Synthesis and Novel Stereochemical Results in the Lithium–Ammonia Reduction of Some 4-Alkyl-$\Delta^{1(9)}$-2-octalones

EDWARD PIERS, WYNONA M. PHILLIPS-JOHNSON, and CHRISTIAN BERGER

Department of Chemistry, University of British Columbia, 2075 Wesbrook Place, Vancouver, British Columbia V6T 1W5

Received November 18, 1974

EDWARD PIERS, WYNONA M. PHILLIPS-JOHNSON, and CHRISTIAN BERGER. Can. J. Chem. **53**, 1291 (1975).

The 4-alkyl-$\Delta^{1(9)}$-2-octalones **7–11**, inclusive, prepared by conjugate addition of appropriate organocuprate reagents to the cross-conjugated dienones **13** and **14**, were subjected to lithium–ammonia reduction. Interestingly, these reductions produced, in each case, a considerably higher proportion (13–35%) of the corresponding *cis*-fused 2-decalone (**27–31**, inclusive) as compared with that normally formed in the alkali metal – ammonia reduction of $\Delta^{1(9)}$-2-octalones. The results are qualitatively explained in terms of the proposals originally set forth by Robinson.

EDWARD PIERS, WYNONA M. PHILLIPS-JOHNSON et CHRISTIAN BERGER. Can. J. Chem. **53**, 1291 (1975).

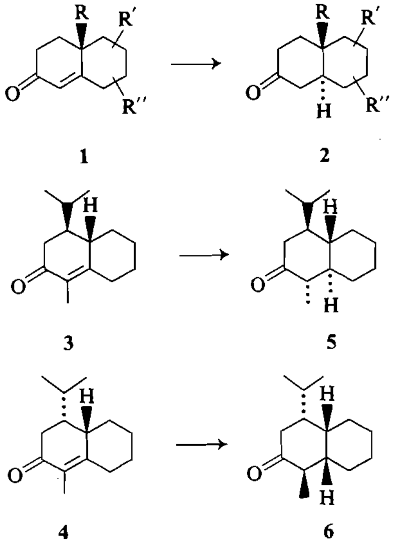
On a soumis à une réduction par le lithium dans l'ammoniac les alkyl-4 $\Delta^{1(9)}$ octalones-2 (**7** à **11**) préparées par l'addition 1–4 des réactifs organocuprates appropriés sur les diénones **13** et **14** conjuguées d'une façon croisée. Il est intéressant de noter que ces réductions produisent dans chaque cas une quantité proportionnellement plus élevée (13–35%) de la décalone-2 *cis* correspondante (**27–31** inclusivement) par opposition avec ce qui est normalement obtenu lors de la réduction par les métaux alcalins dans l'ammoniac des $\Delta^{1(9)}$ octalones-2. Les résultats sont expliqués sur une base qualitative en termes des propositions qui ont été originalement mises de l'avant par Robinson.

[Traduit par le journal]

The alkali metal – ammonia reduction of α,β-unsaturated ketones is a very useful and frequently employed reaction in organic synthesis. Not only is the reaction normally efficient in terms of product yield but it also produces as the initially formed product an enolate anion, which can then be used in a variety of ways. Furthermore, in those cases where new chiral centers are formed (particularly at the β-carbon), the reaction often proceeds with high stereoselectivity. More explicitly, the latter characteristic is of noteworthy importance in the synthesis of natural products (particularly steroids and terpenoids), in which the transformation illustrated in general terms by **1** → **2** is often a requirement. Indeed, it is well known that the alkali metal – ammonia reduction of $\Delta^{1(9)}$-2-octalone systems of type **1** generally proceeds in a highly stereoselective manner, yielding a large predominance of the corresponding *trans*-fused 2-decalone system **2** (1–3).

The mechanistic details of alkali metal – ammonia reduction of α,β-unsaturated carbonyl compounds have been the subject of many reports in the chemical literature. Of particular note in this regard are the recent papers by House *et al.* (4, 5) and by Kemp and co-workers (6, 7). Furthermore, the reasons underlying the high stereoselectivity of reduction of $\Delta^{1(9)}$-2-octalones and related compounds have been the subject of a number of studies (2, 3, 8) and discussions (9–11*a*). However, there does not as yet appear to be complete agreement as to what the reasons for this high stereoselectivity actually are and a number of different proposals have been put forward. The main source of controversy has been, and appears still to be, related to the question of whether the geometry of the transition state for protonation at the β-carbon is pyramidal (2, 5, 9) or trigonal (3).

In the accompanying paper (12) we reported the preparation and lithium–ammonia reduction of the two epimeric octalones **3** and **4**. It was found that although reduction of **3** proceeded in the "normal" manner and produced only the *trans*-fused 2-decalone **5**, a similar reduction of **4** afforded stereoselectively the *cis*-fused 2-decalone **6**. This novel and initially surprising result led us to initiate an investigation into the stereochemistry of lithium–ammonia reduction of a series of analogous $\Delta^{1(9)}$-2-octalones containing an angular methyl group at C_{10} and various axially oriented alkyl groups at C_4. In particular, we report in this paper the preparation and


1 2

3 5

4 6

lithium–ammonia reduction of the substituted $\Delta^{1(9)}$-2-octalones **7**–**11**, inclusive.[1]

Preparation of the 4α-Alkyl-4aβ-methyl-4,4a,5,6,7,8-hexahydro-2(3H)-napthalenones 7–11 (see Scheme 1)

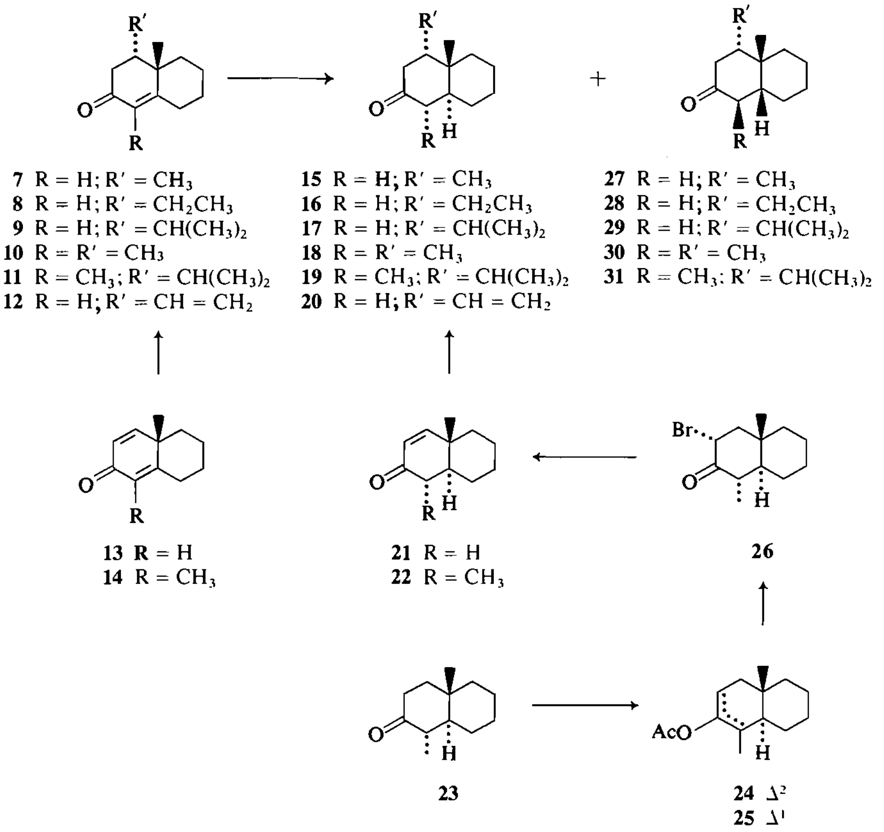
The $\Delta^{1(9)}$-2-octalones chosen for the present study were prepared by conjugate addition of appropriate cuprate reagents (14) to the cross-conjugated dienones **13** (15) and **14** (16). It is now well established that conjugate addition of Grignard reagents (copper catalyzed) or of lithium dialkylcuprate reagents to dienones such as **13** and **14** takes place both regioselectively and stereoselectively to produce the corresponding octalones with an axially oriented alkyl group at C_4 (14, 17–19). In other words, the incoming alkyl group attacks the less hindered β-carbon of the dienone system from the side opposite the already present angular methyl group. Molecular models clearly show that if approach of the reagent were to occur in a stereoelectronically allowed fashion from the other side of the molecule, the incoming alkyl group would, in the transition state, be nearly eclipsed with the angular methyl group. The resulting steric and torsional strain should be a dominant factor and, presumably, ensures that the alternate transition state (α attack at C_4) is favored.

