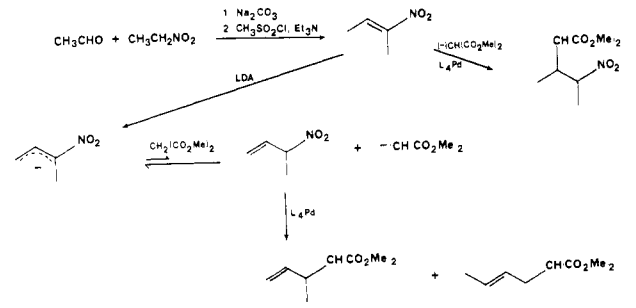
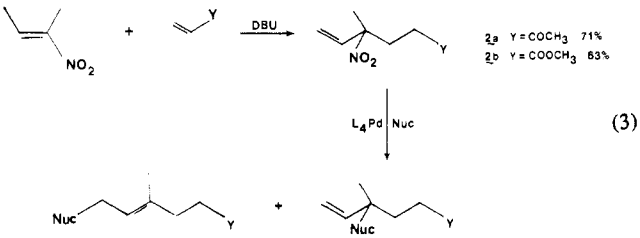
Scheme I



ladium-catalyzed allylic alkylation and amination in good yield (eq 3). With dimethyl malonate and piperidine, mixtures of



regioisomers were obtained, whereas di-*n*-propylamine attacked exclusively at the least substituted position.

Although the mechanism of this palladium-catalyzed allylic alkylation and amination of allylnitro compounds has not yet been studied, it is assumed to proceed in a fashion analogous to the palladium(0)-catalyzed allylic alkylation[14,22] and amination[23] of other allyl substrates such as acetates and ethers—oxidative addition of the allylnitro compound to the palladium(0) complex, followed by nucleophilic attack on the thus-formed allylpalladium(II) species.

The reactions in Table I were carried out in the following manner. The nucleophile (1.2 mmol) in solvent (3 mL) was added to a mixture of substrate (1.0 mmol), $(Ph_3P)_4Pd$ (12 mg, 0.01 mmol), and triphenylphosphine (5 mg, 0.02 mmol) in solvent (1 mL). The resulting yellow mixture was heated for the stated period of time, cooled, and partitioned between ether and water. The ether extracts were washed with saturated brine and dried over anhydrous magnesium sulfate, and the solvent was removed under reduced pressure. Products were purified by evaporative distillation.

The above chemistry significantly expands the scope of palladium-catalyzed allylic alkylation and amination reactions. Allylnitro compounds are generally reactive substrates for this process. Since they are directly available from the condensation of ketones with nitroalkanes or from conjugate additions of β-alkylnitroolefins to α,β-unsaturated carbonyl compounds, the extensive synthetic chemistry of allylpalladium complexes can now be applied directly to these functional groups, which are ubiquitous in organic synthesis. Finally, nitroolefins having γ protons can be made to react as if they were allylnitro compounds. Since nitroolefins are directly available from olefins,[24] ketones, and aldehydes,[25] these classes of compounds are also subject to allylpalladium chemistry. The application of this chemistry to the synthesis of complex organic molecules, including steroid side-chain elaboration, is in progress.

Acknowledgment. Support for this research by the National Science Foundation under Grant CHE-7907832 is gratefully acknowledged.

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(23) (a) B. Åkermark, G. Åkermark, L. S. Hegedus, and K. Zetterberg, *J. Am. Chem. Soc.*, **103**, 3037 (1981). (b) K. Takahashi, A. Miyaka, and G. Hata, *Bull. Chem. Soc. Jpn.*, **45**, 23 (1972).

