displacement of product **4b** by either $PhCH{=}CH_2$ or $Bu^tC{\equiv}CH$ or further isomerization via a second 1,5-hydrogen shift to produce **3c**.[9] The product distribution obtained using styrene-d_8, C_6D_5-$CD{=}CD_2$, shows that a primary kinetic isotope effect is present for the isomerization step (Table I, Scheme II), thus leading to a modification of the ratio of **4b*** to **4c*** but no decrease in overall 1,3-cyclohexadiene formation compared to cyclotrimerization.[10] Careful analysis of the ^1H and ^{13}C NMR spectra of the products **4b*** and **4c*** obtained using styrene-d_8 shows that the sequential 1,5-hydrogen shifts occur in a highly stereoselective, mutually cis fashion consistent with the pathway proposed (Scheme III).[11-13] The lack of isomerization of either **4b** or **4c** upon thermolysis (90 °C, 12 h) or upon exposure to a mixture of **1**, $Bu^tC{\equiv}CH$ and $PhCH{=}CH_2$ shows that the observed product distributions are kinetic in origin.

The catalytic cycloaddition of $Me_3SiC{\equiv}CH$ and $PhCH{=}CH$ in the presence of **1** yields slightly different results (Scheme IV). In this case, although the initial isomeric mixtures obtained are dependent upon the reaction conditions, the isomerization of **5a** to **5b** occurs over time within the reaction mixture. This indicates that recoordination of the generated trimethylsilyl-substituted 1,3-cyclohexadienes can occur, allowing further metal-mediated isomerization.

The scope of this reactivity has been further investigated by utilizing the diyne substrates $[RC{\equiv}C(CH_2)_4C{\equiv}CR]$ (R = Et, $SiMe_3$). Reduction of $[(Ar''O)_2TiCl_2]$ in the presence of 3,9-dodecadiyne leads to titanacyclopentadiene **6** (Scheme V).[14] Compound **6** catalyzes the reaction of 3,9-dodecadiyne with ethylene to produce a mixture of three corresponding hexalins (Scheme V).[15,16] In the case of the bis(trimethylsilyl) substrate, (2 + 2 + 2) cycloaddition with ethylene in the presence of **6** was also found to lead to a mixture of three products (Scheme V). The stereochemistries of **7c**, **7d**, **8c**, and **8d** were confirmed by their ^1H and ^{13}C NMR spectra. This cis stereochemistry is consistent with the stereoselective isomerization shown for **3** (Scheme II). Extended reaction times at 90 °C were found to lead to formation of the corresponding disubstituted tetralin.[15]

Acknowledgment. We acknowledge the National Science Foundation (Grant CHE-8915573) for financial support of this research. We thank the referees for helpful suggestions.

Supplementary Material Available: Spectroscopic data for 1,3-cyclohexadiene products (16 pages). Ordering information is given on any current masthead page.

(8) The isomerization should proceed via cyclohexadienyl hydride intermediates. See: Fischer, M. B.; James, E. J.; McNeese, T. J.; Nyburg, S. C.; Posin, B.; Wong-Ng, W.; Wreford, S. S. *J. Am. Chem. Soc.* **1980**, *102*, 4941.

(9) The results in Table I indicate that release of the final product 1,3-cyclohexadiene can occur by displacement with either olefin or acetylene. The ratio of **4b** to **4c** increases as the concentration of either styrene (Table I, entries 2, 4, and 6) or *tert*-butylacetylene (Table I, entries 2 and 7) increases. Use of $PhCD{=}CD_2$ also increases the ratio of **4b*** to **4c***, entries 7 and 8. However, it is possible that a dissociative pathway is also present, involving an intermediate fragment $[(Ar''O)_2Ti]$ which may be stabilized by intramolecular π-bonding to the aryl substituents of the 2,6-diphenylphenoxide ligands. See: (a) Kerschner, J. L.; Torres, E. M.; Fanwick, P. E.; Rothwell, I. P.; Huffman, J. C. *Organometallics* **1989**, *8*, 1424. (b) Kerschner, J. L.; Fanwick, P. E.; Rothwell, I. P.; Huffman, J. C. *Organometallics* **1989**, *8*, 1431.

(10) Analysis of **4b*** and **4c*** by GC/MS shows no loss of deuterium content by exchange with the other species.

(11) For a discussion of the NMR of 1,3-cyclohexadienes, see: *The Conformational Analysis of Cyclohexenes, Cyclohexadienes, and Related Hydroaromatic Compounds*; Rabideau, P. W., Ed.; VCH Publishers, Inc.: New York, NY, 1989; Chapter 3.

