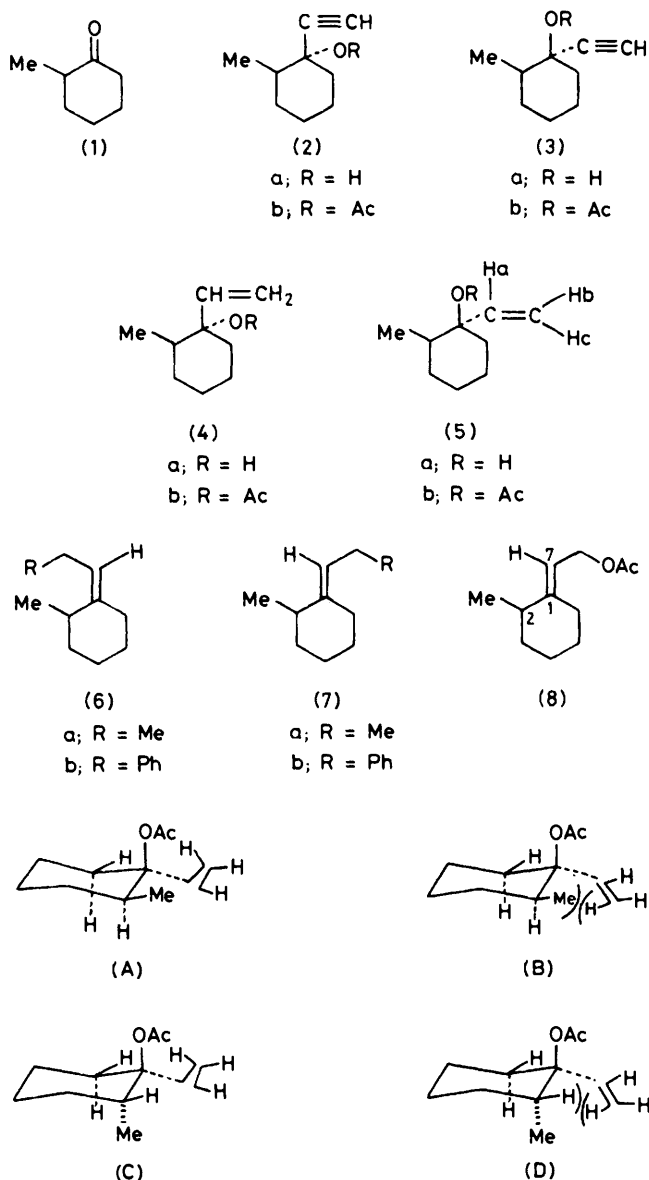


Steric Course of Cross Coupling of Organocopper Reagents with Allylic Acetates¹

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The *trans*- and *cis*-2-methyl-1-vinylcyclohexyl acetates (4b) and (5b) were prepared from 2-methylcyclohexanone (1). The stereochemistry of the reaction of these isomers when treated with lithium dialkylcopper reagents is investigated and the structures are confirmed by ¹³C n.m.r. spectroscopy. The stereoselectivity experienced in the conversion of the *cis*-compound (5b) into the *E*-olefins (7a and b) is not observed with the *trans*-analogue (4b). This is tentatively interpreted in terms of steric hindrance during the attack of the reagent in the case of (5b).

A NEW route to olefins by cross coupling reaction of allylic esters with lithium dialkylcuprates has been



reported.¹ The stereoselectivity, initially observed in the case of a steroidal allylic acetate,¹ has been further

investigated.² A preference for the formation of *trans*-olefins has been observed.^{1,2} In addition to moderate solvent dependence, a correlation has been noted² between the acidity of the conjugate acid of the leaving carboxylate group and the stereoselectivity of alkylation. The present study was initiated to investigate further stereochemical directive effects in lithium dialkylcopper reactions on simple allylic acetates.

2-Methylcyclohexanone (1) was used as starting material for the preparation of the *trans*- and *cis*-2-methyl-1-vinylcyclohexyl acetates (4b) and (5b). Ethynylation of 2-methylcyclohexanone (1) with lithium acetylide-ethylenediamine complex in dimethyl sulphoxide,³ afforded a mixture of *trans*- (2a) and *cis*- (3a) acetylenic alcohols, separated by preparative t.l.c. on silica gel plates. The assignment of configuration of these isomers is based on their physical properties, in particular the relative polarities on t.l.c.⁴ and their ¹³C n.m.r. spectra (*vide infra*).

After acetylation of the tertiary hydroxy-group, the triple bond of the propargyl acetates (2b) and (3b) was reduced catalytically with 5% palladium on calcium carbonate in pyridine solution,⁵ to provide the vinylic acetates (4b) and (5b), respectively.

