$Rh_{13}(CO_{24})^{5-}$.[12] However, instead of an interstitial metal atom, the title molecule contains a ditelluride group holding it together. Fourteen-vertex clusters are quite rare. One 14-vertex cluster has been reported which does not have a shape related to that of molecule I.[13] In addition, there is the enormous class of Chevrel type clusters which have the same elemental composition but are face-capped octahedra.[14]

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**Supplementary Material Available:** Tables of complete structural data, positional parameters, complete distances and angles, thermal parameters, and hydrogen atom coordinates for the title molecule (6 pages); table of observed and calculated structure factors for the title molecule (20 pages). Ordering information is given on any current masthead page.

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## Nitrogen-15-Labeled Deoxynucleosides. 3. Synthesis of [3-$^{15}$N]-2′-Deoxyadenosine

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The purine N3 atom is not involved in either the Watson–Crick H bonding normally present in DNA or the Hoogsteen pairing which has recently been implicated in three- and four-stranded structures.[1-7] It is therefore generally available as a minor groove DNA binding site for the hundreds of small molecules known to bind to DNA and to act as antibiotic, antiviral, and antineoplastic agents.[8] For example, two-dimensional NMR studies and single-crystal X-ray diffraction analysis of complexes between small DNA fragments and the drugs netropsin[9,10] and distamycin[11-13] have shown that amide NH atoms of each drug form H bonds involving the adenine N3, in addition to other H bonds and van der Waals contacts. Although the very high binding affinity of netropsin has been shown to be overwhelmingly enthalpy driven,[14] it has been proposed that the base specificity is due mainly to the close van der Waals contacts rather than to hydrogen bonding.[9] By using [3-$^{15}$N]-labeled DNA fragments it may be possible to elucidate both the existence and the strength of the H bonds to these and other molecules which bind in the minor groove.

The synthesis of [3-$^{15}$N]-labeled adenine has been reported by several groups.[15-17] Each of these syntheses followed essentially the same route, in which the $^{15}$N is introduced by nitration of 4-bromoimidazole under forcing conditions using [$^{15}$N]-$HNO_3$. We have devised an alternate route which uses an azo coupling reaction for introduction of the $^{15}$N and proceeds through the intermediacy of [5-$^{15}$N]-labeled 5-aminoimidazole-4-carboxamide (AICA). An unrelated route to the [5-$^{15}$N]-labeled 5-aminoimidazole ribonucleoside (AIRs) was recently reported.[18] AICA is a versatile precursor, which is most commonly used for entry into the guanine or isoguanine families,[19,20] although it is usually used as the AICA-riboside rather than the heterocycle itself.[21,22] We have found that AICA also can be used for the adenine family by cyclization to hypoxanthine using diethoxymethyl acetate in DMF at reflux. Although these conditions are more vigorous than those required for cyclization of 4,5-diaminopyrimidines using this reagent,[23,24] the reaction works well. In addition, we report high-yield enzymatic conversion of [3-$^{15}$N]-adenine to [3-$^{15}$N]-2′-deoxyadenosine.

Early studies directed toward purine synthesis found that the 2-methyl- and 2-phenylimidazole-4,5-dicarboxylic acids coupled with aryldiazonium ions to give the corresponding 5-arylazo 4-carboxylic acids.[25] The unsubstituted imidazole-4,5-dicarboxylic acid, however, gave largely the 2-arylazo derivative. We reasoned that it might be possible to use a 2-bromo substituent as a protecting group to force the coupling back to the 5-position. The bromine then could be removed concomitantly with reduction of the azo linkage. Thus (Scheme I), commercially available imidazole-4,5-dicarboxylic acid (**1a**) was first esterified to **1b** and then brominated with *N*-bromosuccinimide (NBS) to give **2a**. Direct bromination of the diacid gave a complex mixture, while in contrast the diester reacted cleanly. After hydrolysis to **2b**, coupling with the [$\beta$-$^{15}$N]-4-bromobenzenediazonium ion (**3**), generated in situ by diazotization of 4-bromoaniline using [$^{15}$N]-$NaNO_2$, gave the 5-azo derivative **4** in 85% yield. The preparation of [5-$^{15}$N]-AICA (**6**) proved to be most successfully accomplished by conversion to the 4-carboxamide at this stage, rather than after the reduction. Reaction of **4** with cold ethyl chloroformate followed by treatment with ammonia in THF gave crystalline **5** in quantitative yield.

Removal of the 2-bromo group and cleavage of the azo group were then effected under 8 psi of $H_2$ for 5 h in a mixture of methanol, KOH, and 5% Pd/C. The [5-$^{15}$N]-AICA (**6**) obtained from this reaction has a faint purple color and is contaminated with small amounts of KOH and KBr. Nevertheless, these salts do not interfere with conversion of **6** to [3-$^{15}$N]-hypoxanthine (**7**)