Conjugate addition, under appropriate conditions, of lithium dimethyl-, divinyl-, and diisopropylcuprate to the cross-conjugated dienone **13** afforded, in good yields, the octalones **7**, **12**, and **9**, respectively. In each case, the reaction was highly stereoselective and the spectral properties of the product fully corroborated the assigned structure. The vinyl derivative **12** was found to be quite unstable and was therefore immediately converted, by hydrogenation in the presence of tris(triphenylphosphine)chlororhodium (20), into the corresponding ethyl derivative **8**. In a similar fashion, addition of lithium dimethyl- and diisopropylcuprate to the dienone **14** afforded the octalones **10** and **11**, respectively.

It should be noted that considerable experimentation was done to find optimum conditions for the above-mentioned conjugate additions. Therefore, it is appropriate to make a few general comments regarding these reactions. At the time this work was underway, House and co-workers (21, 22) had already reported a detailed study of the use of lithium dimethylcuprate in conjugate addition to α,β-unsaturated ketones and we therefore experienced no problems in connection with the use of this reagent. However, no analogous information was available for lithium divinyl- or diisopropylcuprate. Initially, therefore, a procedure analogous to that used by House *et al.* (21) for the preparation and use of the dimethyl reagent was also employed for the divinyl and diisopropyl reagents. However, it was found that this procedure gave rise to only a poor yield of conjugate addition product with the divinylcuprate and only recovered starting material or polymeric material in the latter case. In an attempt to enhance the reactivity of the lithium diisopropylcuprate reagent with respect to conjugate addition, the use of various additives was investigated. Indeed, it was found that fair to moderate yields of conjugate addition product could be realized if anhydrous lithium bromide was present in the reaction mixture. However, since these reactions were still rather inefficient as compared with the reactions involving the use of lithium dimethylcuprate, an alternative method of preparing the cuprate reagents was investigated. In this approach, the ether soluble cuprous iodide – tri-*n*-butylphosphine complex (23) was employed instead of cuprous iodide. The solutions of lithium divinyl- and diisopropylcuprates prepared in this manner were homogeneous in contrast to the colloidal appearance of those previously prepared. Fur-

---

[1] For a preliminary report regarding this work, see ref. 13.



7 R = H; R′ = CH_3
8 R = H; R′ = CH_2CH_3
9 R = H; R′ = $CH(CH_3)_2$
10 R = R′ = CH_3
11 R = CH_3; R′ = $CH(CH_3)_2$
12 R = H; R′ = CH = CH_2

15 R = H; R′ = CH_3
16 R = H; R′ = CH_2CH_3
17 R = H; R′ = $CH(CH_3)_2$
18 R = R′ = CH_3
19 R = CH_3; R′ = $CH(CH_3)_2$
20 R = H; R′ = CH = CH_2

27 R = H; R′ = CH_3
28 R = H; R′ = CH_2CH_3
29 R = H; R′ = $CH(CH_3)_2$
30 R = R′ = CH_3
31 R = CH_3; R′ = $CH(CH_3)_2$

13 R = H
14 R = CH_3

21 R = H
22 R = CH_3

26

23

24 Δ^2
25 Δ^1

SCHEME 1

thermore, the yields of conjugate addition products were markedly improved, although, in the case of the diisopropyl reagent, the use of anhydrous lithium bromide as an additive again appeared to be advantageous.

In further attempts to improve the yields of conjugate addition products, the effect of other reaction parameters (reaction time, temperature, reactant concentration, and quenching procedure) was investigated. Firstly, it was generally found that product yields obtained upon varying the reaction time from 4 to 36 h appeared to be invariant, although use of reaction times shorter than 4 h generally resulted in the recovery of some starting material. Secondly, repetition of various reactions at different temperatures clearly revealed that the best yields were obtained at low temperatures and most of the conjugate additions were therefore carried out at −78°. Thirdly, attempted additions using a variety of reactant concentrations indicated that optimum yields were obtained when the reaction solutions were between 0.01 and 0.005 *M* in the organocuprate reagents. Finally, it was found advantageous to quench the reactions by dropwise addition of the reaction mixtures to a rapidly stirred solution of aqueous acid (see ref. 24).

It should be noted that recently, subsequent to the time at which the above-described work was carried out, there have appeared a number of reports concerning the use of lithium divinylcuprate (25–29) and related reagents (30–40) in conjugate addition to a variety of α,β-unsaturated ketones.

Preparation of the Lithium–Ammonia Reduction Products (see Scheme 1)

Having realized the efficient and stereoselective synthesis of each of the octalones required for the projected lithium–ammonia reduction studies, it was necessary to unambiguously prepare the products which could be expected from these reductions. Explicitly, this involved the preparation of the *trans*-fused 2-decalones **15–19**, and the *cis*-fused 2-decalones **27–31**. The former compounds (**15**–**19**) were prepared by the conjugate addition of appropriate organocuprate reagents to the requisite α,β-unsaturated ketone. Thus, when the octalone **21** (41) was allowed to react with each of lithium dimethyl-, divinyl-, and diisopropylcuprate under conditions essentially identical with those outlined previously, the corresponding *trans*-fused 2-decalones (**15**, **20**, and **17**, respectively) were formed in good to excellent yields.[2] Hydrogenation of the vinyl derivative **20** in the presence of palladium-on-charcoal afforded, in 98% yield, the saturated decalone **16**. In a similar fashion, conjugate addition of lithium dimethyl- and diisopropylcuprate to the octalone **22**[3] gave, in excellent yields, the other two required *trans*-fused decalones **18** and **19**, respectively.

The required *cis*-fused decalones (**27**–**31**) were prepared by hydrogenation of the corresponding $\Delta^{1(9)}$-2-octalones **7**–**11**. It is well known that, under appropriate conditions, hydrogenation of Δ^4-3-keto steroids and related materials affords mainly the corresponding *cis*-fused decalone-type system. Furthermore, in the case of each of the octalones **7**–**11**, the presence of an axially oriented alkyl group at C_4 would tend to sterically hinder hydrogenation from the α side. In the event, hydrogenation of compounds **7**–**11** in 0.3 *N* ethanolic potassium hydroxide over palladium-on-charcoal afforded, in each case, a high yield ($\geq 95\%$) of product which consisted nearly entirely ($\geq 94\%$) of the corresponding *cis*-fused 2-decalone (**27**–**31**). In each case, the minor ($\leq 6\%$) hydrogenation product exhibited g.l.c. retention times identical with those of the corresponding *trans*-fused 2-decalones (**15**–**19**).

Lithium–Ammonia Reduction of Octalones 7–11

The lithium–ammonia reduction of each of the octalones **7**–**11** was carried out under standardized conditions. Thus, a solution of the appropriate substrate in ether was added over a period of 30 min to a solution of lithium in anhydrous ammonia, the reaction mixture was stirred for an additional 2 h, and was then quenched by addition of ammonium chloride. Each reduction was repeated at least twice. The crude product mixtures were distilled and then subjected to analysis by g.l.c. The reduction products, the *trans*- and *cis*-fused 2-decalones, were, in each case, isolated by preparative g.l.c. and were shown to be identical with the corresponding authentic materials prepared as described above.