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Registry No. 1a, 2562-42-7; **1a**·Na, 4404-08-4; **1b**, 5330-61-0; **1c**, 52315-51-2; **2a**, 81769-16-6; **2b**, 81769-17-7; dimethyl propanedioate sodium salt, 18424-76-5; ethyl cyanoacetate sodium salt, 18852-51-2; ethyl 3-oxobutanoate sodium salt, 19232-39-4; piperidine, 110-89-4; benzenemethanamine, 100-46-9; dimethyl propanedioate, 108-59-8; dipropylamine, 142-84-7; dimethyl (1-cyclopentenylmethyl)propanedioate, 81769-18-8; ethyl 2-cyano-3-(1-cyclopentenyl)propanoate, 81769-19-9; ethyl 2-cyano-2,2-bis(1-cyclopentenylmethyl)acetate, 81769-20-2; ethyl 2-acetyl-3-(1-cyclopentenyl)propanoate, 81769-21-3; 1-(1-cyclopentenylmethyl)piperidine, 81769-22-4; *N*-(1-cyclopentenylmethyl)-benzylamine, 81769-23-5; methyl 3-(1-cyclohexenyl)propanoate, 54445-57-7; dimethyl (1-cycloheptenylmethyl)propanedioate, 81769-24-6; dimethyl (2-butenyl)propanedioate, 61979-94-0; dimethyl (1-methyl-2-propenyl)propanedioate, 61979-92-8; (*E*)-7-piperidino-5-methyl-5-hepten-2-one, 81769-25-7; (*Z*)-7-piperidino-5-methyl-5-hepten-2-one, 81769-26-8; 5-piperidino-5-methyl-6-hepten-2-one, 81769-27-9; methyl (*E*)-6-piperidino-4-methyl-4-hexenoate, 81769-28-0; methyl (*Z*)-6-piperidino-4-methyl-4-hexenoate, 81769-29-1; methyl 4-methyl-4-piperidino-5-hexenoate, 81769-30-4; methyl (*E*)-4-methyl-6-(dipropylamino)-4-hexenoate, 81769-31-5; methyl (*Z*)-4-methyl-6-(dipropylamino)-4-hexenoate, 81769-32-6; dimethyl (*E*)-2-(methoxycarbonyl)-5-methyl-4-octenedioate, 64562-42-1; dimethyl (*Z*)-2-(methoxycarbonyl)-5-methyl-4-octenedioate, 81769-33-7; dimethyl 2-(methoxycarbonyl)-3-methyl-3-ethenylhexanedioate, 81769-34-8; dimethyl (1-cyclohexenylmethyl)propanedioate, 60045-25-2; 3-nitro-1-butene lithium salt, 81769-35-9; $(Ph_3P)Pd$, 14221-01-3.

Octalene–[14]Annulene Conversion: 1,8-Dimethyl[14]annulene†

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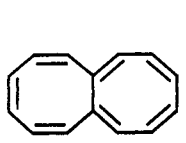
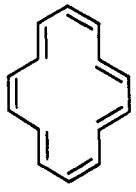
The theoretically interesting 14 π-system octalene (**1**), whose



(1)



(2)

synthesis has recently been achieved,[1] was found by NMR spectroscopic investigations to be a nonplanar olefinic molecule,[2] having the double bonds arranged around the periphery of the two fused eight-membered rings and experiencing a degenerate π-bond shift.[3] In view of its double-bond configuration, octalene can be derived from Sondheimer's [14]annulene (**2**)[4] by connecting carbon atoms 1 and 8, and thus, in a formal sense, it constitutes a perturbed [14]annulene.

That this structural relationship between **1** and **2** actually has chemical significance is shown by the reductive methylation of **1** to give 1,8-dimethyl[14]annulene, reported in this communication.

Conceptually, a conversion of **1** to **2** or derivatives of this annulene by cleavage of the central octalene carbon–carbon bond

† Dedicated to the memory of the late Professor Franz Sondheimer.

(1) Vogel, E.; Runzheimer, H.-V.; Hogrefe, F.; Baasner, B.; Lex, J. *Angew. Chem.* **1977**, *89*, 909; *Angew. Chem., Int. Ed. Engl.* **1977**, *16*, 871 and references cited therein.

(2) In contrast to octalene, the related bicyclo[6.2.0]decapentaenes qualify as pericyclic aromatic systems: Schröder, G.; Ramadas, S. R.; Nikoloff, P. *Chem. Ber.* **1972**, *105*, 1072. Kabuto, C.; Oda, M. *Tetrahedron Lett.* **1980**, *103*. Oda, M.; Oikawa, H. *Ibid.* **1980**, 107.