The *cis*-compound (5b) was also prepared by catalytic hydrogenation of the mixture of alcohols (2a) and (3a), under conditions described above,⁵ yielding the *trans* (4a) and *cis* (5a) allylic alcohols, which were separated by t.l.c. Acetylation of the alcohol function of the *cis*-compound (5a) with acetic anhydride at reflux temperature provided the corresponding acetate (5b), along with some rearranged acetate (8). Under identical reaction conditions the *trans*-alcohol (4a) gave exclusively the primary acetate (8). The configuration of

¹ P. Rona, L. Tökés, J. Tremble, and P. Crabbé, *Chem. Comm.*, 1969, 43.

² R. J. Anderson, C. A. Henrick, and J. B. Siddall, *J. Amer. Chem. Soc.*, 1970, **92**, 735; R. J. Anderson, C. A. Henrick, J. B. Siddall, and R. Zurflüh, *ibid.*, 1972, **94**, 5379; E. J. Corey and J. Mann, *ibid.*, 1973, **95**, 6832; G. E. Gream and C. F. Pincombe, *Austral. J. Chem.*, 1974, **27**, 543; H. L. Goering, and V. D. Singleton, jun., *J. Amer. Chem. Soc.*, 1976, **98**, 7854.

³ J. W. Huffman and P. G. Arapakos, *J. Org. Chem.*, 1965, **30**, 1604.

⁴ See (a) H. Schlossarczyk, W. Sieber, M. Hesse, H. J. Hansen, and H. Schmid, *Helv. Chim. Acta*, 1973, **56**, 875; (b) M. J. Batuev, A. A. Akhrem, A. D. Matveeva, and A. V. Kamernitskii, *Doklady Akad. Nauk. S.S.S.R.*, 1958, **120**, 779.

⁵ See R. L. Augustine, 'Catalytic Hydrogenation,' Dekker, New York, 1965.

this substance is based on its conversion into olefin (7a) (see below). The primary acetate (8) was also formed by prolonged treatment of compound (5b) with acetic anhydride at reflux temperature.

chemistry of these *Z*- (6a) and *E*- (7a) olefins was ascertained through n.m.r. analysis. In a similar manner, treatment of compound (4b) with lithium diphenylcopper gave 75% of a 1 : 1 mixture of isomeric trisubstituted

¹³C N.m.r. spectral data (22.62 MHz) in CDCl₃^a

Assignment	(2a)	(3a)	(4a)	(4b)	(5a)	(5b)	(6a)	(7a)	(9)	(10)	(11)	(12)
1	73.21	69.55	75.10	85.69	74.22	84.46	142.68	143.14	149.97	140.12	41.77	28.87
2	42.46	40.49	41.68	37.91	38.91	41.71	30.14	38.43	35.70	37.52	32.74	32.64
3	32.22	29.32	31.57	29.97 ^c	29.97	30.36 ^c	33.32 ^c	36.90	28.61	28.51 ^c	26.17	24.84
4	25.55	25.05	25.13	22.85 ^b	26.07	25.42	21.10 ^b	25.65 ^c	26.66	27.41 ^b	26.37	25.91
5	24.22	21.03	23.63	22.76 ^b	21.49	21.57	28.64 ^b	28.28 ^c	28.61	28.97 ^b	26.17	24.84
6	40.77	39.32	39.73	30.92 ^c	38.72	32.31 ^c	32.48 ^c	28.19 ^c	35.70	27.96 ^c	32.74	32.64
7	16.03	15.96	15.44	15.08	15.51	15.41	18.34	18.73				
8	85.11	88.73	140.44	137.55	146.39	142.03	123.34	120.64	106.86	115.41	144.96	89.01
9	74.22	71.07	113.65	115.38	111.46	112.68	20.09	20.42		12.61	111.70	67.91
10				169.76		170.12	14.95	14.95				
11				22.30		21.91						

^a Chemical shifts in p.p.m. downfield from Me₄Si. ^{b,c} Assignments in a vertical column may be interchanged.

Although rearrangements of this type under similar reaction conditions are known in the chemical literature,⁶ it is of interest to note that both the *trans*- (4a) and *cis*- (5a) allylic alcohols yielded the thermodynamically more stable *trans*-ethylene acetate (8).

Treatment of the *cis*-isomer (5b) with 1.1–1.5 equiv. lithium dimethylcopper⁷ in ether solution at 0° led to an S_N2' type process providing the *trans*-olefin (7a) in 76% yield. Similarly, coupling of (5b) with lithium diphenylcopper gave the *E*-olefin (7b), in agreement with the results obtained with the steroidal allylic acetate.¹ These findings also tend to indicate that in the course of the organocuprate reactions with the *cis*-compound (5b), steric factors can easily be envisioned as the primary directors of stereoselectivity.

In contrast, when the *trans*-vinyl acetate derivative (4b) was treated with lithium dimethylcopper, under identical reaction conditions, a 1 : 1 mixture of *Z*- (6a) and *E*- (7a) geometrical isomers was obtained in 79% yield. Separation was achieved by g.l.c. using a 10% OV-17 column or by preparative t.l.c. The stereo-

olefins (6b) and (7b), separated by g.l.c. or t.l.c. The *E*-isomer (7a) was also formed when the acetoxy-derivative (8) (see above) was treated with lithium dimethylcopper.