The composition of the reduction products was determined by integration (disc integrator) of the g.l.c. trace obtained by analysis of the product mixtures. It was found that the molar response factor was, within experimental error, the same for each pair of *cis*- and *trans*-fused 2-decalones. This factor was determined, in each case, by preparing a mixture of authentic *cis*- and *trans*-fused decalones in a ratio very similar to that observed in the lithium–ammonia reduction product. The mixture of known composition was then analyzed by g.l.c. and the ratio of the two components obtained by integration of the g.l.c. trace was found to be within experimental error, the same as the known ratio. This was not unexpected, since it is known that molecules of similar structure and molecular complexity generally have identical molar response factors (43).

The results (yields and product compositions) obtained from several reductions of each individual octalone were averaged and the resultant figures are recorded in Table 1.[4]

As can be seen from an examination of the results summarized in Table 1, small amounts (2–14%) of starting material were recovered from the lithium–ammonia reduction of octalones **7**–**11**. This was not surprising, since it is well known (3, 4) that alkali metal – ammonia reduction of α,β-unsaturated ketones in the absence of proton donors which are more acidic than ammonia generally leads to the recovery of some starting material. Presumably, this is largely due to the fact that some of the unreduced enone reacts with amide ion (produced when the β-carbon of the substrate is protonated by ammonia) to form either the corresponding enolate anion or the product of conjugate addi-

---

[2] For a discussion regarding the stereochemistry of this type of reaction, see ref. 41. The decalone **17** had been prepared previously (41) via a somewhat different, although related, method.

[3] This compound was prepared as follows. Conversion of the decalone **23** (42) into a mixture of the enol acetates **24** and **25** (85:15, respectively), followed by bromination of this mixture with bromine in acetic acid, afforded the bromoketone **26**. Dehydrobromination of the latter with anhydrous lithium bromide in hot hexamethylphosphoramide afforded octalone **22**.

[4] The results obtained from three or more reductions of each octalone (**7**–**11**) were found to be reproducible to within ±2%.

TABLE 1. Stereochemistry of lithium–ammonia reduction of 4-alkyl-$\Delta^{1(9)}$-2-octalones

Experiment No.	Octalone	Yield (%)*	Ratio of *trans*:*cis* decalone	Recovered starting material
1	**3**†	91	>99: 1	—
2	**4**†	80	<1:99	—
3	**7**	93	87:13	2
4	**8**	94	75:25	13
5	**9**	98	69:31	14
6	**10**	90	82:18	8
7	**11**	98	65:35	7

*Yield of distilled product, including any recovered starting material.
†See ref. 12.

tion (11*b*), both of which would be inert to reduction. This can be avoided by employing an alcohol as a proton source. However, in the presence of an alcohol, the product of reduction is generally the 2-decalol, which must subsequently be oxidized back to the decalone. In the present work, recovery of small amounts of starting material presented no problem to the analysis of product mixtures. That is, in each case, g.l.c. conditions were found in which the starting material (octalone) and the two corresponding products (*cis*- and *trans*-fused decalones) exhibited distinct retention times. Furthermore, the yields of the reduction products were higher when the additional oxidation step could be omitted. Therefore, all of the reductions were carried out in the absence of an alcohol.

From a stereochemical point of view, a number of interesting conclusions can be drawn from the results tabulated in Table 1. Firstly, the results showed that the lithium–ammonia reduction of $\Delta^{1(9)}$-2-octalones possessing an axially oriented alkyl substituent at C_4 afforded, in each case, a much greater proportion of the corresponding *cis*-fused 2-decalone than that normally found in this type of reduction. For example, whereas the parent $\Delta^{1(9)}$-2-octalone was known to afford nearly exclusively *trans*-2-decalone (3, 5), the isopropyloctalone **4** yielded only the corresponding *cis*-fused 2-decalone **6** (Expt. No. 2). Similarly, although less strikingly, the octalones **7–11** afforded upon lithium–ammonia reduction significant amounts (13–35%) of the corresponding *cis*-fused decalones **27–31**, respectively (Expt. Nos. 3–7). In contrast, a similar reduction of the parent 10-methyl-$\Delta^{1(9)}$-2-octalone was known to yield nearly exclusively *trans*-10-methyl-2-decalone (3, 5).

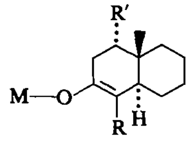
Secondly, the results summarized in Table 1 indicated that the presence (or absence) of an angular methyl group (at C_{10}) in these compounds had a very significant effect on the stereochemical outcome of reduction. Thus, although the C_{10}-unsubstituted octalone **4** afforded only the *cis*-fused product **6** (Expt. No. 2), the 4α-isopropyloctalones **9** and **11**, containing a 10β-methyl group, yielded significantly lower amounts (31 and 35%) of the *cis*-fused decalones (Expt. Nos. 5 and 7). Thirdly, in the case of octalones **7–11**, the results showed that the relative amount of *cis*-fused decalone in the product increased with increasing size of the axially oriented C_4-alkyl group (Expt. Nos. 3–5 and 6, 7). Finally, the results indicated that the presence or absence of a methyl group at C_1 had little or no effect on the stereochemical outcome of the reduction (Expt. Nos. 3, 5–7).

Discussion

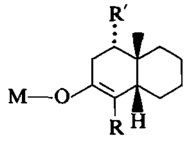
It is important to note that, with regards to the lithium–ammonia reduction of octalones **7–11**, the results (Table 1) showed that the energy difference between the transition states leading from the starting material to the Δ^1-enolates (or enols) of the *trans* and *cis*-fused 2-decalones (**32** and **33**) was quite small. Furthermore, the conformational analysis of substituted Δ^1-octalines of the type **32** and **33** has not as yet been put on a quantitative basis and it is thus very difficult to accurately assess the magnitude of the various nonbonded interactions involved in the different conformations of possible intermediates and/or transition states. Therefore, it is difficult to offer, in *quantitative* terms, an explanation for the stereochemical results summarized in Table 1. However, we feel that the results can be *qualitatively* explained in terms of the proposals originally set forth by Robinson (3).

Briefly, Robinson's conclusions can be summarized as follows. (*a*) The β-carbon of the intermediate anion is planar in shape and the transition state for protonation at the β-carbon should resemble this shape (reactant-like transition state).[5] It was recognized, however, that the planarity is not necessarily perfectly retained in the transition state. (*b*) The intermediate anion can adopt three different conformations (**34**, **35**, **36**),[6] each of which could theoretically lead to protonation transition states to afford **32** and/or **33**. However, considering angle and torsional strain, Robinson concluded that **36** would generally involve too high an energy (large angle strain, lack of planarity of the conjugated system) to be a likely conformation. Of the two remaining conformations, Robinson proposed that **34** would normally be favored and would lead largely to a transition state (resembling **34** in geometry) forming *trans*-fused enolate (or enol) **32**, whereas **35** would normally be more strained (less stable) and would lead mainly to a transition state (resembling **35** in geometry) forming *cis*-fused enolate (or enol) **33**. Therefore, it would be expected that for "normal" $\Delta^{1(9)}$-2-octalones (R′ = H), the transition state arising from **34** (leading to **32**) would be favored over the transition state arising from **35** (leading to **33**), thus accounting for the observed predominance of the *trans*-fused decalone in the product.