(12) The ^1H NMR spectra of **4b** and **4c** are consistent with a ground-state structure containing a pseudoequatorial *tert*-butyl substituent. The aliphatic ring proton in **4c*** (Scheme II) is pseudoaxial on the basis of ^1H NMR spectra, i.e., mutually cis to the *tert*-butyl group. See: (a) Lightner, D. A.; Bouman, T. D.; Gawroński, J. K.; Gawroński, K.; Chappuis, J. L.; Crist, B. V.; Hansen, A. E. *J. Am. Chem. Soc.* **1981**, *103*, 5314. (b) Copley, S. D.; Knowles, J. R. *J. Am. Chem. Soc.* **1987**, *109*, 5008.

(13) The ground-state stereochemistries of **4b** and **4c** have been confirmed by photochemical ring opening to produce the corresponding linear triene (Scheme III). For leading references to the photochemistry of 1,3-cyclohexadienes and related molecules, see: Woning, J.; Lijten, F. A. T.; Laarhoven, W. H. *J. Org. Chem.* **1991**, *56*, 2427.

(14) Anal. Calcd for $TiC_{48}H_{44}O_2$: C, 82.27; H, 6.33. Found: C, 82.24; H, 7.19%. ^1H NMR (C_6D_6, 30 °C): δ 6.8-7.5 (aromatics); 2.04 (m), 1.41 (m, CH_2CH_2); 1.53 (q, CH_2CH_3); 0.44 (t, CH_2CH_3). Selected ^{13}C NMR (C_6D_6, 30 °C): δ 229.9 (TiCEt); 159.6 (TiOC); 132.4 (β-C); 27.9, 24.1, 21.9 (CH_2); 13.0 (CH_2CH_3).

(15) (a) Jacobson, B. M. *J. Am. Chem. Soc.* **1973**, *95*, 2579. (b) Dauben, W. G.; Hart, D. J.; Ipakschi, J.; Kozikowski, A. P. *Tetrahedron Lett.* **1973**, *44*, 4425.

(16) (a) Matuszewski, B.; Burgstahler, A. W.; Givens, R. S. *J. Am. Chem. Soc.* **1982**, *104*, 6874. (b) Dauben, W. G.; Kellogg, M. S. *J. Am. Chem. Soc.* **1980**, *102*, 4456.

α-C–H and α'-C–C Bond Cleavage in an Iridacyclohexadiene. Interchange of α-Hydrogen and α'-Phenyl Substituents without Accompanying Skeletal Rearrangement

Russell P. Hughes,*[1a] Hernando A. Trujillo,[1a,b] and Arnold L. Rheingold[1c]

Departments of Chemistry, Dartmouth College Hanover, New Hampshire 03755 University of Delaware, Newark, Delaware 19716

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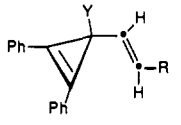
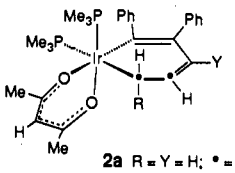
While metallacyclohexadienes have been invoked as key intermediates in the Dötz reaction,[2] few isolated examples exist, and their reaction chemistry is poorly defined. The first isolable examples were obtained from the ring-opening reactions of 3-vinyl-1-cyclopropenes with low-valent transition-metal complexes.[3] Subsequently, iridacyclohexadiene species, obtained by a different route,[4] were shown to undergo a facile deprotonation at the α-carbon to afford the first examples of iridabenzene complexes.[5] Here we report the unprecedented rearrangement of a 1,2-disubstituted iridacyclohexadiene to its 1,4-disubstituted isomer, which is shown by isotope labeling experiments to proceed by a quantitative interchange of H and Ph substituents between the α- and α'-carbon atoms of the metallacyclic ring rather than by a skeletal reorganization.

Room temperature reaction of the 16-electron Ir(I) complex $[Ir(acac)(PMe_3)_2]$ (acac = acetylacetonate) with 1,2-diphenyl-3-vinyl-1-cyclopropene (**1a**) affords the iridacyclohexadiene complex (**2a**).[6] On heating **2a** in benzene solution (95 °C, 33 h), a smooth isomerization occurs to give the corresponding trans isomer **3a** without any isomerization of the metallacycle. However,



1a R = Y = H; • = ^{12}C
1b R = Y = H; • = ^{13}C
1c R = D; Y = H; • = ^{12}C
1d R = H; Y = D; • = ^{12}C



2a R = Y = H; • = ^{12}C
2b R = Y = H; • = ^{13}C
2c R = D; Y = H; • = ^{12}C
2d R = H; Y = D; • = ^{12}C

(1) (a) Dartmouth College. (b) American Chemical Society, Division of Organic Chemistry Fellow, 1990-1991, sponsored by the American Cyanamid Company. (c) University of Delaware.