Although various types of reductive processes have been observed during organocuprate reactions,⁸ often as side reactions, it is worth noting that the conversion of the primary acetate (8) into the methyl derivative (7a) occurred in almost quantitative yield.

The stereochemistry of the substrates and products from these cross-coupling reactions with organocuprate reagents was investigated by ¹³C and shift reagent n.m.r. studies. The assignments of the carbon resonances (Table) for model compounds (9)–(12) are straightforward using standard techniques⁹ while those for (2a) and (3a) can be calculated from established parameters,^{10,11} and agree very well with the analogous 1-methyl compounds.¹² The stereochemical assignments of compounds (2a) and (3a) as the *trans*- and *cis*-isomers, respectively, are based on these carbon resonances [with axial ethynyl in (3a), C-8 is shifted to higher field] and on shift reagent studies (*vide infra*). These assignments are in agreement with those reported by Schlosarczyk *et al.*^{4a} and Batuev *et al.*^{4b} but disagree with the assignments of some other workers.¹³

⁶ *Inter alia* K. Dimroth, *Ber.*, 1938, **71**, 1333; A. Serini, W. Logemann, and W. Hildebrand, *ibid.*, 1939, **72**, 391; see also L. Fieser and M. Fieser, *Steroids*, Reinhold, New York, 1959, p. 618.

⁷ H. Gilman and J. M. Straley, *Rec. Trav. chim.*, 1936, **55**, 821; H. Gilman, R. G. Jones, and L. A. Woods, *J. Org. Chem.*, 1952, **17**, 1630.

⁸ See J. A. Marshall and R. A. Ruden, *Tetrahedron Letters*, 1971, 2875; *J. Org. Chem.*, 1972, **37**, 659; P. Crabbé and H. Carpio, *J.C.S. Chem. Comm.*, 1972, 904; J. A. Katzenellenbogen and E. J. Corey, *J. Org. Chem.*, 1972, **37**, 1441; J. Klein and R. Levene, *J. Amer. Chem. Soc.*, 1972, **94**, 2520; L. T. Scott and W. D. Cotton, *J.C.S. Chem. Comm.*, 1973, 320; P. Ortiz de Montellano, *ibid.*, p. 709; J. R. Bull and H. H. Lackmann, *Tetrahedron Letters*, 1973, 3055; J. R. Bull and A. Tuinmann, *ibid.*, p. 4349; C. R. Johnson, R. W. Herr, and D. M. Wieland, *J. Org. Chem.*, 1973, **38**, 4626; P. Crabbé, E. Barreiro, J. M. Dollat, and J. L. Luche, *J.C.S. Chem. Comm.*, 1976, 183, and references therein; H. O. House and J. C. DuBose, *J. Org. Chem.*, 1975, **40**, 788; J. A. Thompson and P. Crabbé, in preparation; see also ref. 2.

⁹ J. B. Stothers, 'Carbon-13 N.M.R. Spectroscopy,' Academic Press, New York, 1972; G. C. Levy and G. L. Nelson, 'Carbon-13 Nuclear Magnetic Resonance for Organic Chemists,' Wiley-Interscience, New York, 1972.

¹⁰ D. K. Dalling and D. M. Grant, *J. Amer. Chem. Soc.*, 1967, **89**, 6612.

¹¹ Sadtler Research Labs, Inc., Standard Carbon-13 N.M.R. Spectra N° 1013.

¹² Y. Senda, J. Ishiyama, and S. Imaizumi, *Tetrahedron*, 1975, **31**, 1601.

¹³ See (a) J. L. M. A. Schlattmann and E. Havinga, *Rec. Trav. chim.*, 1961, **80**, 1101; (b) M. L. Roumestant and J. Goré, *Bull. Soc. chim. France*, 1972, 598.

Similarly, the ring carbon resonance assignments of isomers (4a) and (5a) are based on the corresponding resonances of the acetylene compounds (2a) and (3a), respectively, as well as on the work of Senda *et al.*¹² The assignment of configuration at C-1 in the olefins (4a) and (5a) is based on the chemical shifts of C-8, with the higher field C-8 being assigned to the isomer with the axial vinyl group, assuming that in both isomers 2-methyl stays in the equatorial position. This is in complete agreement with compound (4a) being derived from (2a) by catalytic reduction. In the acetates (4b) and (5b) unambiguous assignment of the ring carbons were not possible although expected shifts were observed for C-1 and -6.^{14,15} In these compounds as well, the C-8 resonance is shifted to higher field in (4b), in which the vinyl group is axial, in agreement with their genesis.

In the geometrical isomers (6a) and (7a), C-2 was readily identified through off resonance decoupling; however, unambiguous assignments were not possible for the remaining ring carbons. From published work^{9,16,17} on double bond isomers, the chemical shift of C-2 is expected at higher field in the *Z*-isomer. Using compound (10) (see Table) as a model, this chemical shift difference should be *ca.* 9–10 p.p.m. The difference in the observed shifts of C-2 in compounds (6a) and (7a) is 8.3 p.p.m. and requires that compound (6a) be assigned as the *Z* configuration.