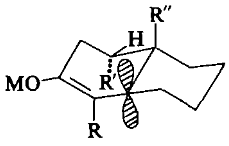
Considering now the stereochemical results obtained from the lithium–ammonia reduction of octalones **4** and **7**–**11**, inclusive, it is reasonable to propose that the stability gained by changing the conformation of the reduction intermediate from **34** (axial C_4-alkyl group) to **35** (equatorial-like C_4-alkyl group) would at least partially off-set the angle and torsional strain inherent in conformation **35**. If the protonation transition state is reactant like, this would result in a lowering of the energy of the transition state resembling **35** relative to that resembling **34**. Robinson's theory would thus correctly predict a higher proportion of *cis*-fused decalone product in the present examples, relative to that "normally" found.



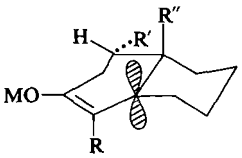
32 M = Li or H



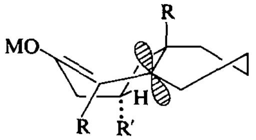
33 = Li or H



34



35



36

The effect of a C_{10} angular methyl group can also be understood in terms of Robinson's theory. In octalones **7**–**11**, the relative stabilization arising from changing the conformation of the intermediate from **34** to **35** would be somewhat off-set by the increased skew nonbonded interaction between the C_4-alkyl group (R′ in **35**) and the C_{10}-methyl group (R″ = CH_3 in **35**). Hence, in these octalones, the amount of *cis*-fused decalone formed on lithium–ammonia reduction would be expected to be less than in the case of octalone **4**. In the latter, as the conformation of the intermediate changes from **34** (R = R″ = H, R′ = isoPr) to **35**, there is no developing nonbonded interaction between the C_4-isopropyl group and the C_{10}-proton (R″ = H in **35**). Thus, although the magnitude of the effect of changing the C_{10}-substituent from a proton (in **4**) to a methyl group (in **9** and **11**) was not expected *a priori*, the results can be accounted for on a qualitative basis.

Finally, the effect of changing the size of the C_4-alkyl group must be mentioned. As the bulk of the C_4-alkyl group increases, it seems prob-

---

[5] The reasoning which led to this conclusion will not be reproduced here. However, Robinson has convincingly argued that the transition state for protonation at the β-carbon is not tetrahedral in shape (product-like transition state), since there is no correlation between product ratios and relative product stabilities.

[6] The representations used here differ slightly in detail from those in Robinson's paper. In our representations, we have taken into account the recent mechanistic work of House and co-workers (4, 5).

able that the stabilization arising from changing the alkyl group from the axial orientation (**34**) to the equatorial-like orientation (**35**) would also increase somewhat. This would make the transition state resembling **35** increasingly more favored and could thus account for the observed fact that as the C_4-alkyl group increases in size, the amount of *cis*-fused decalone obtained also increases.

Experimental[7]

4α,4aβ-Dimethyl-4,4a,5,6,7,8-hexahydro-2(3H)-naphthalenone (7)

To a stirred, ice-cold slurry of 6.84 g of cuprous iodide in 150 ml of anhydrous ether was added 34.3 ml of 2.1 *M* methyllithium in ether. To the resulting clear solution was added dropwise, over a period of 1 h, 1 g (6.2 mmol) of the cross-conjugated dienone **13**. The resulting thick yellow reaction mixture was thoroughly extracted with ether. The combined ether extracts were successively washed with water, dilute ammonium hydroxide, water, and brine and then dried over anhydrous magnesium sulfate. Removal of the solvent followed by distillation of the residue under reduced pressure gave a clear oil, b.p. 124° at 0.3 mm, which was subjected to chromatography on 40 g of silica gel. The fractions eluted with 15% ether – petroleum ether (b.p. 30–60°) contained 900 mg (82%) of the octalone **7** (19, 44), a clear colorless oil which showed a single peak on analysis by g.l.c. (column A, 190°, 86). This material exhibited u.v. λ_{max} 239 nm (ε 14 000); i.r. (film) λ_{max} 6.0, 6.15 μ; p.m.r. τ 9.02 (d, 3H, secondary CH_3, J = 7 Hz), 8.74 (s, 3H, tertiary CH_3), 4.30 (s, 1H, vinyl H).

1,4α,4aβ-Trimethyl-4,4a,5,6,7,8-hexahydro-2(3H)-naphthalenone (10)

The reaction of dienone **14** with lithium dimethylcuprate was carried out by a procedure identical with that described above for the preparation of **7**. From 1 g of dienone **14** there was obtained 1 g (92%) of the trimethyloctalone **10**, b.p. 125°/0.3 mm, which was shown to be homogeneous by g.l.c. (column A, 200°, 86); u.v. λ_{max} 249 nm (ε 13 800); i.r. (film) λ_{max} 6.0, 6.2 μ; p.m.r. τ 9.04 (d, 3H, secondary CH_3, J = 6.5 Hz), 8.74 (s, 3H, tertiary CH_3), 8.25 (d, 3H, vinyl CH_3, J = 1 Hz).

This compound was further characterized as a red 2,4-dinitrophenylhydrazone, recrystallized from ethanol, m.p. 174–175°.

Anal. Calcd. for $C_{19}H_{24}N_4O_4$: C, 61.28; H, 6.50; N, 15.04. Found: C, 60.98; H, 6.42; N, 15.11.

4aβ-Methyl-4α-vinyl-4,4a,5,6,7,8-hexahydro-2(3H)-naphthalenone (12)

A solution of 15 g of tri-*n*-butylphosphine copper(I) iodide (23) in 150 ml of anhydrous ether was cooled to −78° by an external Dry Ice – acetone bath. Addition of 22.8 ml of 3.2 *M* vinyllithium in tetrahydrofuran gave a pale green solution, to which was added, over a period of 1 h, a solution of 1 g of the dienone **13** in 50 ml of dry ether. The resulting thick yellow reaction mixture was allowed to stir at −78° for 4 h. The mixture was allowed to warm to room temperature and was then poured into 250 ml of rapidly stirring 10% hydrochloric acid. The aqueous mixture was thoroughly extracted with ether. The combined ether extracts were washed successively with water, dilute ammonium hydroxide, water, and brine and then dried over anhydrous magnesium sulfate. After removal of the solvent, the desired product was roughly separated from the high boiling material by collecting all material with a boiling point less than 130° at 0.2 mm. The resulting distillate was subjected to chromatography on 100 g of silica gel. The fractions eluted with 10% ether – petroleum ether (b.p. 30–60°) afforded 870 mg (73%) of the desired octalone **12**. The latter showed only one peak by g.l.c. analysis (column A, 195°, 100), and exhibited i.r. (film) λ_{max} 6.0, 6.2, 10.9 μ; p.m.r. τ 8.72 (s, 3H, tertiary methyl), 3.89–5.13 (m, 3H, $—CH{=}CH_2$), 4.25 (s, 1H, vinyl H). Due to its instability, octalone **12** was not characterized further but was immediately subjected to hydrogenation.

4α-Ethyl-4aβ-methyl-4,4a,5,6,7,8-hexahydro-2(3H)-naphthalenone (8)

The hydrogenation of the octalone **12** (708 mg) was carried out in benzene (50 ml) solution at room temperature and atmospheric pressure using tris(triphenylphosphine)chlororhodium (120 mg) as catalyst. After uptake of hydrogen had essentially ceased, the reaction mixture was filtered through a column of Woelm activity III neutral alumina (20 g). The column was eluted with an additional 100 ml of benzene. Removal of the solvent, followed by distillation of the crude product under reduced pressure afforded 650 mg of a clear colorless oil. Analysis of this material by g.l.c. (column A, 180°, 100) showed that it consisted of a mixture of the decalone **28** (~10%) and the desired octalone **8** (~90%). The mixture was separated by chromotography on 50 g of silica gel. The fractions eluted with 8% ether – petroleum ether (b.p. 30–60°) contained 57 mg of the *cis*-fused decalone **28**, while the fractions eluted with 15% ether – petroleum ether (b.p. 30–60°) contained 413 mg (58%) of the desired octalone **8**; u.v. λ_{max} 239 nm (ε 11 000); i.r. (film) λ_{max} 6.0, 6.2 μ; p.m.r. τ 9.07 (t, 3H, $—CH_2—CH_3$, J = 4 Hz), 8.73 (s, 3H, tertiary CH_3), 4.21 (broad s, 1H, vinyl H).