(2) Dötz, K. H. *Angew. Chem., Int. Ed. Engl.* **1984**, *23*, 587-608. For recent discussion, see: Bos, M. E.; Wulff, W. D.; Miller, R. A.; Chamberlin, S.; Brandvold, T. A. *J. Am. Chem. Soc.* **1991**, *113*, 9293-9319.

(3) Grabowski, N. A.; Hughes, R. P.; Jaynes, B. S.; Rheingold, A. L. *J. Chem. Soc., Chem. Commun.* **1986**, 1694-1695.

(4) Bleeke, J. R.; Peng, W. J. *Organometallics* **1987**, *6*, 1576-1578.

(5) Bleeke, J. R.; Xie, Y.-F.; Peng, W. J.; Chiang, M. Y. *J. Am. Chem. Soc.* **1989**, *111*, 4118-4120. Bleeke, J. R. *Acc. Chem. Res.* **1991**, *24*, 271-277. Bleeke, J. R.; Xie, Y.-F.; Bass, L.; Chiang, M. Y. *J. Am. Chem. Soc.* **1991**, *113*, 4703-4704.

(6) Full details of the synthesis and spectroscopic characterization of all compounds reported herein and the crystallographic characterization of **4a** are provided as supplementary material.

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Table I. ^1H, ^2H, ^{31}P, and ^{13}C NMR data for Complexes **3** and **4** (see Figure 1 for numbering scheme)[a]

complex	H_2	H_3	H_4	H_5	$^{31}P\{^1H\}$	^{13}C
3a		6.41 (dt) J_{HH} = 10,3	5.42 (dt) J_{HH} = 10,5	3.37 (ddt) J_{HH} = 5,2 J_{PH} = 13	−25.76 (s)	
3b		6.45 (tt) J_{HH} = 11,2 $^3J_{CH}$ = 10	5.46 (bd) $^1J_{CH}$ = 146	3.41 (bd) $^1J_{CH}$ = 123	−25.57 (dd) J_{CP} = 6,2	129.52 (ddt) C_4 $^1J_{CH}$ = 146 $^1J_{CC}$ = 40, J_{CP} = 2 −9.69 (tddt) C_5 $^1J_{CH}$ = 123, $^3J_{CH}$ = 10 $^1J_{CC}$ = 40, J_{CP} = 6
3c		6.42 (dd) J_{HH} = 10,2	5.41 (ddd) J_{HH} = 10,5 J_{PH} = 1	3.34 (br) ^2H 3.32 (br)	−25.54 −25.57	
3d		^2H 6.39 (br)	5.49 (bm)	3.43 (dt) J_{HH} = 4 J_{PH} = 13	−25.42	
4a	6.59 (dt) J_{HH} = 7 J_{PH} = 2	6.70 (dt) J_{HH} = 7,2		3.69 (dt) J_{HH} = 2 J_{PH} = 13	−29.46	
4b	6.63 (ddq) J_{HH} = 8 $^1J_{CH}$ = 147 $^2J_{CH}$ = 2 J_{PH} = 2	6.75 (br t) J_{HH} = 8 $^3J_{CH}$ = 8		3.72 (td) J_{HH} = 2 J_{PH} = 13	−24.88 (dd) J_{CP} = 10,4	140.51 (dtdd) C_1 $^1J_{CC}$ = 63, $^3J_{CH}$ = 8 $^2J_{CH}$ = 2, J_{CP} = 10 130.20 (ddt) C_2 $^1J_{CC}$ = 63 $^1J_{CH}$ = 147, J_{CP} = 4
4c	6.61 (dt) J_{HH} = 7 J_{PH} = 2	6.71 (dd) J_{HH} = 7,2		3.67 (ddd) J_{HH} = 2 J_{PH} = 12,5 ^2H 3.62 (br)	−26.47	
4d	6.63 (t) J_{PH} = 2	^2H 6.73 (br)		3.71 (t) J_{PH} = 13	−29.46	

[a] δ Values are given in ppm downfield of TMS for ^1H, ^2H, and ^{13}C and upfield of H_3PO_4 for ^{31}P spectra. J values are in Hz.