(3) Oth, J. F. M.; Müllen, K.; Runzheimer, H.-V.; Mues, P.; Vogel, E. *Angew. Chem.* **1977**, *89*, 910; *Angew. Chem., Int. Ed. Engl.* **1977**, *16*, 872.

(4) Sondheimer, F.; Gaoni, Y. *J. Am. Chem. Soc.* **1960**, *82*, 5765. Jackman, L. M.; Sondheimer, F.; Amiel, Y.; Ben-Efraim, D. A.; Gaoni, Y.; Wolovsky, R.; Bothner-By, A. A. *Ibid.* **1962**, *84*, 4307. Sondheimer, F. *Pure Appl. Chem.* **1963**, *7*, 363. Sondheimer, F. *Proc. Robert A. Welch Found. Conf. Chem. Res.* **1968**, *12*, 125.

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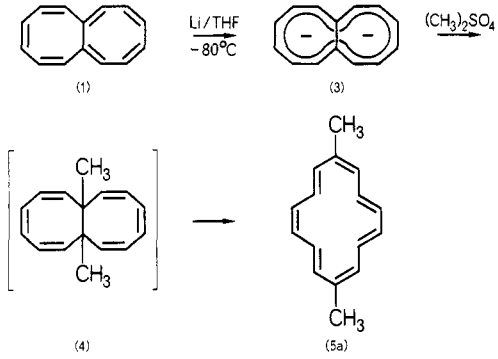
might be initiated by addition of appropriate reagents to the quarternary carbon atoms of **1** with formation of 13,14-dihydrooctalenes. There is strong evidence to support the assumption that such dihydrooctalenes are prone to isomerize thermally to the corresponding [14]annulenes by electrocyclic pathways.[5] Whereas the chance of realizing the crucial addition step of this sequence seems remote with octalene itself, such a step is predicted to be more facile with its ionic derivative, the diamagnetic octalene dianion (**3**). As borne out by spectroscopic findings, in particular



by ^{13}C NMR chemical shift data, as well as by MO calculations, **3** possesses the highest local π-charge density at the quarternary carbon atoms.[6] Accordingly, **3** should be susceptible to attack by electrophilic reagents preferentially at these positions.[7]

The experimental realization of this concept proved to be remarkably straightforward: octalene (**1**) (180 mg, 1 mmol) is reduced in vacuo with lithium in etheral solvents (tetrahydrofuran, dimethyl ether) at −80 °C. Formation of the dianion **3** must be monitored by NMR spectroscopy in order to avoid overreduction leading to the octalene tetraanion. Upon addition of an excess of degassed dimethyl sulfate to the cold dianion solution (inverse addition does not offer an advantage) and subsequent warming, the original red-brown of the medium instantaneously changes to greenish brown. After removal of the solvent, filtration through aluminum oxide (hexane), and crystallization from ethanol, 1,8-dimethyl[14]annulene (53 mg, 25%) is obtained as greenish brown needles [mp 97–98 °C; UV (cyclohexane) 385 (6700), 326 (74 000), 340 sh (39 000) nm; IR (CsI) 1611 cm^{-1} (C=C)]. The presumed primary product of the methylation of **3**, *cis*- and/or *trans*-13,14-dihydro-13,14-dimethyloctalene (**4**), has as yet escaped detection under the prevailing conditions.[8]

The ^1H NMR spectrum (CF_2Br_2/CD_2Cl_2) of 1,8-dimethyl[14]annulene at low temperature (−100 °C) exhibits multiplets at δ 7.52 and 0.28 as well as a singlet at δ 2.73 (relative intensity ca. 8:4:6), which can be assigned to the outer ring protons, the inner ring protons, and the methyl protons, respectively. The resonances of the ring protons indicate that the molecule, similar to the parent **2**, is distinguished by a pronounced diamagnetic ring current.[9] In further analogy to **2**, 1,8-dimethyl[14]annulene must