This compound was further characterized as a red 2,4-dinitrophenylhydrazone derivative, recrystallized from ethanol, m.p. 118–120°.

Anal. Calcd. for $C_{19}H_{24}N_4O_4$: C, 61.28; H, 6.50; N, 15.04. Found: C, 61.07; H, 6.42; N, 15.05.

4α-Isopropyl-4aβ-methyl-4,4a,5,6,7,8-hexahydro-2(3H)-naphthalenone (9)

A solution of 15 g (38 mmol) of tri-*n*-butylphosphine copper(I) iodide and 0.5 g of anhydrous lithium bromide in 150 ml of anhydrous ether was cooled to −78° with an external Dry Ice – acetone bath. A solution of isopropyllithium in pentane (39 ml, 1.86 *M*, 73 mmol) was added, forming first a dark red and then a pale aqua solution. To this solution was added, over a period of 45 min, a solution of 1 g (6.1 mmol) of the dienone **13** in 50 ml of anhydrous ether. The dark red reaction mixture was allowed to stir at −78° for an additional 5 h and was then allowed to warm to room temperature. The reaction mixture was transferred under nitrogen to a dropping funnel and then added slowly to a rapidly stirring solution of

---

[7] For general information, see preceding paper (ref. 12).

10% hydrochloric acid. The resulting mixture was extracted thoroughly with ether. The combined ether extracts were washed successively with water, dilute ammonium hydroxide, water, and brine and then dried over anhydrous magnesium sulfate. Removal of the solvent and distillation of the residue under reduced pressure afforded an oil which was further purified by chromatography on 25 g of silica gel. The fractions eluted with 20% ether – petroleum ether (b.p. 30–60°) gave 395 mg (95%) of the desired octalone **9**. This material showed one component by g.l.c. (column A, 180°, 86) and exhibited u.v. λ_{max} 240 nm (ε 9400); i.r. (film) λ_{max} 6.0, 6.15 μ; p.m.r. τ 9.20, 9.05 (d, d, 6H, —CH(CH_3)$_2$, J = 6.5 Hz), 8.74 (s, 3H, tertiary CH_3), 4.22 (broad s, 1H, vinyl H).

This compound was further characterized as its 2,4-dinitrophenylhydrazone derivative, recrystallized from ethanol, m.p. 153–155°.

Anal. Calcd. for $C_{20}H_{26}N_4O_4$: C, 62.16; H, 6.78; N, 14.50. Found: C, 62.01; H, 6.80; N, 14.40.

*4α-Isopropyl-1,4aβ-dimethyl-4,4a,5,6,7,8-hexahydro-2(3H)-naphthalenone (**11**)*

The reaction of lithium diisopropylcuprate with the cross-conjugated dienone **14** was carried out via a procedure identical with that described above for the preparation of octalone **9**.

From 2 g of the dienone **14** there was obtained, after chromatography of the crude product on 140 g of silica gel, 2.38 g (95%) of the desired octalone **11**. This material showed one component by g.l.c. (column A, 190°, 86) and exhibited u.v. λ_{max} 294 nm (ε 14 000); i.r. (film) λ_{max} 6.0, 6.2 μ; p.m.r. τ 9.23, 9.04 (d, d, 6H, —CH(CH_3)$_2$, J = 7 Hz), 8.73 (s, 3H, tertiary CH_3), 8.22 (s, 3H, vinyl CH_3).

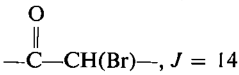
This compound was further characterized as a red 2,4-dinitrophenylhydrazone derivative, recrystallized from ethanol, m.p. 134–135°.

Anal. Calcd. for $C_{21}H_{28}N_4O_4$: C, 62.98; H, 7.05; N, 13.99. Found: C, 63.13; H, 6.90; N, 13.76.

*3α-Bromo-1α,4aβ-dimethyl-trans-3,4,4a,5,6,7,8,8a-octahydro-2(1H)-naphthalenone (**26**)*

To a solution of 7.9 g (44 mmol) of the dimethyldecalone **23** (42) in 50 ml of isopropenyl acetate was added 0.1 ml of 98% sulfuric acid. The solution was refluxed under an atmosphere of nitrogen for 2.5 h. Most of the isopropenyl acetate was removed under reduced pressure and the residue was diluted with ether. The ether solution was washed successively with water, 5% aqueous sodium bicarbonate, water, and brine and dried over anhydrous magnesium sulfate. Removal of the solvent followed by chromatography of the crude product on 150 g of Woelm activity III neutral alumina, gave 9.5 g of a mixture of enol acetates **24** and **25**, in a ratio of approximately 85:15, respectively. The mixture exhibited i.r. (film) λ_{max} 5.7, 5.95 μ.

The mixture of enol acetates (9.5 g) **24** and **25** was dissolved in 100 ml of glacial acetic acid containing 10 g of anhydrous sodium acetate. To the resulting solution was added, over a period of 1 h, a solution of 7.2 g of bromine in 50 ml of glacial acetic acid. After the addition was complete, the reaction mixture was allowed to stir for an additional 15 min. The glacial acetic acid was removed under reduced pressure, the residue was diluted with water and then thoroughly extracted with ether. The combined ether extracts were washed successively with water, aqueous sodium bicarbonate, water, and brine and dried over anhydrous magnesium sulfate. Removal of the solvent gave a crystalline material which, upon recrystallization from petroleum ether (b.p. 30–60°), afforded 9.2 g (85%) of the bromoketone **26**, m.p. 69–70°; i.r. ($CHCl_3$) λ_{max} 5.8 μ; p.m.r. τ 8.99 (d, 3H, secondary CH_3, J = 6.5 Hz), 8.84 (s, 3H, tertiary CH_3), 5.13 (d of d, 1H,



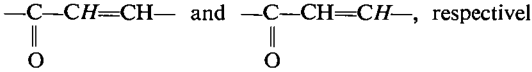
$$\overset{\displaystyle O}{\overset{\|}{\text{—C}}}\text{—CH(Br)—}$$

, J = 14, 6 Hz).

Anal. Calcd. for $C_{12}H_{19}OBr$: C, 55.60; H, 7.34; Br, 30.89. Found: C, 55.59; H, 7.26; Br, 30.86.

*1α,4aβ-Dimethyl-trans-4a,5,6,7,8,8a-hexahydro-2(1H)-naphthalenone (**22**)*

A solution of 4 g (15 mmol) of the bromoketone **26** and 1.5 g of anhydrous lithium bromide in 35 ml of hexamethylphosphoramide was heated to 120° and kept at this temperature for 3 h. The solution was cooled, diluted with water, and thoroughly extracted with ether. The combined ether extracts were washed thrice with water, once with brine, and dried over anhydrous magnesium sulfate. Removal of the solvent gave an oil which was shown by g.l.c. (column A, 185°, 86) to consist mainly of the desired octalone **22**, contaminated by a small amount of 1,10-dimethyl-$\Delta^{1,9}$-2-octalone. Chromatography of this material on 100 g of silica gel gave, upon elution of the column with 3% ether – benzene, 2 g (72%) of the octalone **22**. The latter exhibited u.v. λ_{max} 229 nm (ε 9200); i.r. (film) λ_{max} 6.0, 6.15 μ; p.m.r. τ 8.93 (s, 3H, tertiary CH_3), 8.92 (d, 3H, secondary CH_3, J = 7 Hz), 4.19, 3.35 (d of d, 2H,



$$\underset{\displaystyle O}{\underset{\|}{\text{—C}}}\text{—C}H\text{=CH—} \quad \text{and} \quad \underset{\displaystyle O}{\underset{\|}{\text{—C}}}\text{—CH=C}H\text{—}$$

, respectively, J = 9 Hz).

