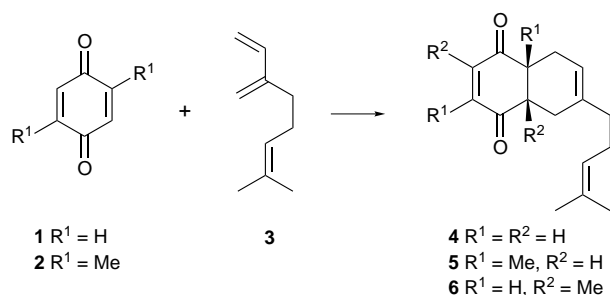
Kazuhiro Chiba,* Madoka Jinno, Ayako Nozaki and Masahiro Tada

Laboratory of Bio-organic Chemistry, Tokyo University of Agriculture and Technology, 3-5-8 Saiwai-cho, Fuchu, Tokyo 183, Japan

Diels–Alder reaction of *in situ* generated quinones with dienes is accomplished in excellent yield in an aqueous sodium dodecyl sulfate solution by selective electrooxidation on a glassy carbon electrode modified by cation-exchange resin.

A solvent system which possesses internal solvent pressures induces rate acceleration of intermolecular cycloaddition processes.¹ Previously we produced varied cycloadducts *via* electrochemically-generated intermediates in a lithium perchlorate–nitroalkane solution, which was found to accelerate cycloaddition reactions.² Aqueous solutions were also shown to be powerful media for Diels–Alder reactions which involved hydrophilic dienes and/or dienophiles.³ An aqueous solution can also be a facile electrolytic medium for large scale reaction systems, although the acceleration properties of aqueous media are less effective for many organic compounds which are

insoluble in water. In addition, dispersion of lipophilic or easily oxidizable compounds in the electrolytic medium often prevents electron transfer by coating, and oxidatively decomposing on, the electrodes. We therefore envisioned that the desired cycloaddition reaction should proceed at the interface of or inside of a micelle in which less polar, easily oxidizable dienes

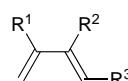
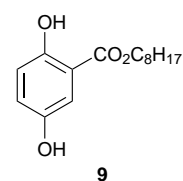
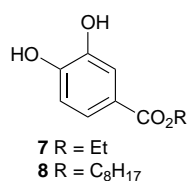


Scheme 1

Table 1 Effect of emulsifiers on the acceleration of Diels–Alder reaction in aqueous media^a

Quinone	Products	Emulsifier	Concentration/ mM	Yield T/°C (%)
1	4	—	—	25 5.2
1	4	sodium toluene- <i>p</i> -sulfonate	20	25 12.8
1	4	sodium dodecylsulfonate	20	25 8.0
1	4	sodium dodecylbenzenesulfonate	20	25 15.4
1	4	sodium dodecylbenzenesulfonate	200	25 18.6
1	4	sodium dodecyl sulfate	20	25 35.1
1	4	sodium dodecyl sulfate	200	25 99.8
2	5 + 6 (1:1)	—	—	25 ND ^b
2	5 + 6 (1:1)	—	—	40 12.1
2	5 + 6 (1:1)	sodium dodecyl sulfate	20	25 43.0
2	5 + 6 (1:1)	sodium dodecyl sulfate	20	40 82.2

^a All reactions were performed with dienophile and diene (10 mM each) in 0.1% aq. acetic acid. The reaction mixtures were allowed to stand for 40 h. Yields were determined by NMR by using internal standards. ^b ND = Not detected.