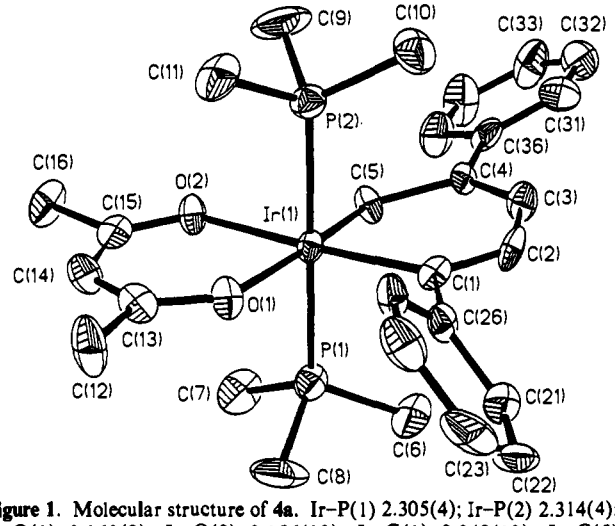
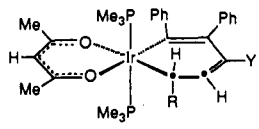
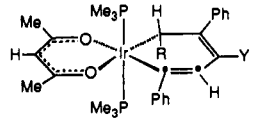


Figure 1. Molecular structure of **4a**. Ir–P(1) 2.305(4); Ir–P(2) 2.314(4); Ir–O(1) 2.162(9); Ir–O(2) 2.156(10); Ir–C(1) 2.049(12); Ir–C(5) 2.080(14); C(1)–C(2) 1.334(19); C(2)–C(3) 1.465(21); C(3)–C(4) 1.317(20); C(4)–C(5) 1.532(19) Å.

further heating of **3a** (benzene, 130 °C, 45 h) yields a new isomer (**4a**) in which the phenyl groups occupy positions 1 and 4 on the iridacyclohexadiene ring. Some NMR data for complexes **3** and



3a R = Y = H; • = ^{12}C
3b R = Y = H; • = ^{13}C
3c R = D; Y = H; • = ^{12}C
3d R = H; Y = D; • = ^{12}C



4a R = Y = H; • = ^{12}C
4b R = Y = H; • = ^{13}C
4c R = D; Y = H; • = ^{12}C
4d R = H; Y = D; • = ^{12}C

4 are shown in Table I.[6] The molecular structure of **4a** has been confirmed by a single crystal X-ray diffraction study; an ORTEP diagram and selected bond distances and angles are provided in Figure 1.[7]

The nature of this novel rearrangement is clearly defined using a series of isotopically labeled complexes obtained from the appropriate vinylcyclopropenes **1b–d**.[6] ^1H and ^{13}C NMR spectra of the doubly ^{13}C-labeled iridacycles **2b** and **3d** clearly show that the labeled carbons are adjacent and occupy positions 5 (CH_2) and 4 (CH) in the ring. However, the transformation of **3b** to **4b** results in an *unlabeled* CH_2 carbon! The ^{13}C NMR spectrum shows that the two ^{13}C labels are still adjacent; one labeled carbon has a single H atom directly bound, and the other bears no hydrogens. The absence of a triplet $^2J_{CH}$ or $^3J_{CH}$ demonstrates that neither is α or β to the CH_2. Given the known substitution pattern in **4**, these observations are consistent only with the presence of ^{13}C labels at positions 1 (CPh) and 2 (CH) in the metallacyclic ring. Rearrangement of the monodeuteriomethylene complex **3c** to **4c** occurs with preservation of the CHD group, implying that the rearrangement is intramolecular, and conversion of **3d** to **4d** confirms that the deuterium at position 3 is not involved in any migrations.[6]

These experiments clearly show that this rearrangement is not a skeletal transformation of the metallacycle but must involve an interchange of substituents between the two carbon atoms directly bonded to iridium, probably driven by relief of steric repulsion between adjacent phenyl groups. An attractive mechanism involves a sequence of α-elimination/addition reactions with iridabenzene intermediates to accomplish the observed transformation. Reversible migrations of H from α-carbon positions to metals are well known,[8] as are iridabenzene species,[5] but the unprecedented step required by this mechanism is the transfer of a phenyl substituent from one α-carbon to the other. While we have no direct evidence that this process occurs via an iridium–phenyl inter-

(7) **4a**: $C_{38}H_{39}IrO_2P_2$, fw = 661.7, orthorhombic, *Pbca*, a = 19.939(4), b = 9.475(2), and c = 30.100(7) Å, V = 5687(2) Å^3, Z = 8, T = 292 K, $R(F)$ = 5.48%. Of 6201 independent data collected (Siemens P4, Mo Kα, $2\theta_{max}$ = 54°), 3180 were observed ($4\sigma F_o$).[6]

