the *absence* of intermolecular hydrogen bonding. (See first paragraph of the present communication.)

Supplementary Material Available: Tables of crystal data, positional parameters, bond lengths and angles, and torsion angles for **1** (15 pages); listing of observed and calculated structure factors for **1** (8 pages). Ordering information is given on any current masthead page.

Laser Vaporization of Single-Stranded DNA. A Study of Photoinduced Phosphodiester Bond Scission

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One prerequisite for gas-phase analysis of large, fragile biomolecules is the molecular transfer of these species into the vapor state. This transfer has been accomplished for proteins,[1] duplex DNA,[2,3] and short oligonucleotides[4] via laser vaporization. Here *a thin film of biomolecule and excess chromophore is irradiated* with an intense laser pulse such that energy is deposited into the system so rapidly (10 ns) that molecular ejection occurs before thermal degradation begins. It is possible that laser vaporization may ultimately form the foundation for high-speed DNA sequencing wherein gel electrophoresis is replaced by mass spectrometry. In this scenario, a single-stranded dideoxy DNA sequencing product is molecularly vaporized by a pulsed laser, then ionized, and detected by mass spectrometry. We report in this communication the laser vaporization of a 17-base-long single-stranded oligonucleotide. We find that the extent of phosphodiester bond scission is dependent on the power of the laser pulse and, more importantly, that the extent of *molecular* vaporization scales with the laser pulse power. The significance of this result rests in the fact that vaporization of single-stranded DNA without strand scission is a crucial step for mass spectral based DNA sequencing.

To investigate the laser vaporization of single-stranded DNA, a mixture of a ^{32}P-labeled 17-mer and rhodamine 6G (1:17 000 molar ratio) is deposited onto a glass microscope slide. The *resulting thin film will absorb green light by virtue of the rhodamine 6G dye chromophore.*[5] The dried sample is then placed into a vacuum chamber (1×10^{-6} Torr) 10 mm from a piece of Whatman 3MM filter paper. A doubled Nd:YAG laser (532 nm, 7-ns pulse) is directed at the front of the sample, and the vaporized materials are collected on the filter paper. Figure 1 (panels A–C) shows an autoradiograph of the filter papers obtained upon exposing the 17-mer sample to laser pulses having powers of 130, 85, and 45 mJ/cm^2, respectively. Note that the ^{32}P-labeled material present on the filter paper is evenly distributed in a tightly focused spot, as is expected for molecular vaporization. Prior studies[2] have shown that the removal of macroscopic pieces of the mixture (spallation) results in a spotted or speckled appearance. While these results strongly suggest that spallation does not occur when rhodamine 6G is used, we cannot rule out the formation of small amounts of molecular dimer and trimer.

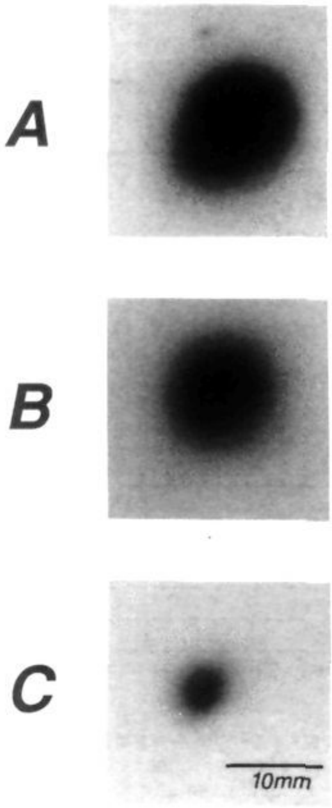

Figure 1. Autoradiograms of filters containing a vaporized oligonucleotide (17-mer, MW ≅ 5600) as a function of vaporization laser power: panel A, 130 mJ/cm^2; panel B, 85 mJ/cm^2; panel C, 45 mJ/cm^2.