This compound was further characterized as a red 2,4-dinitrophenylhydrazone derivative, recrystallized from ethanol, m.p. 198–199°.

Anal. Calcd. for $C_{18}H_{22}N_4O_4$: C, 60.32; H, 6.19; N, 15.63. Found: C, 60.51; H, 6.11; N, 15.73.

*4α,4aβ-Dimethyl-trans-3,4,4a,5,6,7,8,8a-octahydro-2(1H)-naphthalenone (**15**)*

To a stirred ice-cold slurry of 2.3 g of cuprous iodide in 67 ml of anhydrous ether under nitrogen, was added 11.4 ml of 2.1 *M* ethereal methyllithium. To the resulting clear solution was added dropwise over a period of 30 min, a solution of 328 mg (2 mmol) of the octalone **21** (41) in 40 ml of anhydrous ether. The reaction mixture was allowed to stir at 0° for an additional 1.5 h and was then poured slowly into rapidly stirring 10% aqueous hydrochloric acid. The resulting mixture was thoroughly extracted with ether. The combined ether extracts were washed with water and brine and dried over anhydrous magnesium sulfate. Removal of the solvent, followed by distillation of the residue under reduced pressure, afforded 345 mg (98%) of the desired dimethyldecalone **15**, b.p. 110°/0.2 mm (lit. (44) b.p. 133–137°/9 mm). This material showed one component by g.l.c. (column A, 190°, 100) and exhibited i.r. (film) λ_{max} 3.45, 5.85 μ; p.m.r. τ 9.08 (d, H, secondary CH_3, J = 6.5 Hz), 8.87 (s, 3H, tertiary CH_3).

*1α,4α,4aβ-Trimethyl-trans-3,4,4a,5,6,7,8,8a-octahydro-2(1H)-naphthalenone (**18**)*

This compound was prepared by the reaction of lithium dimethylcuprate with the dimethyloctalone **22** via a procedure essentially identical with that described above for the preparation of decalone **15**. The crude product obtained from 200 mg (1.2 mmol) of the octalone **22** was subjected to chromatography on silica gel (20 g). The fractions eluted with 5% ether - petroleum ether (b.p. 30–60°) afforded 189 mg (93%) of the desired *trans*-decalone **18**. An analytical sample was obtained by preparative g.l.c. (column A, 190°, 86) and exhibited i.r. (film) λ_{max} 5.85 μ; p.m.r. τ 9.10, 9.02 (d, d, 6H, secondary methyls, $J = 7$ Hz), 8.77 (s, 3H, tertiary CH_3), 7.97 (d of d, 1H, H-3e, $J = 2.2$ and 14 Hz), 7.21 (d of d, H-3a, $J = 6$ and 14 Hz).

This compound was further characterized as an orange 2,4-dinitrophenylhydrazone derivative, recrystallized from ethanol, m.p. 167–168°.

Anal. Calcd. for $C_{19}H_{26}N_4O_4$: C, 60.95; H, 7.00; N, 14.96. Found: C, 60.66; H, 6.87; N, 15.06.

4aβ-Methyl-4α-vinyl-trans-3,4,4a,5,6,7,8,8a-octahydro-2(1H)-naphthalenone (20)

A solution of tri-*n*-butylphosphine copper(I) iodide (4 g) in anhydrous ether (50 ml) was cooled, under nitrogen, to −78° by means of an external Dry Ice - acetone cooling bath. A solution of 3.1 *M* vinyllithium in tetrahydrofuran (6.4 ml) was added dropwise until the initially formed red solution became colorless. To this solution was added dropwise, over a period of 30 min, a solution of the octalone **21** (328 mg, 2 mmol) in 50 ml of anhydrous ether. The brown reaction mixture was allowed to stir for an additional 5 h at −78° and then allowed to warm slowly to room temperature. The reaction mixture was transferred under nitrogen to an addition funnel and was added dropwise to 100 ml of rapidly stirring 10% hydrochloric acid. The mixture was extracted thoroughly with ether. The combined ethereal extracts were washed successively with dilute ammonium hydroxide, water, and brine and dried over anhydrous magnesium sulfate. Removal of the solvent gave a viscous yellow oil which was subjected to chromatography on 50 g of silica gel. The fractions eluted with 15% ether - petroleum ether (b.p. 30–60°) contained 280 mg (73%) of the desired decalone **20**. This material was distilled (b.p. 130° at 0.15 mm) to afford an oil which showed only one component by g.l.c. (column A, 190°, 100) and exhibited i.r. (film) λ_{max} 5.85, 6.1, 10.9 μ; p.m.r. τ 8.88 (s, 3H, tertiary CH_3), 4.0–5.2 (m, 3H, $—CH{=}CH_2$).

This compound was further characterized as a dark red 2,4-dinitrophenylhydrazone derivative, m.p. 186° (from ethanol).

Anal. Calcd. for $C_{19}H_{24}N_4O_4$: C, 61.28; H, 6.50; N, 15.04. Found: C, 60.98; H, 6.41; N, 14.94.

4α-Ethyl-4aβ-methyl-trans-3,4,4a,5,6,7,8,8a-octahydro-2(1H)-naphthalenone (16)

The hydrogenation of the vinyl-substituted decalone **20** was done at atmospheric pressure and room temperature using 10% palladium-on-charcoal as catalyst and absolute ethanol as solvent. From 675 mg of decalone **20** there was obtained 670 mg (98%) of the ethyl-substituted decalone **16**. The product showed one component by g.l.c. (column A, 180° 86) and exhibited i.r. (film) λ_{max} 5.85 μ; p.m.r. τ 8.88 (s, 3H, tertiary CH_3).

This compound was further characterized as a pale orange 2,4-dinitrophenylhydrazone, m.p. 192–193° (from ethanol).

Anal. Calcd. for $C_{19}H_{26}N_4O_4$: C, 60.95; H, 7.00; N, 14.96. Found: 60.74; H, 6.89; N, 14.92.

4α-Isopropyl-4aβ-methyl-trans-3,4,4a,5,6,7,8,8a-octahydro-2 (1H)-naphthalenone (17)

To a solution of 4 g of tri-*n*-butylphosphine copper(I) iodide in 60 ml of anhydrous ether at −78° under nitrogen was added 11 ml of 1.86 *M* isopropyllithium in *n*-pentane. To the resulting aqua solution was added dropwise, over a period of 30 min, a solution of 328 mg (2 mmol) of the octalone **21** in 10 ml of anhydrous ether. After the addition was complete, the dark red reaction mixture was allowed to stir for an additional 3h at −78°, was transferred under nitrogen to an addition funnel, and then added dropwise to 50 ml of rapidly stirring 10% hydrochloric acid. The resulting mixture was thoroughly extracted with ether. The combined ether extracts were washed successively with water, dilute ammonium hydroxide, water, and brine and dried over anhydrous magnesium sulfate. Removal of the solvent gave a viscous oil which was distilled under reduced pressure (0.1 mm). All material with b.p. of less than 150° was collected. The distillate was further purified by chromatography over 35 g of silica gel. The fractions eluted with 20% ether - petroleum ether (b.p. 30–60°) contained 297 mg (72%) of the *trans*-fused decalone **17**, which crystallized on standing. Recrystallization of this material from *n*-hexane gave an analytical sample, m.p. 49–50° (lit. m.p. (41) 49–50°); i.r. ($CHCl_3$) λ_{max} 5.87 μ; p.m.r. τ 9.08, 9.17 (d, d, 6H, $—CH(CH_3)_2$, $J = 6.8$ Hz), 8.89 (s, 3H, tertiary CH_3).