In addition to the ¹³C n.m.r. studies, isomers (2a) and (3a) were examined by ¹H n.m.r. spectroscopy using the shift reagent, Eu(fod)₃.¹⁸ Although the pseudo-contact shift has both an angular and distance dependence, the *r*⁻³ term is usually dominant.¹⁹ An examination of Dreiding molecular models indicates that an axial hydroxy is closer to the equatorial hydrogen on the adjacent carbon than to the axial hydrogen, and thus the pseudo-contact shift in the presence of Eu(fod)₃ should be larger for 6e-H in isomer (3a). In the isomer with the equatorial hydroxy-group as in compound (2a) the distances between the oxygen and 6e- and 6a-H are approximately equal; therefore, the induced shifts should be similar. In the ¹H spectrum of the acetylenic alcohol (3a) (measured in C₆D₆) in the presence of 0.98 equiv. Eu(fod)₃, 6e-H resonated at δ 7.27 while the 6a-H signal was at δ 5.44. In the spectrum of (2a) however [0.988 equiv. Eu(fod)₃] the corresponding shifts were δ 11.53 and 11.27. Similar effects in an analogous case have been reported by Bélanger *et al.*²⁰ These observations are in agreement only with compound (2a) being assigned as the *trans*-isomer.

The Table summarizes the ¹³C n.m.r. data of these

¹⁴ H. J. Reich, M. Jantelat, M. T. Messe, F. J. Weigart, and J. D. Roberts, *J. Amer. Chem. Soc.*, 1969, **91**, 7445.

¹⁵ M. Christl, H. J. Reich, and J. D. Roberts, *J. Amer. Chem. Soc.*, 1971, **93**, 3463.

¹⁶ G. Van Binst and D. Tourwe, *Org. Magnetic Resonance*, 1972, **4**, 625.

¹⁷ J. W. deHann and L. J. M. van de Von, *Org. Magnetic Resonance*, 1973, **5**, 147.

¹⁸ R. E. Rondeau and R. E. Sievers, *J. Amer. Chem. Soc.*, 1971, **93**, 1522; obtained from Ventron Corp, San Leandro.

isomeric compounds. The apparent discrepancy between the behaviour of the *trans*-isomer (4b) and its *cis*-counterpart (5b) during the coupling reaction can be explained either in terms of orbital overlap during the cross-coupling reaction with the organocopper reagents or the geometric possibility of forming an organocopper intermediate of the type suggested by House and Umen.²¹ In order to allow an S_N2' process the vinyl group has to adopt a conformation in which the plane of the double bond is perpendicular to the carbon-oxygen bond of the acetate.

In the case of compound (5b) conformations (A) and (B) fulfil this requirement, although (A) may be expected to be energetically favoured, so that the product of the reaction would have the *E*-configuration, as in (7).

The case of compound (4b) is more complex. If we assume that the acetoxy-group chooses the axial configuration for kinetic reasons, conformations (C) and (D) are energetically similar, thus explaining the formation of both geometric isomers (6) and (7) during the cross-coupling reaction.

The stereoselectivity observed in the transformation of the *cis*-compound (5b) into (7a or b) does not exclude the existence of an allyl radical, linked through π -bonding (π -allyl complex) with the copper atoms of an aggregate, during the course of the reaction.²² In fact, the much faster capture by the free radical of a Lialkyl-Cu[•] from the molecule may be responsible for the retention of configuration in this 'ate' reaction, in contrast to the situation observed with the *trans*-isomer. However, the complete stereochemical control in the case of conversion of the *cis*-isomer (5b) into (7a and b) *versus* the 1:1 mixture of geometric isomers (6) and (7) obtained from the *trans*-allylic acetate (4b), would tend to favour the hypothesis that these displacements occur through S_N2' reaction mechanisms.

In conclusion, the organocopper method is shown to be stereoselective provided some requirements are satisfied. Hence, this organometallic technique constitutes a useful new reaction for the introduction of double bonds in a controlled stereospecific or highly stereoselective manner.²³

EXPERIMENTAL

Microanalyses were performed by Midwest Microlab Inc., Indianapolis. M.p.s were determined with a Fisher-Johns apparatus. T.l.c. was performed with silica gel GF-254 (Merck). I.r. spectra were taken with a Perkin-Elmer model 21 (NaCl prism) instrument. U.v. spectra were obtained with a Beckman DU spectrophotometer. Unless otherwise stated, the n.m.r. spectra were recorded with

¹⁹ A. F. Cockerill, G. L. O. Davies, R. C. Harden, and D. M. Rackham, *Chem. Rev.*, 1973, **73**, 553.

²⁰ P. Bélanger, C. Freppel, D. Tizané, and J. C. Richer, *Canad. J. Chem.*, 1971, **49**, 1985.