To further characterize the 17-mer vaporization products, the radioactive material on each filter is eluted by soaking in water and then analyzed by high-resolution polyacrylamide gel electrophoresis.[6] The sample that had been vaporized with a laser power of 45 mJ/cm^2 shows extensive strand scission, giving rise to strands of an average chain length of four nucleotides (Figure 2, lane 3). However, the samples vaporized at 130 and 85 mJ/cm^2 (Figure 2, lanes 1 and 2) display no observable strand scission, although some inorganic phosphate (P$_i$) is produced. The vaporized product should display less decomposition at high fluences because of collisional cooling. This results from the increased density of desorbed material resembling a free jet expansion.[3,7-9]

To gain insight into the chemical bond-breaking process observed in the 17-mer experiment, the vaporization of a simpler chemical species, $[\alpha\text{-}^{32}\text{P}]$dATP, as a function of laser power was studied. Laser vaporization is carried out at laser fluences between 45 and 320 mJ/cm^2. The products of the vaporization process are collected on filter paper, analyzed by TLC, and compared to a series of standards,[10] and the amount of radioactivity in each of the components present is quantified (Figure 3). As predicted from the 17-mer experiments, the highest power levels result in little decomposition: at 320 mJ/cm^2 approximately 90% of the radioactivity present on the filter paper is recovered as intact dATP. As the laser power is reduced, several trends are observed:

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(10) The standards included sodium phosphate, sodium pyrophosphate, sodium tripolyphosphate, dAMP, dADP, and dATP.

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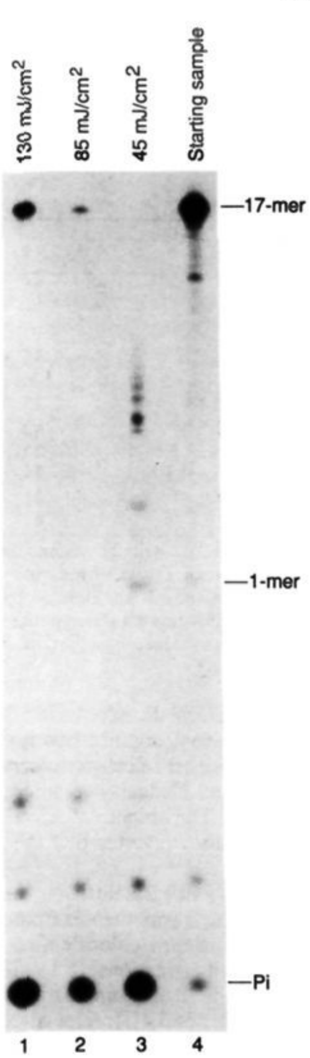

Figure 2. Polyacrylamide gel electrophoretic analysis of a vaporized oligonucleotide. The vaporized radioactive materials on the filter papers shown in Figure 1 are excised and extracted with two 150-μL portions of water, and the resulting solutions are concentrated and then loaded onto a 20% polyacrylamide gel:[6] lane 1, 130 mJ/cm^2; lane 2, 85 mJ/cm^2; lane 3, 45 mJ/cm^2; lane 4, starting oligonucleotide. The gel is electrophoresed at 1000 V for 2 h, and then the positions of the bands are determined by autoradiography. Authentic inorganic phosphate and mononucleotide are run in adjacent lanes.

(i) less molecular dATP is obtained; (ii) more dAMP is produced; (iii) more phosphate and diphosphate are formed; and (iv) less tripolyphosphate is observed (not shown; less than 4%). These trends are consistent with photochemical activation of the P–O–P bonds at intermediate and low vaporization power. The incident photon fluence ($\sim 2 \times 10^{17}$ photons cm^{-2} s^{-1}) is high enough that this activation can proceed through a two-photon excitation of the 274-nm electronic absorption band of the phosphate[11] or through an excitation of the adenine base with subsequent energy transfer to the phosphate bonds. Alternatively, the photon energy may degrade to thermal energy before vaporization occurs. This would result in a photothermal mechanism for cleaving the weak phosphodiester bond at low laser powers. At the highest powers, the P–O–P bonds are still activated, but the energy is most likely quenched by the high number of subsequent collisions.