4α-Isopropyl-1α,4aβ-dimethyl-trans-3,4,4a,5,6,7,8,8a-octahydro-2(1H)-naphthalenone (19)

This compound was prepared by the reaction of lithium diisopropylcuprate with the dimethyloctalone **22** via a procedure essentially identical with that described above for the preparation of decalone **17**. The crude product obtained from 356 mg (2.1 mmol) of octalone **22** was distilled (b.p. 120°/0.3 mm) and the distillate was further purified by chromatography on 20 g of silica gel. Elution with benzene afforded 262 mg (82%) of the desired decalone **19**, which showed one component by g.l.c. analysis (column A, 198°, 86) and exhibited i.r. (film) λ_{max} 5.85 μ; p.m.r. τ 9.21, 9.09 (d, d, 6H, $—CH(CH_3)_2$, $J = 6.5$ Hz), 9.00 (d, 3H, secondary CH_3, $J = 6$ Hz), 8.87 (s, 3H, tertiary CH_3); p.m.r. (benzene) τ 7.74 (d of d, 1H, H-3a, $J = 15.5$, 7.6 Hz), 7.56 (d of d, 1H, H-3e, $J = 15.5$, 2.4 Hz).

The product was further characterized as a yellow 2,4-dinitrophenylhydrazone derivative, recrystallized from ethanol, m.p. 145–146°.

Anal. Calcd. for $C_{21}H_{30}N_4O_4$: C, 62.67; H, 7.51; N, 13.92. Found: C, 62.55; H, 7.50; N, 13.73.

4α,4aβ-Dimethyl-cis-3,4,4a,5,6,7,8,8a-octahydro-2(1H)-naphthalenone (27)

A suspension of 20 mg of 10% palladium-on-charcoal in 15 ml of 0.3 *N* ethanolic sodium hydroxide solution was stirred for 1 h under an atmosphere of hydrogen at room temperature. A solution of 122 mg (0.68 mmol) of octalone **7** in 10 ml of ethanol was added by means of a syringe. After the calculated amount of hydrogen had been taken up, the mixture was filtered and the filtrate was concentrated under reduced pressure. The residue was diluted with water and the resulting mixture was thoroughly extracted with ether. The combined ether extracts were washed successively with 5% hydrochloric acid, 5% aqueous sodium bicarbonate, water, and brine and dried over anhydrous magnesium sulfate. Removal of the solvent, followed by distillation of the residue under reduced pressure, gave 119 mg (97%) of the *cis*-fused decalone **27**, b.p. 110°/0.2 mm. This material was shown to be homogeneous by g.l.c. (column A, 190°, 86) and exhibited i.r. (film) λ_{max} 5.85 μ; p.m.r. τ 9.10 (d, 3H, secondary CH_3, $J = 7$ Hz), 8.95 (s, 3H, tertiary CH_3).

This compound was further characterized as a yellow 2,4-dinitrophenylhydrazone derivative, m.p. 161–162° (from ethanol).

Anal. Calcd. for $C_{18}H_{24}N_4O_4$: C, 59.99; H, 6.71; N, 15.55. Found: C, 59.99; H, 6.80; N, 15.46.

1β,4α,4aβ-Trimethyl-cis-3,4,4a,5,6,7,8,8a-octahydro-2(1H)-naphthalenone (30)

This compound was obtained by hydrogenation of octalone **10** under conditions identical with those used for the preparation of **27**. From 130 mg of **10** there was obtained 125 mg (95%) of a colorless oil, b.p. 115°/0.2 mm, which showed one component by g.l.c. (column A, 180°, 86). Compound **30** exhibited i.r. (film) λ_{max} 5.85 μ; p.m.r. τ 9.08, 9.01 (d, d, 6H, secondary methyls, $J =$ 6.5 Hz), 8.92 (s, 3H, tertiary CH_3), 7.85 (d of d, 1H, H-3e, $J = 13$, 3.6 Hz), 7.64 (d of d, 1H, H-3a, $J = 13$, 14.4 Hz), 7.35 (overlapped d of q, 1H, H-1a, $J = 13$, 6 Hz).

The decalone **30** was further characterized as its 2,4-dinitrophenylhydrazone derivative, m.p. 213–214° (from ethanol).

Anal. Calcd. for $C_{19}H_{26}N_4O_4$: C, 60.95; H, 7.00; N, 14.96. Found: C, 60.85; H, 7.08; N, 14.93.

4α-Ethyl-4aβ-methyl-cis-3,4,4a,5,6,7,8,8a-octahydro-2(1H)-naphthalenone (28)

The hydrogenation of octalone **8** was carried out under conditions identical with those employed for the synthesis of decalone **27**. From 100 mg of octalone **8** there was obtained 96 mg (95%) of a clear colorless oil which was shown by g.l.c. analysis (column A, 180°, 86) to be greater than 95% pure. An analytical sample of the decalone **28** was collected by preparative g.l.c. and exhibited i.r. (film) λ_{max} 5.85 μ; p.m.r. τ 8.90 (s, 1H, tertiary CH_3).

This compound was further characterized as a yellow 2,4-dinitrophenylhydrazone derivative, m.p. 174° (from ethanol).

Anal. Calcd. for $C_{19}H_{26}N_4O_4$: C, 60.95; H, 7.00; N, 14.96. Found: C, 60.81; H, 6.85; N, 14.88.

4α-Isopropyl-4aβ-methyl-cis-3,4,4a,5,6,7,8,8a-octahydro-2(1H)-naphthalenone (29)

Octalone **9** was subjected to hydrogenation under conditions identical with those described previously for the preparation of decalone **27**. From 100 mg of octalone **9** there was obtained 96 mg (96%) of an oil which was shown by g.l.c. analysis (column A, 190°, 86) to consist of two components in a ratio of 95:5. The minor component exhibited a retention time identical with that of the *trans*-fused decalone **17**. An analytical sample of the major component, *cis*-fused decalone **29**, was collected by preparative g.l.c. and exhibited i.r. (film) λ_{max} 5.85 μ; p.m.r. τ 9.19, 9.10 (d, d, 6H, $—CH(CH_3)_2$, $J = 6.5$ Hz), 8.88 (s, 3H, tertiary CH_3).

This compound was further characterized as an orange 2,4,-dinitrophenylhydrazone derivative, recrystallized from ethanol; m.p. 180–181°.

Anal. Calcd. for $C_{20}H_{28}N_4O_4$: C, 61.84; H, 7.27; N, 14.42. Found: C, 61.86; H, 7.35; N, 14.30.

4α-Isopropyl-1β,4aβ-dimethyl-cis-3,4,4a,5,6,7,8,8a-octahydro-2(1H)-naphthalenone (31)

This compound was prepared by hydrogenation of octalone **11** via a procedure identical with that described for the preparation of decalone **27**. From 100 mg of octalone **11** there was obtained 96 mg (95%) of an oil which exhibited one component by g.l.c. (column A, 180°, 86) and produced the following spectral data: i.r. (film) λ_{max} 5.85 μ; p.m.r. τ 9.19, 9.11 (d, d, 6H, $—CH(CH_3)_2$, $J = 6.5$ Hz), 9.01 (d, 3H, secondary CH_3, $J = 6$ Hz), 8.89 (s, 3H, tertiary CH_3), 7.86 (m, 1H, H-3e, $J = 14$, 3.6 Hz), 7.63 (m, 1H, H-3a, $J = 14$, 14.3 Hz), 8.30 (m, 1H, H-1a, $J = 13$, 6 Hz).

This *cis*-fused decalone **31** was further characterized as its 2,4-dinitrophenylhydrazone derivative, m.p. 188–189° (from ethanol).

Anal. Calcd. for $C_{21}H_{30}N_4O_4$: C, 62.67; H, 7.51; N, 13.92. Found: C, 62.46; H, 7.28; N, 14.01.