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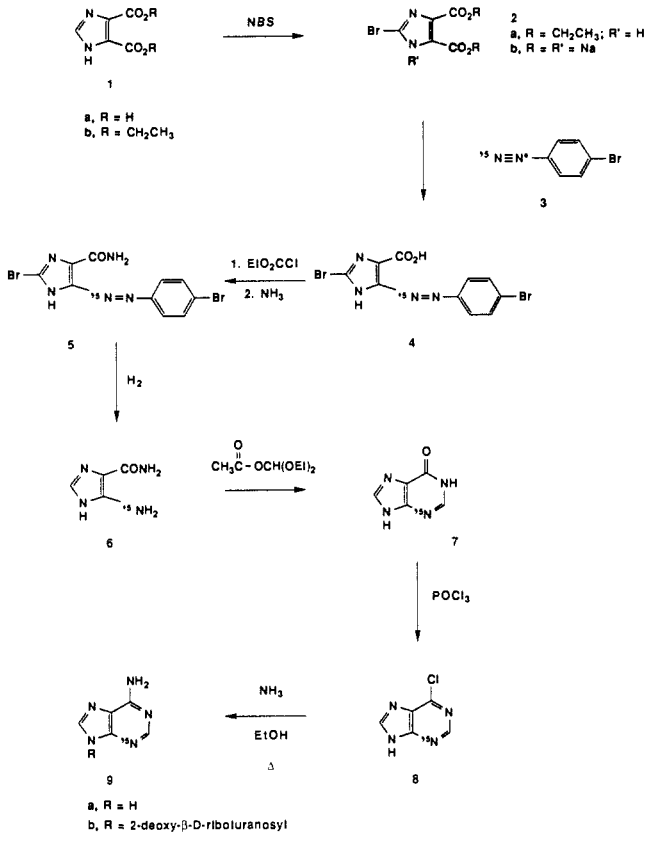
Scheme I



using diethoxymethyl acetate. This reaction was carried out in DMF for 3 h at reflux. After evaporation of solvents, but without additional purification, **7** was then converted to [3-$^{15}$N]-6-chloropurine (**8**) by reaction with $POCl_3$ and dimethylaniline.[26] The overall yield from **5** was 72%. The amination of **8** to [3-$^{15}$N]-adenine (**9a**) was effected by using ethanolic ammonia in a bomb at 120 °C. The crude **9a** contains some ammonium chloride, but it can be used directly for glycosylation without further purification. The glycosylation reaction was carried out by enzymatic transglycosylation using thymidine, thymidine phosphorylase, and purine nucleoside phosphorylase,[27,28] as we had done for synthesis of [7-$^{15}$N]-labeled deoxynucleosides.[24] The overall yield was 46% from **5** or 64% from **8**.

This route is an overall highly efficient synthesis of [3-$^{15}$N]-adenine and [3-$^{15}$N]-2'-deoxyadenosine. The reactions employed are generally high yield and require minimal purification procedures. The labeled ribonucleoside is also available by this route simply by using uridine as the glycosyl donor in the enzymatic transglycosylation reaction rather than thymidine.[27,28] Moreover, the [5-$^{15}$N]-AICA intermediate (**6**) is a useful precursor for [3-$^{15}$N]-labeled guanine and isoguanine derivatives.[19,20] Thus this route provides formal entry into [3-$^{15}$N]-labeled nucleosides of both the adenine and guanine families.

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# Chirality Transmission Involving a Free-Radical-Mediated 6-Exo Cyclization Process. Stereocontrolled Synthesis of Branched-Chain 1,4-Diols

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Drawing upon the vast wealth of information accumulated on free-radical-mediated cyclization reactions, organic chemists have effectively exploited the well-documented overwhelming predilection for the 5-exo mode of cyclization of the 5-hexenyl radicals and their equivalents over the corresponding 6-endo pathway.[1] A notable exception to this general rule includes the reaction of the 2-sila- and 2-sila-3-oxahexenyl radicals where the 6-endo mode of cyclization becomes competitive[2-4] or, with certain olefin structures, predominant.[5] In contrast, there has been much less investigative focus on the use of the 6-heptenyl radical or its equivalent in regio- and stereoselective synthesis.[6] In connection with our synthetic study of the plant hormone brassinolides, we became interested in the intramolecular cyclization of the 2-sila-3-oxa-6-heptenyl radicals (**1**) which do not carry electron-withdrawing groups at the distal olefinic carbon (Scheme I). Interestingly, the results obtained by Nishiyama and co-workers show only marginal acyclic regio- and stereoselectivity in the 5-exo and/or 6-endo cyclizations of the radicals generated from several (bromomethyl)dimethylsilyl allyl ethers.[3] We report herein that radicals **1** ($R^1$ = H, $R^2$ = Me, and $R^1$ = $R^2$ = Me) undergo highly regio- and stereoselective 6-exo-mode cyclization (pathway a, Scheme I) to produce six-membered siloxanes, which upon oxidation afford branched-chain 1,4-diols. This formally constitutes a net syn-selective reductive hydroxymethylation of chiral homoallylic alcohols.

The requisite (bromomethyl)silyl ethers were obtained in quantitative yield from their corresponding homoallylic alcohols with (bromomethyl)dimethylsilyl chloride/$Et_3N$ in $CH_2Cl_2$ (0 °C, 2-3 h). Cyclization was then effected with (*n*-Bu)$_3$SnH, generated in situ from a catalytic amount of (*n*-Bu)$_3$SnCl and an excess of $NaB(CN)H_3$,[7] in refluxing *t*-BuOH (12-16 h) in the presence of a catalytic amount of AIBN. The cyclic siloxanes thus obtained were smoothly converted into the corresponding diols by treatment with excess 30% $H_2O_2$/$KHCO_3$ in refluxing THF/MeOH (2-3 h).[8] As summarized in Table I, the radicals generated from the (bromomethyl)silyl ethers with mono- or dimethyl-substituted olefins (entries 2, 3, 5, and 7) underwent regioselective 6-exo-mode cyclization to produce exclusively the six-membered *cis*-siloxanes in 89-98% yield (see pathway a in Scheme I). The cis stereochemistry of these disubstituted siloxanes was ascertained through

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