

Ene Reactions of β -Pinene at Room Temperature and 40 kbar Pressure

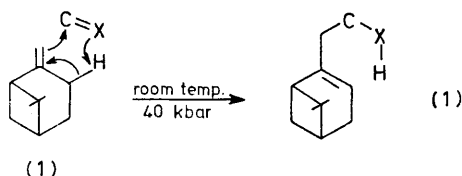
By J. A. GLADYSZ* and YEUNG S. YU

(Department of Chemistry, University of California, Los Angeles, California 90024)

Summary Ene reactions of β -pinene, which otherwise occur only at $>150^\circ\text{C}$ (if at all), proceed readily at room temperature under 40 kbar pressure.

THE application of pressure enhances the rates of chemical reactions which have $\Delta V^\ddagger < 0$ and retards the rates of those which have $\Delta V^\ddagger > 0$.¹ Our studies² and those of Dauben³ have demonstrated that pressures in the 10–40 kbar (9,870–39,500 atm) range are useful in effecting Diels–Alder reactions of pyrones,² dienamines,^{3a} and furans^{3b} which are impossible to achieve under conventional thermal cycloaddition conditions. Although the requisite apparatus for executing large-scale high-pressure syntheses is only moderately expensive,⁴ preparative studies, apart from Diels–Alder reactions, have not been undertaken.

We here report that 40 kbar pressures can be used to effect ene reactions of β -pinene (**1**) at room temperature (equation 1) which otherwise occur only at $>150^\circ\text{C}$, if at all. This establishes for the first time a negative ΔV^\ddagger for the ene reaction, and a new area of synthetically useful high-pressure chemistry.

TABLE. Ene reactions of β -pinene (**1**) at 40 kbar.

Enophile	Time/h	Product	% Yield
(2)	17	(6)	100 ^a
(3)	15	(7)	74 ^b
(4)	13	(8)	80
(5)	10	(9)	85

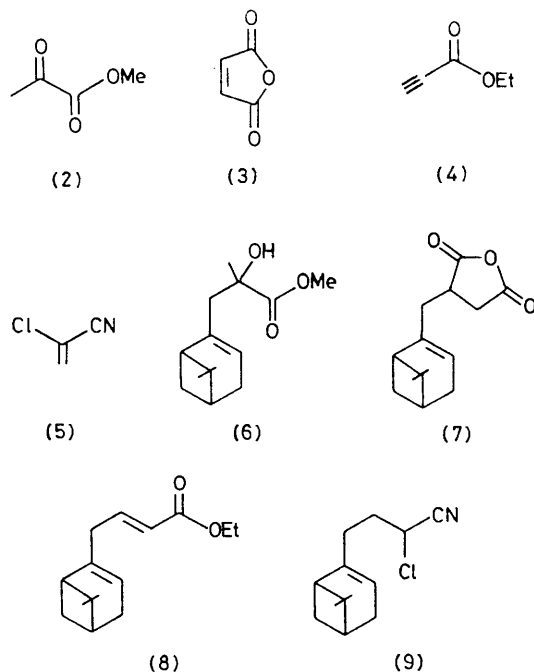
^a Compound (**6**) is obtained as a mixture of diastereoisomers (n.m.r., t.l.c.) although the thermal reaction is believed to be stereospecific (ref. 5). ^b Compound (**7**) is produced as a *ca.* 80:20 mixture of diastereoisomers under both thermal (ref. 6) and high pressure conditions.

β -Pinene (**1**) was allowed to react with 1–1.05 equiv. of each enophile in the Table. Reactions were conducted in acetone on a 150–200 mg scale in 0.3 ml Teflon screw-top vials as previously described.² Pressure was increased slowly to 40 kbar during 0.5 h to minimize compressional heating. Reaction mixtures were analysed by ¹H and ¹³C n.m.r. spectroscopy and yields shown represent the ratio of product to unchanged β -pinene; no by-products from β -pinene were formed. Chromatographic purification and/or recrystallization followed. The products (**7**) and (**8**) were identified by comparison with authentic samples prepared by published procedures.^{5–7}

Methyl pyruvate (**2**) and (**1**) have been reported to react at 165°C to afford (**6**) in 55% yield.⁵ Since (**6**) undergoes

a rapid retro-ene reaction at 165°C , this yield is believed to represent the maximum equilibrium yield obtainable.⁵ However, pressurization of (**2**) and (**1**) to 40 kbar at room temperature resulted in the quantitative formation of (**6**). Thus a reaction which is nearly thermoneutral at 1 atm goes to 100% completion under pressure.

Maleic anhydride (**3**) and (**1**) afforded a 74% yield of (**7**) after 17 h at 40 kbar. Only a 31% yield of (**7**) could be obtained when this reaction was conducted at 160°C for 22 h.⁶



Reaction of (**4**) and (**1**) at 40 kbar for 13 h gave (**8**) in 80% yield. This ene reaction can also be executed using AlCl_3 as a catalyst.⁷ We found that (**4**) and (**1**) did not react in refluxing xylene, but a 70% yield of (**8**) was obtained after 3 days at 175°C in a sealed tube.

The enophile (**5**) and (**1**) reacted over 10 h at 40 kbar, affording (**9**) in 85% yield. The attempted preparation of this new compound [*m/e* 223 (M^+ , ³⁵Cl); ¹H n.m.r. (δ , CDCl_3): 5.53 (1H, m), 4.43 (1H, t, *J* 8 Hz), 2.58–1.83 (11H, overlapping multiplets), 1.28 (3H, s), and 0.83 (3H, s); ¹³C n.m.r. (CDCl_3): 144.8, 118.8, 116.8 (CN), 45.7, 42.0, 40.7, 38.0, 34.1, 32.7, 31.7, 31.3, 26.2, and 21.1 p.p.m.] using conventional thermal conditions resulted only in a black tar.

In summary, we have demonstrated that pressure can be used in place of high temperatures or Lewis acid catalysts to effect ene reactions. Thus yield-limiting bond homolyses, retro-ene reactions, and acid-catalysed side reactions can be avoided. Furthermore, many potential enophiles

may become kinetically active at 40 kbar and 100—200 °C; hence the application of both pressure and temperature may substantially extend the scope of the ene reaction.

We thank the U.C.L.A. Research Committee for financial

support and Professor George C. Kennedy for the generous use of his high pressure facilities.

(Received, 21st March 1978; Com. 309.)

¹ W. J. le Noble, *Progr. Phys. Org. Chem.*, 1967, **5**, 207; *J. Chem. Educ.*, 1967, **44**, 729.

² J. A. Gladysz, S. J. Lee, J. A. V. Tomasello, and Y. S. Yu, *J. Org. Chem.*, 1977, **42**, 4170.

³ (a) W. G. Dauben and A. P. Kozikowski, *J. Amer. Chem. Soc.*, 1974, **96**, 3664; (b) W. G. Dauben and H. O. Krabbenhoft, *ibid.*, 1976, **98**, 1992.

⁴ See W. G. Dauben and H. O. Krabbenhoft, *J. Org. Chem.*, 1977, **42**, 282, and supplementary material.

⁵ R. T. Arnold and P. Veeravagu, *J. Amer. Chem. Soc.*, 1960, **82**, 5411.

⁶ R. T. Arnold and J. S. Showell, *J. Amer. Chem. Soc.*, 1957, **79**, 419.

⁷ B. B. Snider, *J. Org. Chem.*, 1976, **41**, 3061.