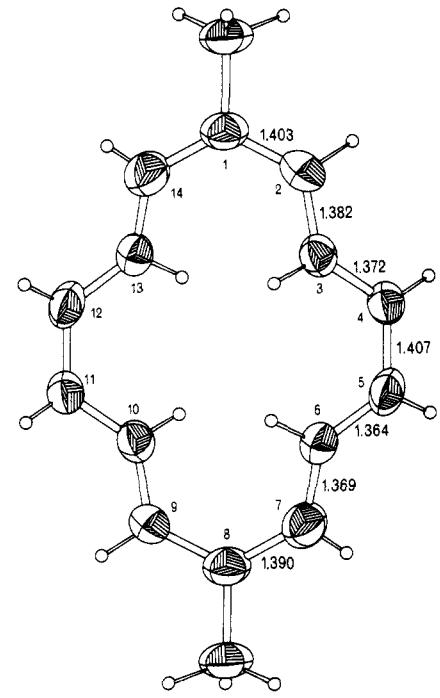


Figure 1. Molecular structure of 1,8-dimethyl[14]annulene (**5a**).

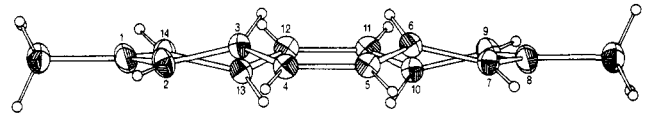
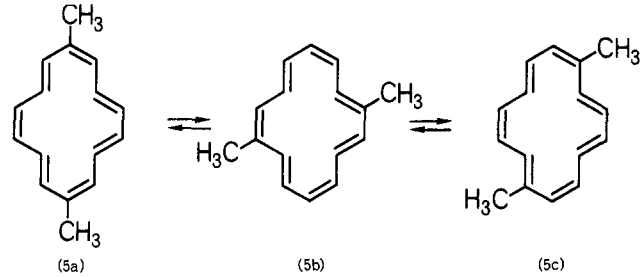


Figure 2. Side view of 1,8-dimethyl[14]annulene (**5a**).

have a pyrene-type configuration as four inner ring protons are observed.[10] The resonances of the inner and outer ring protons broaden progressively on raising the temperature, until at −50 °C a coalescence signal at δ 5.57 emerges. Further warming to room temperature brings about a splitting of this signal into three multiplets, centered at δ 6.18 (4 H), 5.48 (4 H), and 4.55 (4 H), respectively, and into a singlet at δ 2.71 (6 H).

The dynamic process responsible for the temperature dependence of the NMR spectrum is a rotation of the trans double bonds around the neighboring single bonds, which causes the inner and outer ring protons to be exchanged. From this conformational interconversion it must be concluded that 1,8-dimethyl[14]-annulene, in solution, exists as an equilibrating mixture of **5a**, **5b**, and **5c**, even though the methyl protons give rise to only one singlet (relatively broad) over the entire temperature range studied.



An X-ray structural analysis performed on 1,8-dimethyl[14]-

(5) Hexacarbonyl(*trans*-13,14-dihydrooctalene)dichromium(0), formed on reaction of [14]annulene (**2**) with tricarbonyltriamminechromium(0), regenerates **2** when solutions of the complex are allowed to stand at room temperature: Stöckel, K.; Sondheimer, F.; Clarke, T. A.; Guss, M.; Mason, R. *J. Am. Chem. Soc.* **1971**, *93*, 2571. For the electrocyclic ring opening of cycloocta-1,3,5-trienes to octa-1,3,5,7-tetraenes and the reversal of this isomerization, see: Cantrell, T. S. *Tetrahedron Lett.* **1968**, 5635. Cantrell, T. S. *J. Am. Chem. Soc.* **1970**, *92*, 5480. Kaupp, G.; Rösch, K. *Angew. Chem.* **1976**, *88*, 185; *Angew. Chem., Int. Ed. Engl.* **1976**, *15*, 163. Staley, S. W.; Henry, T. J. *J. Am. Chem. Soc.* **1970**, *92*, 7612. Huisgen, R.; Dahmen, A.; Huber, H. *Ibid.* **1967**, *89*, 7130; *Tetrahedron Lett.* **1969**, 1461; Dahmen, A.; Huisgen, R. *Ibid.* **1969**, 1465.

(6) Müllen, K.; Oth, J. F. M.; Engels, H.-W.; Vogel, E. *Angew. Chem.* **1979**, *91*, 251; *Angew. Chem., Int. Ed. Engl.* **1979**, *18*, 229.