²¹ H. O. House and M. J. Umen, *J. Org. Chem.*, 1973, **38**, 3893.

²² See, for example, G. M. Whitesides and C. P. Casey, *J. Amer. Chem. Soc.*, 1966, **88**, 4541.

²³ *Inter alia* J. W. Cornforth, R. H. Cornforth, and K. K. Mathew, *J. Chem. Soc.*, 1959, **112**, 2539; D. J. Faulkner, *Synthesis*, 1971, 175; J. Reucroft and P. G. Sammes, *Quart. Rev.*, 1971, **25**, 135.

Varian HA-100 and T-60 instruments, for 5–8% w/v solutions in deuteriochloroform containing tetramethylsilane as internal reference. Coupling constants are accurate to ± 1 Hz. The ^{13}C n.m.r. spectra were measured on a Bruker WH-90 spectrometer in CDCl_3 solution (10 mm tubes, 0.1–0.5M) with tetramethylsilane as internal reference. 5 μs Pulses (33° flip angle) at a repetition rate of 0.68 s with a computer limited resolution of 0.735 Hz were used with a 6024 Hz spectral width. Compounds (9)–(12) were obtained from Aldrich Chemical Co., San Leandro, and used without further purification for n.m.r. studies. Mass spectra were recorded with an Atlas CH-4 spectrometer equipped with an EFO-4B ion source; ionizing energy 70 eV.

Ethynylation of 2-Methylcyclohexanone (1).—A stream of acetylene was passed for 10 min through a solution of lithium acetylide–ethylenediamine (180 g) suspended in anhydrous dimethyl sulphoxide (250 ml),³ stirred mechanically. While keeping the reaction mixture at 0–5°, 2-methylcyclohexanone (1) (50 g) was slowly added. Acetylene was bubbled through the solution for 30 min and the mixture was left with stirring, at room temperature for 20 h. Dilute hydrochloric acid (20%) was then added at 0°, and the product was extracted with ether, washed until neutral, and dried (Na_2SO_4).

After removal of the solvent *in vacuo*, there was obtained a 3 : 2 mixture of isomeric alcohols (2a) and (3a) (49.28 g), b.p. 65–67° at 7 mmHg; ν_{max} 3590 and 2100 cm^{-1} .

The separation of the isomeric mixture was carried out by preparative t.l.c. on silica gel, eluting with hexane–ethyl acetate (95 : 5) giving two fractions.

The less polar fraction was identified as the *cis*-1-ethynyl-2-methylcyclohexanol (3a), a colourless liquid, b.p. 62.5–63.5° at 6 mmHg; ν_{max} 3590, 3300, and 2100 cm^{-1} ; δ 1.08 (d, J 6 Hz, Me), 1.70 (s, OH), and 2.40 (s, $\equiv\text{CH}$); m/e 138 (M^+), 123 ($M^+ - \text{Me}$), 109 ($M^+ - \text{C}_2\text{H}_5$), and 95 ($M^+ - \text{C}_3\text{H}_7$) (Found: C, 78.1; H, 10.45. $\text{C}_9\text{H}_{14}\text{O}$ requires C, 78.2; H, 10.2%).

The more polar fraction is the *trans*-isomer (2a), obtained in the crystalline form, m.p. 56–57°; b.p. 63–64° at 6 mmHg; ν_{max} 3590, 3300, and 2100 cm^{-1} ; δ 1.10 (d, J 5 Hz, Me), 2.11 (s, OH), and 2.51 (s, $\equiv\text{CH}$); m/e 138 (M^+), and 123 ($M^+ - \text{Me}$) (Found: C, 77.9; H, 10.45%).

Preparation of the *cis*-Acetate (3b).—A solution containing *cis*-1-ethynyl-2-methylcyclohexanol (3a) (1 g) in acetic anhydride (5 ml), acetic acid (25 ml), and toluene-*p*-sulphonic acid (250 mg), was kept at room temperature with stirring, for 1.3 h. After addition of water and extraction with ether, the organic phase was washed with a solution of sodium hydrogencarbonate and then water to neutrality, dried (Na_2SO_4), and evaporated under reduced pressure.

cis-1-Ethynyl-2-methylcyclohexyl acetate (3b) (1.226 g) exhibited b.p. 76–79° at 5 mmHg; ν_{max} 3300, 2100, 1735, and 1230 cm^{-1} ; δ 1.06 (d, J 7 Hz, Me), 2.03 (s, acetate), and 2.53 (s, $\equiv\text{CH}$); m/e 180 (M^+), 165 ($M^+ - \text{Me}$), 138 ($M^+ - \text{CH}_2\text{CO}$) (Found: C, 72.4; H, 9.9. $\text{C}_{11}\text{H}_{16}\text{O}_2$ requires C, 72.5; H, 9.95%).