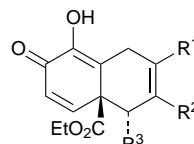
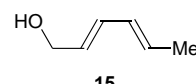


11 $R^1 = R^2 = Me, R^3 = H$

12 $R^1 = R^2 = H, R^3 = CH_2CO_2Et$

13 $R^1 = H, R^2 = Me, R^3 = CH_2CO_2Et$

14 $R^1 = H, R^2 = Me, R^3 = CH_2CH=CMe_2$



17 $R^1 = Me, R^2 = R^3 = H$

18 $R^1 = R^3 = H, R^2 = (CH_2)_2CH=CMe_2$

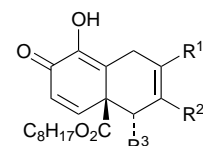
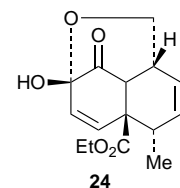
19 $R^1 = (CH_2)_2CH=CMe_2, R^2 = R^3 = H$

20 $R^1 = R^2 = Me, R^3 = H$

21 $R^1 = R^2 = H, R^3 = CH_2CO_2Et$

22 $R^1 = H, R^2 = Me, R^3 = CH_2CO_2Et$

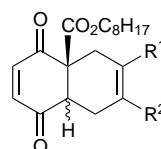
23 $R^1 = H, R^2 = Me, R^3 = CH_2CH=CMe_2$



26 $R^1 = (CH_2)_2CH=CMe_2, R^2 = R^3 = H$

27 $R^1 = R^2 = Me, R^3 = H$

28 $R^1 = H, R^2 = Me, R^3 = CH_2CH=CMe_2$



30 $R^1 = R^2 = Me$

could be maintained. Here we report our findings, which show that an aqueous sodium dodecyl sulfate (SDS) micellar system can realize the oxidative generation of unstable quinones and the marked acceleration of their cycloaddition with varied dienes.

In a preliminary study, the acceleration properties of emulsifiers for Diels–Alder reactions were examined. An equimolar mixture of quinone (**1** or **2**) and myrcene **3** in benzene or MeCN gave no product after 40 h standing at 25 °C,⁴ but very small amounts of cycloadducts were obtained in water even though the starting materials scarcely dissolved (Scheme 1). Although the Diels–Alder reaction was slightly accelerated by some emulsifiers, only SDS was found to accelerate significantly the cycloaddition reaction, which was further promoted by an increase in SDS concentration (Table 1).

As SDS also played a role as supporting electrolyte in water, the dispersion of SDS could be directly applied to the electrolytic system. The anode (glassy carbon, 60 × 20 mm) was firstly coated with Nafion,[†] and surface sulfonic acid moieties were converted to sulfonamide groups by treating with phenyl(ethyl)amine and DCC in dry MeCN (2 h at room temp.). Electrochemical oxidation was performed in a dispersion of ethyl 3,4-dihydroxybenzoate **7** (1.0 mM) and **10** (1.5 equiv.) in 20 mM SDS in 15 ml of 0.5% acetic acid using the modified anode and a Pt plate (10 × 10 mm) as the cathode in an undivided cell (2.2 F mol⁻¹, 0.8 V vs. SCE). In this reaction system, water soluble hydroquinones were directly oxidized on the electrode in the presence of dienes to yield the desired cycloadducts **16–24** (Table 2). Although dienes **12**, **13** and **14** were labile on a bare glassy carbon anode, giving cycloadducts in low yield (0–30%), the modified electrode successfully gave the desired products **20–23**. Hydrophobic hydroquinones **8** and **9** were barely oxidized in the micellar system, although the selective oxidation of hydroquinones followed by the cycloaddition reaction with dienes proceeded after addition of cerium(III) sulfate (0.02 equiv.) to the electrolytic system (1.2 V vs. SCE). It is presumed that Ce^{IV} was effectively generated at the electrode, thus oxidizing the hydrophobic hydroquinones at the interface of the SDS micelle (Fig. 1). Although hydrophilic *p*-quinones which possess electron withdrawing groups were unstable in aqueous media due to Michael addition of H₂O, it was found that hydrophobic *p*-quinone generated by cerium