(7) Another striking example of this approach is provided by the direct transformation of a polycyclic π system into a bridged annulene: in the dianion of the pyrene isomer dicyclopenta[*ef,kl*]heptalene one can deduce from spectroscopic evidence that the excess π charge preferentially resides on the inner vinyl bridge. Consequently, methylation proceeds via attack at the central carbon atoms to yield a pericyclic 14π-aromatic system; see: Huber, W.; Lex, J.; Meul, T.; Müllen, K. *Angew. Chem.* **1981**, *93*, 401; *Angew. Chem., Int. Ed. Engl.* **1981**, *20*, 391.

(8) Although **4** appears to be a logical intermediate, the possibility that the electrocyclic ring opening already occurs at the stage of a monomethylated intermediate cannot be ruled out rigorously.

(9) Oth, J. F. M. *Pure Appl. Chem.* **1971**, *25*, 573.

(10) The ^1H NMR chemical shifts of 1,8-dimethyl[14]annulene closely resemble those of the parent [14]annulene (**2**). In compound **2**, however, an additional signal of outer-ring protons (δ 6.8) occurs, which is indicative of the existence of another configurational isomer.[9] This isomer differs from that with a pyrene type configuration by having only three inner protons. Although 1,8-dimethyl[14]annulene is shown to be represented by **5a–c**, the relative signal intensities of outer- and inner-ring protons do not allow the exclusion of a small amount of a second configurational isomer. A detailed NMR spectroscopic study of 1,8-dimethyl[14]annulene, including the complex conformational mobility, will be presented elsewhere.

annulene[11] shows that in its crystalline state the compound is solely present as conformer **5a** (Figure 1). The fact that **5a** is found to be centrosymmetric allows one to rule out bond alternation immediately. In accord with predictions based on molecular models, **5a** avoids the severe crowding of the inner hydrogen atoms that would exist in the planar molecule. As demonstrated by the side view of **5a** (Figure 2), the carbon skeleton adopts the shape of a puckered loop with the inner hydrogen atoms H3/H6 and H10/H13 located above and below, respectively, the median ring plane. Most significantly, the carbon–carbon bond lengths ranging from 1.364 to 1.407 Å are typical of benzenoid aromatic bonds although torsional angles in the carbon skeleton of up to 20° are encountered.[12] These structural findings on 1,8-dimethyl[14]-annulene attest to our previous conclusions, derived from a study of bent bridged [14]annulenes, that a cyclically conjugated $(4n + 2)\pi$-electron system is capable of tolerating rather striking deviations from planarity without suffering a substantial loss in π-electron delocalization.[13]

From the preparative point of view the conversion of octalene to 1,8-dimethyl[14]annulene harmoniously complements the previous synthesis of the parent [14]annulene since treatment of the latter with electrophilic reagents leads to polymerization rather than to substitution products.[14] Further work on this new approach to the [14]annulene system is currently in progress.

Registry No. 1, 257-55-6; **3**, 69502-53-0; **5a**, 81770-67-4; dihydrodilithiooctalene, 69517-01-7.

Supplementary Material Available: Crystallographic data of 1,8-dimethyl[14]annulene and a structure indicating the numbering of the atoms of 1,8-dimethyl[14]annulene according to the crystallographic data given (2 pages). Ordering information is given on any current masthead page.

(11) The compound crystallizes in the monoclinic system, space group $C2/c$, with $a = 19.010$ (7) Å, $b = 4.178$ (1) Å, $c = 15.926$ (4) Å, $\beta = 98.70$ (3)°, $d_{obsd} = 1.10$, $d_{calcd} = 1.117$ g cm^{-3}, $Z = 4$. Three-dimensional intensity data were collected on an Enraf-Nonius CAD-4 diffractometer. The structure was solved by direct methods and refined by full-matrix least-squares calculations to $R = 0.069$ for 497 observed reflections with $I \geq 2\sigma(I)$.

(12) For an X-ray structure determination of the [14]annulene (2), see: Chiang, C. C.; Paul, I. C. *J. Am. Chem. Soc.* **1972**, *94*, 4741.