Preparation of the *trans*-Acetate (2b).—The *trans*-alcohol (2a) (1 g) was dissolved in acetic acid (25 ml). There was added acetic anhydride (5 ml) and toluene-*p*-sulphonic acid (250 mg). The mixture was left at room temperature with stirring for 1.30 h. Water was then carefully added and the acetate (2b) was extracted with ether. The organic phase was washed with a solution of sodium hydrogen-

carbonate and then with water to neutrality, dried over anhydrous sodium sulphate, and evaporated *in vacuo*.

trans-1-Ethynyl-2-methylcyclohexyl acetate (2b) (1.144 g) showed the following properties, b.p. 77–79° at 5 mmHg; ν_{max} 3290, 2100, 1735, and 1230 cm^{-1} ; δ 1.01 (d, J 7 Hz, Me), 2.01 (s, acetate), 2.61 (s, $\equiv\text{CH}$); m/e 180 (M^+), 165 ($M^+ - \text{Me}$), 138 ($M^+ - \text{CH}_2\text{CO}$) (Found: C, 72.55; H, 9.85. $\text{C}_{11}\text{H}_{16}\text{O}_2$ requires C, 72.5; H, 9.95%).

***cis*-2-Methyl-1-vinylcyclohexyl Acetate (5b).**—*cis*-1-Ethynyl-2-methylcyclohexyl acetate (3b) (1 g) in anhydrous pyridine (1.4 ml) was hydrogenated at atmospheric pressure and at room temperature, in the presence of prehydrogenated 5% palladium (0.451 g) on calcium carbonate. Hydrogenation was stopped after the up-take of one equivalent of hydrogen. The catalyst was filtered off on Celite, washed with methanol, and the solvent was removed by distillation. The product was purified by t.l.c. on silica gel and eluted with hexane–ethyl acetate (97 : 3). *cis*-2-Methyl-1-vinylcyclohexyl acetate (5b), showed b.p. 70–72° at 15 mmHg; ν_{max} 1725, 1640, and 1230 cm^{-1} ; δ 0.91 (d, J 6 Hz, Me), 2.03 (s, acetate), 4.98 (dd, J_{ca} 18, J_{cb} 2 Hz, H_c), 5.11 (dd, J_{ba} 12, J_{bc} 2 Hz, H_b), and 6.1 (dd, J_{ab} 12, J_{ac} 18 Hz, H_a), m/e 182 (M^+) and 122 ($M^+ - \text{AcOH}$) (Found: C, 72.4; H, 10.0. $\text{C}_{11}\text{H}_{18}\text{O}_2$ requires C, 72.5; H, 9.95%).

***trans*-2-Methyl-1-vinylcyclohexyl Acetate (4b).**—*trans*-2-Methyl-1-ethynylcyclohexyl acetate (2b) (1 g) was hydrogenated under the same conditions as its *cis*-isomer (5b). The product was purified by t.l.c. on silica gel, and eluted with hexane–ethyl acetate (95 : 5).

trans-2-Methyl-1-vinylcyclohexyl acetate (4b) exhibited b.p. 70–72° at 15 mmHg, ν_{max} 1725, 1640, and 1230 cm^{-1} ; δ 0.90 (d, J 6 Hz, Me), 2.00 (s, acetate), 5.16 (dd, J_{ca} 18, J_{cb} 2 Hz, H_c), 5.26 (dd, J_{ba} 12 Hz, H_b), and 6.06 (dd, J_{ab} 12, J_{ac} 18 Hz, H_a); m/e 182 (M^+) and 122 ($M^+ - \text{AcOH}$) (Found: C, 72.25; H, 10.2%).

Catalytic Hydrogenation of 2-Methyl-1-ethynylcyclohexanol (2a) and (3a).—The mixture of 2-methyl-1-ethynylcyclohexanol isomers (2a) and (3a) (10 g) was hydrogenated at room temperature under atmospheric pressure in anhydrous pyridine (70 ml), with prehydrogenated 5% palladium (2 g) on calcium carbonate. The hydrogenation was stopped after hydrogen up-take equivalent to one mole. The catalyst was filtered off, washed with methanol, and the solvents were evaporated under reduced pressure. The isomeric mixture was separated on preparative chromatoplates (t.l.c.) in hexane–ethyl acetate (9 : 1).

The less polar compound (3.54 g) was identified as the *cis*-2-methyl-1-vinylcyclohexanol (5a), b.p. 82° at 20 mmHg; ν_{max} 3550, 1640, 1450, and 995 cm^{-1} ; δ 0.80 (d, J 5.4 Hz, 2-Me), 5.05 (dd, J_{bc} 2, J_{ba} 11 Hz, H_b), 5.22 (dd, J_{ca} 18, J_{cb} 2 Hz, H_c), and 5.90 (dd, J_{ab} 11, J_{ac} 18 Hz, H_a) (Found: C, 77.3; H, 11.3. $\text{C}_9\text{H}_{16}\text{O}$ requires C, 77.1; H, 11.5%).