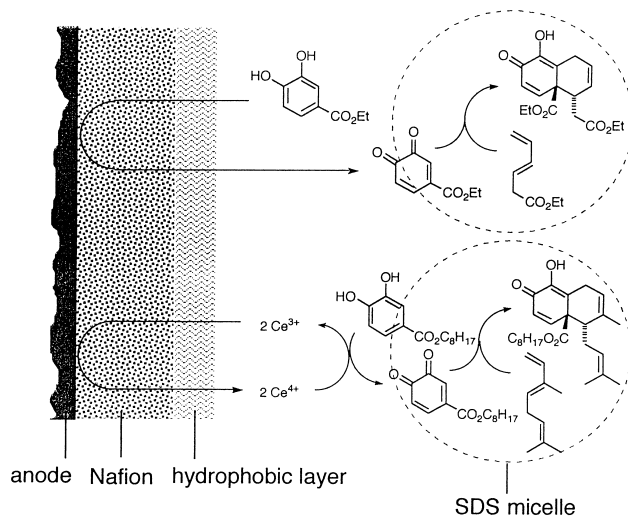


Fig. 1 Proposed mechanism of Diels–Alder reaction of *in situ* generated quinones in the SDS micellar system using the modified electrode

oxidation in the SDS micelle gave the desired cycloadducts in excellent yields **29** and **30**. This result showed that decomposition of quinones by the addition of H₂O was prevented in the hydrophobic micelle to give cycloadducts with dienes selectively.

In conclusion, the electrochemical generation of quinones and subsequent Diels–Alder reaction was accomplished to give varied cycloadducts in a simple, moderate aqueous SDS solution in which the Diels–Alder reaction was markedly accelerated. The modified anode in the SDS micellar solution provided selective oxidation of hydroquinones to give the desired products in high yields (84–100%) and current efficiency (88–96%).

Footnotes

* E-mail: chiba@cc.tuat.ac.jp

† A 5 wt% solution of Nafion in a mixture of alcohol and water (Aldrich) was coated and dried on the glassy carbon plate (0.05 ml cm⁻²).

References

- 1 P. A. Grieco, J. J. Nunes and M. D. Gaul, *J. Am. Chem. Soc.*, 1990, **112**, 4595; M. A. Forman and W. P. Dailey, *J. Am. Chem. Soc.*, 1991, **113**, 2761.
- 2 K. Chiba and M. Tada, *J. Chem. Soc., Chem. Commun.*, 1994, 2485; K. Chiba, J. Sonoyama and M. Tada, *J. Chem. Soc., Chem. Commun.*, 1995, 1381; *J. Chem. Soc., Perkin Trans. 1*, 1996, 1435.
- 3 R. Breslow, U. Maitra and Darry Rideout, *Tetrahedron Lett.*, 1983, **24**, 1901; D. A. Jaegler, H. Shinozuka and P. Goodson, *J. Org. Chem.*, 1991, **56**, 2482; P. A. Grieco, P. Garner and Z. He, *Tetrahedron Lett.*, 1983, **24**, 1897; D. A. Jaeger and J. Wang, *Tetrahedron Lett.*, 1992, **33**, 6415; W. Blokzijl, M. J. Blandamer and J. B. F. N. Engberts, *J. Am. Chem. Soc.*, 1991, **113**, 4241.
- 4 J. B. Hendrickson and V. Singh, *J. Chem. Soc., Chem. Commun.*, 1983, 837.

Received in Cambridge, UK, 7th May 1997; 7/03113K

Table 2 Electrochemical generation and cycloaddition of quinones with dienes in the micellar solution

Hydroquinone	Diene	Products	Yield (%)
7	10	16 + 17	quant. (16:17 1 : 1)
7	3	18 + 19	96 (18:19 1 : 2)
7	11	20	quant.
7	12	21	88
7	13	22	94
7	14	23	96
7	15	24	84
8	3	25 + 26	96 (25:26 1 : 2)
8	11	27	quant.
8	14	28	94
9	3	29	92
9	11	30	95