Lithium–Ammonia Reduction of 4α-Alkyl-4aβ-methyl-4,4a,5,6,7,8-hexahydro-2(3H)-naphthalenones (7, 8, 9) and of 4α-Alkyl-1,4aβ-dimethyl-4,4a,5,6,7,8-hexahydro-2(3H)-naphthalenones (10, 11). General Procedure

To 60 ml of liquid ammonia (freshly distilled from sodium metal) was added 55 mg of finely cut lithium wire. After all the lithium had dissolved, a solution of 0.56 mmol of the appropriate octalone in 10 ml of anhydrous ether was added dropwise over a period of 30 min. The reaction mixture was allowed to stir for an additional 2 h and the blue color was then discharged by careful addition of ammonium chloride. The liquid ammonia was allowed to evaporate and the residue was diluted with water and neutralized by addition of hydrochloric acid. The resulting mixture was thoroughly extracted with ether. The combined ether extracts were washed with water and brine and dried over anhydrous magnesium sulfate. Removal of the solvent, followed by distillation of the residual material under reduced pressure afforded an oil which was subjected to analysis by g.l.c. (column A, 160–190°, 86). In each case, g.l.c. conditions were found in which the starting material (octalone), the corresponding *cis*-fused decalone, and the corresponding *trans*-fused decalone exhibited distinct retention times. The percent composition of each product was determined by integration (disc integrator). The products from each reduction were identified by isolation (preparative g.l.c.) and comparison (i.r., p.m.r.) with authentic samples prepared as described previously.

In each case, samples of *cis*-fused and *trans*-fused decalones were carefully weighed and then combined to afford authentic mixtures of known composition approximating that observed in the appropriate lithium–ammonia reduction. Analysis of these authentic mixtures by g.l.c. showed that the observed ratio was, within experimental error, identical with the known ratio; that is, in each case, the g.l.c. molar response factors of the *cis*- and *trans*-fused decalones were, within experimental error, identical.

Each lithium–ammonia reduction was carried out at least in triplicate. The results recorded in Table 1 represent average values.

Financial support from the National Research Council of Canada and a National Research Council of Canada Studentship (to W.M.P) are gratefully acknowledged.

1. R. Howe and F. J. McQuillin. J. Chem. Soc. 2670 (1956).
2. G. Stork and S. D. Darling. J. Am. Chem. Soc. **86**, 1761 (1964).
3. M. J. T. Robinson. Tetrahedron, **21**, 2475 (1965).
4. K. W. Bowers, R. W. Giese, J. Grimshaw, H. O. House, N. H. Kolodny, K. Kronberger, and D. K. Roe. J. Am. Chem. Soc. **92**, 2783 (1970).
5. H. O. House, R. W. Giese, K. Kronberger, J. P. Kaplan, and J. F. Simeone. J. Am. Chem. Soc. **92**, 2800 (1970).
6. I. H. Elson, T. J. Kemp, D. Greatorex, and H. D. B. Jenkins. J. Chem. Soc. Faraday II, **69**, 665 (1973).
7. I. H. Elson, T. J. Kemp, D. Greatorex, and H. D. B. Jenkins. J. Chem. Soc. Faraday II, **69**, 1402 (1973).
8. S. K. Malhotra, D. F. Moakley, and F. Johnson. Tetrahedron Lett. 1089 (1967).
9. H. E. Zimmerman. *In* Molecular rearrangements. Pt. 1. *Edited by* P. de Mayo. John Wiley and Sons, Inc., New York. 1963. pp. 352–358.
10. F. Johnson. Chem. Rev. **68**, 375 (1968).
11. H. L. Dryden, Jr. *In* Organic reactions in steroid chemistry. Vol. 1. *Edited by* J. Fried and J. A. Edwards. Van Nostrand Reinhold Company, New York. 1972. (*a*) pp. 34–35; (*b*) pp. 40–42.
12. E. Piers and W. M. Phillips-Johnson. Can. J. Chem. This issue.
13. E. Piers, W. M. Phillips-Johnson, and C. Berger. Tetrahedron Lett. 2915 (1972).
14. G. Posner. Org. React. **19**, 1 (1972).
15. R. B. Woodward and T. Singh. J. Am. Chem. Soc. **72**, 494 (1950); D. Caine, P. F. Brake, J. F. DeBardelen, Jr., and J. B. Dawson. J. Org. Chem. **38**, 967 (1973).
16. P. J. Kropp. J. Org. Chem. **29**, 3110 (1964).
17. M. Pesaro, G. Bozzato and P. Schudel. Chem. Commun. 1152 (1968).
18. J. A. Marshall and T. M. Warne, Jr. J. Org. Chem. **36**, 178 (1971).
19. J. A. Marshall and R. A. Ruden. J. Org. Chem. **37**, 659 (1972).
20. J. A. Osborn, E. F. Jardine, J. F. Young, and G. Wilkinson. J. Chem. Soc. A, 1711 (1966).
21. H. O. House and W. F. Fischer, Jr. J. Org. Chem. **33**, 949 (1968).
22. H. O. House, W. L. Respess and G. M. Whitesides. J. Org. Chem. **31**, 3128 (1966).
23. G. B. Kauffman and L. A. Teter. Inorg. Syn. **7**, 9 (1963).
24. E. Piers and R. J. Keziere. Can. J. Chem. **47**, 137 (1969).
25. J. Hooz and R. B. Layton. Can. J. Chem. **48**, 1626 (1970).
26. E. J. Corey and R. L. Carney. J. Am. Chem. Soc. **93**, 7318 (1971).
27. E. J. Corey, C. U. Kim, R. H. K. Chen, and M. Takeda. J. Am. Chem. Soc. **94**, 4395 (1972).
28. R. L. Cargill, D. F. Bushey, and P. D. Ellis. J. Org. Chem. **39**, 573 (1974).
29. F. E. Ziegler and P. A. Wender. Tetrahedron Lett. 449 (1974).
30. C. P. Casey and R. A. Boggs. Tetrahedron Lett. 2455 (1971).
31. C. J. Sih, R. G. Salomon, P. Price, G. Peruzzotti, and R. Sood. J. Chem. Soc. Chem. Commun. 240 (1972).
32. C. J. Sih, P. Price, R. Sood, R. G. Salomon, G. Peruzzotti, and M. Casey. J. Am. Chem. Soc. **94**, 3643 (1972).
33. C. J. Sih, R. G. Salomon, P. Price, R. Sood, and G. Peruzzotti. Tetrahedron Lett. 2435 (1972).
34. R. Pappo and P. W. Collins. Tetrahedron Lett. 2627 (1972).
35. F. S. Alvarez, D. Wren, and A. Prince. J. Am. Chem. Soc. **94**, 7823 (1972).
36. A. F. Kluge, K. G. Untch, and J. H. Fried. J. Am. Chem Soc. **94**, 9256 (1972).
37. C. V. Grudzinskas and M. J. Weiss. Tetrahedron Lett. 141 (1973).
38. C. J. Sih, J. B. Heather, G. P. Peruzzotti, P. Price, R. Sood, and L-F. H. Lee. J. Am. Chem. Soc. **95**, 1676 (1973).
39. J. B. Heather, R. Sood, P. Price, G. P. Peruzzotti, S. S. Lee, L-F. H. Lee, and C. J. Sih. Tetrahedron Lett. 2313 (1973).
40. E. J. Corey and J. Mann. J. Am. Chem. Soc. **95**, 6832 (1973).
41. E. Piers, W. de Waal, and R. W. Britton. Can. J. Chem. **47**, 4299 (1969).
42. M. Yanagita and R. Futaki. J. Org. Chem. **21**, 949 (1956).
43. G. G. S. Dutton, K. B. Gibney, G. D. Jensen, and P. E. Reid. J. Chromatog. **36**, 152 (1968).
44. R. M. Coates and J. E. Shaw. J. Am. Chem. Soc. **92**, 5657 (1970).