The more polar fraction (3.72 g) was identified as the *trans*-2-methyl-1-vinylcyclohexanol (4a) with the following properties, b.p. 84° at 20 mmHg, ν_{max} 3550, 1640, 1462, 1140, and 999 cm^{-1} ; δ 0.83 (d, J 6 Hz, 2-Me), 5.15 (dd, J_{ba} 12, J_{bc} 2 Hz, H_b), 5.30 (dd, J_{ca} 18, J_{cb} 2 Hz, H_c), and 6.2 (dd, J_{ab} 12, J_{ac} 18 Hz, H_a) (Found: C, 77.1; H, 11.4%).

Acetylation of *cis*-2-Methyl-1-vinylcyclohexanol (5a).—*cis*-2-Methyl-1-vinylcyclohexanol (5a) (2.59 g) was dissolved in acetic anhydride (8 ml). The mixture was heated at reflux temperature for 8 h, then cooled, poured into cold water, extracted with ether, and washed with a saturated solution of sodium hydrogencarbonate. After washing with

water to neutrality, the solution was dried (Na_2SO_4), filtered, and then evaporated under reduced pressure. The product was purified by t.l.c. using hexane-ethyl acetate 97:3 as eluant, yielding a liquid (1.51 g, 45%), b.p. 94° at 18 mmHg, shown to be a mixture of compounds (5b) and (8) (see below) by t.l.c. and n.m.r. analysis.

Acetylation of trans-2-Methyl-1-vinylcyclohexanol (4a).—*trans-2-Methyl-1-vinylcyclohexanol (4a)* (3.27 g) was dissolved in acetic anhydride (10.7 ml), and gently refluxed for 15 h. The solution was cooled, extracted with ether, washed with a saturated solution of sodium hydrogen-carbonate, then with water to neutrality, dried (Na_2SO_4), filtered, and then evaporated under reduced pressure. The product was purified by t.l.c. using hexane-ethyl acetate (99:1) as eluant. Distillation of the product yielded (*E*)-2-(2-methylcyclohexylidene)ethyl acetate (8) (1.31 g) showing the following properties, b.p. 96° at 16 mmHg, ν_{max} . 1 730, 1 668, 1 450, and 1 230 cm^{-1} , δ 1.04 (d, *J* 7 Hz, Me), 1.95 (s, acetate), 4.5 (d, *J* 7 Hz, =C-CH₂), and 5.18 (t, *J* 7 Hz, vinyl H); *m/e* 182 (M^+), 122 ($M^+ - \text{AcOH}$), 107 ($M^+ - \text{AcOH} - \text{Me}$) (Found: C, 72.4; H, 10.0. $\text{C}_{11}\text{H}_{18}\text{O}_2$ requires C, 72.5; H, 9.95%).

Treatment of cis-2-Methyl-1-vinylcyclohexyl Acetate (5b) with Acetic Anhydride.—Compound (5b) (0.1 g) was dissolved in acetic anhydride (3 ml) and heated under reflux for 15 h. The mixture was cooled, water was then added, and the solution extracted with ether. After washing with a saturated solution of sodium hydrogencarbonate, then with water to neutrality, and drying (Na_2SO_4), the solution was filtered and evaporated under reduced pressure. The resulting liquid was purified by t.l.c. and was shown to be identical with acetate (8) by the usual criteria (see above).

Reaction of the Primary Acetate (8) with Lithium Dimethylcopper.—To a suspension of copper(I) iodide (0.719 g) in anhydrous ether (8 ml), there was added at 0° with stirring under nitrogen, a methyl-lithium solution (3.78 ml, 2.2M), and acetate (8) (0.500 g) in anhydrous ether (10 ml). The reaction mixture was kept at 0° with stirring under nitrogen for 5 h. A saturated solution of ammonium chloride was added to the mixture, which was then filtered and extracted with ether. The ether solution was washed to neutrality, dried (Na_2SO_4), and evaporated under reduced pressure. The residue was purified by column chromatography on neutral alumina (20 g), eluted with pentane, affording 90% of hydrocarbon (7a).

After distillation, (*E*)-1-(2-methylcyclohexylidene)propane (7a) was obtained as a liquid, exhibiting b.p. 73° at 105 mmHg; ν_{max} . 1 670 and 1 460 cm^{-1} ; δ 0.92 (t, *J* 7 Hz, CH_3CH_2), 0.99 (d, *J* 7 Hz, Me), 1.99 (quintet, *J* 7 Hz, CH_3CH_2), and 5.015 (t, *J* 7 Hz, vinyl H); *m/e* 138 (M^+), 109 ($M^+ - \text{C}_2\text{H}_5$) (Found: C, 86.85; H, 13.2. $\text{C}_{10}\text{H}_{18}$ requires C, 86.9; H, 13.1%). This compound was shown to be identical with a sample of (7a) obtained by the copper reaction on (5b) (i.r., n.m.r., and t.l.c.).