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(14) Sondheimer, F. *Acc. Chem. Res.* **1972**, *5*, 81.

Exploring Nuclear Spin Systems by Relayed Magnetization Transfer

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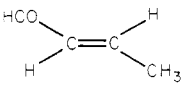
We should like to address one of the basic problems of NMR spectroscopy: the task of identifying families of signals belonging to the same network of coupled spins. For large molecules such as biopolymers, this is by no means straightforward. Consider for example a scalar-coupled AMX system with a vanishing long-range coupling $J_{AX} = 0$ Hz. There are situations where none of the methods available to date can provide unequivocal proof that A and X belong to the same spin system. Selective double resonance or two-dimensional (2-D) correlation spectroscopy[1,2] can certainly be employed to identify the couplings J_{AM} and J_{MX}. Very similar responses could, however, be obtained from two distinct pairs AM and M′X with accidental overlap in the M region. Experimental evidence of two couplings does not constitute sufficient proof that one is dealing with a three-spin system, unless the multiplet structure of all lines can be fully analyzed, which is usually impossible for biomolecules.

We propose a novel approach that exploits the existence of a coupling network to prove the connectivity between two remote nuclei A and X. The method employs two or more consecutive steps where transverse magnetization is relayed from nucleus to nucleus along a path defined by a sequence of resolved couplings.

Conventional 2-D correlation spectroscopy[1-4] uses a $90°-t_1-\beta-t_2$ sequence, where the second "mixing" pulse with flip angle β induces transfer of transverse magnetization between coupled spins. After 2-D Fourier transformation, such coherence transfer processes lead to cross-peaks, the frequency coordinates being characteristic of the chemical shifts of directly coupled pairs of nuclei.

In relayed correlation spectroscopy, the second pulse of the two-dimensional experiment is replaced by a $90°-\tau-180°-\tau-90°$ sequence, which may induce two consecutive coherence transfer processes. More sophisticated sequences can be designed to relay the information over a greater number of couplings. It can be shown for the AMX system with $J_{AX} = 0$ Hz that the transfer efficiency from A to X is proportional to the product $\sin(2\pi J_{AM}\tau) \cdot \sin(2\pi J_{MX}\tau)$ if all three pulses have the same phase.

Crotonaldehyde (I) provides an interesting test case. In the



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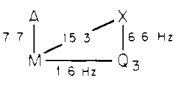

II

AMQ_3X proton coupling network (II), the aldehyde proton A does not exhibit a resolved coupling to either Q or X nuclei. As a result, the normal 2-D correlation spectrum fails to reveal connectivities between A and either Q or X (empty circles in Figure 1a). The complexity of the M region makes it difficult to obtain clear-cut information from the multiplet structure: the spectrum in Figure 1a could also be explained by invoking a superposition of an AM system with an $M'Q_3X$ system.

The new two-dimensional method, as can be appreciated in Figure 1b, provides unequivocal proof that all six spins belong to one and the same coupling network. In this spectrum, the interval τ has been adjusted intentionally to favor the transfer from A to Q. Nonetheless sufficient magnetization is transferred from A to X to allow immediate identification.

Variations of the basic relay experiment discussed here can be designed to obtain responses for arbitrary scalar couplings in unknown coupling networks. Besides inclusion of more coherence transfer steps, it is possible to increment the interval τ in concert with t_1 in the manner of accordion spectroscopy.[5-7] In principle, the transfer processes can be made virtually independent of the magnitude and the number of couplings if a spin-locking period is inserted between evolution and detection periods of the two-dimensional experiment.[8]

Relayed coherence transfer need not be combined with two-dimensional spectroscopy. It is also possible to replace the initial excitation by a selective 90° pulse in order to monitor the propagation of magnetization throughout the coupling network in a one-dimensional experiment.[9]

A number of promising applications are feasible in heteronuclear systems. In particular, the chemical shift of carbon-13 can be correlated not only with the chemical shift of directly bound protons (as is customary in conventional correlation spectroscopy[10]) but also with the shifts of protons attached to neighboring carbons.[11] This information makes it possible to trace out the entire

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(6) Bodenhausen, G.; Ernst, R. R., *J. Am. Chem. Soc.* **1982**, *104*, 1304.

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