These results strongly suggest that fragile, single-stranded DNA molecules can be molecularly vaporized out of a rhodamine 6G thin film using laser pulse energies greater than 85 mJ/cm^2. At lower energies the phosphodiester bonds cleave, presumably through photochemical activation. Finally, recent studies in our laboratory suggest that single strands as long as 1000 bases can be vaporized intact.[12]

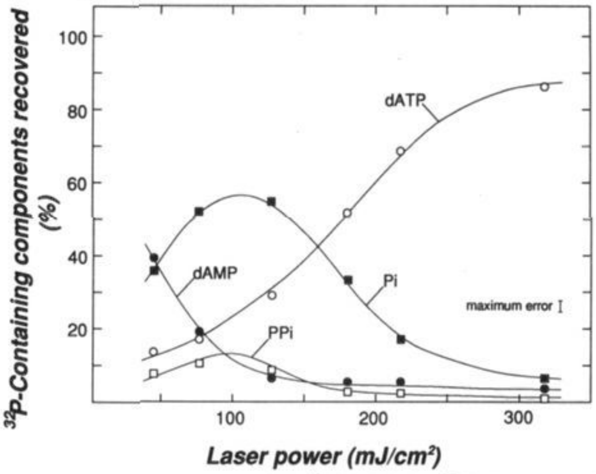

Figure 3. Analysis of vaporized [α-^{32}P]dATP. [α-^{32}P]ATP (60 pmol, 3000 Ci/mmol) is dissolved in 20 μL of water containing 10% methanol and 10 mg/mL rhodamine 6G. The thin film is vaporized from a fresh spot for each power level. The vaporized radioactive materials are eluted and adjusted so that each has 20 000 cpm/μL. Two microliters are spotted onto a glass-backed PEI-cellulose F TLC plate (EM Science) and are eluted with a solution of 0.6 M LiCl in 1.0 M formic acid. The amount of radioactivity present in each spot is determined by using an Ambis radioactivity image scanner: (○) dATP, (●) dAMP, (□) pyrophosphate, (■) phosphate.

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(11) The visible/ultraviolet spectra of sodium phosphate, pyrophosphate, and polytriphosphate were obtained on a Hewlett-Packard 8452A diode array spectrophotometer. In essence, two electronic absorptions were observed for each sample, a strong feature at 198 nm and a weak feature at 274 nm.

(12) Romano, L. J.; Levis, R. J., manuscript in preparation. These recent experiments provide further evidence for molecular vaporization. These studies show that there is a considerable difference between the autoradiographic band intensities for single-stranded DNA mixtures that have been either vaporized or directly loaded onto a gel. For example, a comparison of the ratio of the 20-mer to 75-mer intensities for the two samples indicated that the intensity of the 75-mer band was reduced by 90% in the vaporized sample relative to the starting sample. Spallation would be expected to generate materials on the filters having band intensity distributions identical with those of the starting sample.

Reactions of Sulfinylated Radicals. Solvent Effect and Efficient Stereoselectivity Enhancement by Complexation of the Sulfinyl Group with Lewis Acids

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Control of the stereoselectivity of radical reactions[1] is an important problem to solve in order to generalize the application of these reactions in preparative organic synthesis.[2] Very little is known about controlling the stereochemical outcome of radical reactions by external factors like solvent[3] or coordinating species. In the course of our studies on the reactions of sulfinylated radicals, we have decided to address this particular problem. We report herein a unique case of stereoselectivity enhancement of a radical reaction based on complexation of the radical intermediate with metals and Lewis acids.

The use of sulfoxides as chiral auxiliaries for radical reactions has recently attracted much attention. Cyclization of acyclic radicals has been reported.[4-7] A cyclic radical generated from

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(2) Giese, B. *Angew. Chem., Int. Ed. Engl.* **1989**, *28*, 969.

(3) The first case of a solvent effect in this context was reported by Giese in ref 2, p 971.

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