Reaction of cis-2-Methyl-1-vinylcyclohexyl Acetate (5b) with Lithium Dimethylcopper.—To a suspension of copper(I) iodide (0.730 g) in anhydrous ether (8 ml), there was added a methyl-lithium solution (3.48 ml, 2.2M), with stirring, at 0° under nitrogen, and then *cis*-2-methyl-1-vinylcyclohexyl acetate (5b) (500 mg) in anhydrous ether (10 ml). The mixture was kept for 5 h at 0° with stirring under nitrogen. A saturated solution of ammonium chloride was added to the mixture, which was then filtered and extracted

with ether. The organic layer was washed to neutrality, dried (Na_2SO_4), and evaporated under reduced pressure. The product was chromatographed on neutral alumina (20 g) and eluted with pentane. The product (7a) (76%) showed the same spectral properties as the sample obtained by the cuprate reaction on compound (8).

Reaction of trans-2-Methyl-1-vinylcyclohexyl Acetate (4b) with Lithium Dimethylcopper.—To a suspension of copper(I) iodide (0.730 g, 3.8 mmol) in anhydrous ether (8 ml) under nitrogen, there was added a methyl-lithium solution (3.48 ml, 7.7 mmol, 2.2M) with stirring at 0° . Then *trans*-2-methyl-1-vinylcyclohexyl acetate (4b) (500 mg, 2.74 mmol) in anhydrous ether (10 ml) was introduced. The mixture was left for 5 h at 0° under nitrogen and with stirring. The reaction mixture was worked-up and purified as above, yielding a mixture of *E*- (7a) and *Z*- (6a) isomers (79%) which was then separated by preparative t.l.c. on silica gel. Distillation gave (*Z*)-(2-methylcyclohexylidene)propane (6a) with the following properties, b.p. $70-72^\circ$ at 110 mmHg; ν_{max} . 1 660 and 1 460 cm^{-1} ; δ 0.96 (t, *J* 7 Hz, CH_3CH_2), 0.97 (d, *J* 7 Hz, Me), 1.98 (quintet, *J* 7 Hz, CH_3CH_2), and 5.01 (m, vinyl H); *m/e* 138 (M^+), 109 ($M^+ - \text{C}_2\text{H}_5$) (Found: C, 86.9; H, 13.1. $\text{C}_{10}\text{H}_{18}$ requires C, 86.9; H, 13.1%). The (*E*)-isomer (7a) was shown by usual criteria to be identical with the substance obtained from (5b).

Reaction of cis-2-Methyl-1-vinylcyclohexyl Acetate (5b) with Lithium Diphenylcopper.—To a suspension of copper(I) iodide (0.719 g, 3.75 mmol) in anhydrous ether (8 ml), kept at 0° under nitrogen, there was added with stirring a phenyl-lithium solution (3.1 ml, 6.2 mmol, 2M). Then the *cis*-derivative (5b) (0.500 g, 2.74 mmol) in anhydrous ether (10 ml) was added to the above solution. The mixture was stirred for 7 h at 0° under nitrogen. After the usual work-up, the product was purified by t.l.c. on silica gel using hexane-ethyl acetate (99:1) as eluant. The resulting (*E*)-1-(2-methylcyclohexylidene)-2-phenylethane (7b) (0.395 g) exhibited b.p. $79-82^\circ$ at 2 mmHg; λ_{max} . 256 (ϵ 282), 262 (347), and 269 nm (302); ν_{max} . 1 590 and 1 460 cm^{-1} ; δ 1.03 (d, *J* 7 Hz, Me), 3.36 (d, *J* 7 Hz, PhCH_2), and 5.22 (t, *J* 7 Hz, vinyl H); *m/e* 200 (M^+), 109 ($M^+ - \text{PhCH}_2$) (Found: C, 89.75; H, 10.15. $\text{C}_{15}\text{H}_{20}$ requires C, 89.95; H, 10.05%).

Reaction of trans-2-Methyl-1-vinylcyclohexyl Acetate (4b) with Lithium Diphenylcopper.—The conditions described above for the *cis*-isomer (5b) were applied to the *trans*-analogue (4b). The product was purified by t.l.c. on silica gel, using hexane-ethyl acetate (99:1) as eluant. A mixture of compound (7b) and (*Z*)-1-(2-methylcyclohexylidene)-2-phenylethane (6b) was obtained. After distillation, b.p. $78-82^\circ$ at 2 mmHg, the pure (*Z*)-isomer (6b) was obtained. It exhibited ν_{max} . 1 590 and 1 460 cm^{-1} ; λ_{max} . 256 (ϵ 363), 262 (ϵ 442), and 269 nm (372); δ 1.08 (d, *J* 7 Hz, Me), 3.37 (d, *J* 7 Hz, PhCH_2), and 5.18 (t, *J* 7 Hz, vinylic H); *m/e* 200 (M^+) and 109 ($M^+ - \text{PhCH}_2$) (Found: C, 89.65; H, 10.15. $\text{C}_{15}\text{H}_{20}$ requires C, 89.95; H, 10.05%). The *E*-isomer (7b) was shown by usual criteria to be identical with the pure compound prepared directly from the *cis*-acetate (5b).

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