(8) For examples involving iridium, see ref 5 and: Burk, M. J.; McGrath, M. P.; Crabtree, R. H. *J. Am. Chem. Soc.* **1988**, *110*, 620. Fryzuk, M. D.; MacNeil, P. A.; Rettig, S. J. *J. Am. Chem. Soc.* **1985**, *107*, 6708–6710. Crocker, C.; Empsall, H. D.; Errington, R. J.; Hyde, E. M.; McDonald, W. S.; Markham, R.; Norton, M. C.; Shaw, B. L.; Weeks, B. *J. Chem. Soc., Dalton Trans.* **1982**, 1217–1224. Bleeke, J. R.; Peng, W.-J.; Xie, Y.-F.; Chiang, M. Y. *Organometallics* **1990**, *9*, 1113–1119.

mediate, we note the well-precedented migrations of phenyl and other carbon substituents from coordinated tertiary phosphorus centers to transition metals.[9,10] A recent example of a phenyl migration from silicon to platinum has also been reported.[11] These results demonstrate for the first time that analogous migrations from ligated carbon atoms may also be feasible.

Acknowledgment. We are grateful to the National Science Foundation for generous support of our research. A generous loan of iridium chloride from Johnson Matthey Aesar/Alfa is gratefully acknowledged. Helpful discussions with Dr. O. J. Curnow are gratefully acknowledged.

Supplementary Material Available: Full experimental methodology and spectroscopic characterization of all compounds reported herein; crystallographic summary for **4a**; tables of fractional coordinates, bond lengths, bond angles, anisotropic displacement coefficients, H atom coordinates, and isotropic displacement coefficients (16 pages); tables of observed and calculated structure factors (23 pages). Ordering information is given on any current masthead page.

(9) Garrou, P. E. *Chem. Rev.* **1985**, *85*, 171-185. Dubois, R. A.; Garrou, P. E.; Lavin, K. D.; Allcock, H. R. *Organometallics* **1984**, *3*, 649-650; *Ibid.* **1986**, *5*, 460-466. Dubois, R. A.; Garrou, P. E. *Ibid.* **1986**, *5*, 466-473. Jung, C. W.; Fellmann, J. D.; Garrou, P. E. *Ibid.* **1983**, *2*, 1042-1044. A theoretical treatment appears in: Ortiz, J. V.; Havlas, Z.; Hoffmann, R. *Helv. Chim. Acta* **1984**, *67*, 1-17.

(10) α-Elimination of H or Ph from carbon to iridium requires that either dissociation of a PMe_3 ligand or of one arm of the acac occurs in order to provide the required coordination site on the metal.

(11) Chang, L. S.; Johnson, M. P.; Fink, M. J. *Organometallics* **1991**, *10*, 1219-1221.

Evidence for Induced Fit in Antibody·DNA Complexes

Shawn Y. Stevens,† Patrick C. Swanson,†
Edward W. Voss, Jr.,‡ and Gary D. Glick*,†

Department of Chemistry, University of Michigan
Ann Arbor, Michigan 48109-1055
Department of Microbiology
University of Illinois at Urbana-Champaign
Urbana, Illinois 61801

Received November 20, 1992

Anti-DNA autoantibodies (anti-DNA) are a hallmark of the autoimmune disorder systemic lupus erythematosus (SLE). Most subjects with active SLE spontaneously produce antibodies that bind both double-stranded and single-stranded DNA (dsDNA and ssDNA, respectively).[1,2] Deposition of these anti-DNA·DNA complexes in the kidneys is thought to mediate the tissue injury associated with SLE. However, the elements of DNA that are targeted by anti-DNA have not been identified.[3] One problem in trying to correlate anti-DNA specificity with DNA structure is that binding may be accompanied by conformational changes in polynucleotide ligands, facilitating a better fit to the antibody combining site ("induced fit").[4] For example, studies of antibody-protein,[5] antibody-peptide,[6] protein-DNA,[7] and protein-small molecule complexes[8] show that structural reorganization of ligands can help stabilize biomolecular complexes.[9] We have examined the importance of induced fit in anti-DNA·DNA binding and report that monoclonal anti-ssDNA BV04-01,[10] which is typical of anti-DNA in lupus-prone mice, forces structural changes in DNA ligands upon binding.

X-ray analysis of an F(ab) fragment from BV04-01 bound to $d(pT)_3$ and $d(pT)_6$ has provided insight into the molecular basis of anti-DNA·DNA recognition.[11] In these complexes the DNA conformation is very different from the extended stacked geometry of oligo(dT),[12] which suggests that the antibody might drive this conformational change.[13] To explore this hypothesis we studied BV04-01 recognition of four DNA hairpin sequences[14] (**1-4**) along with disulfide cross-linked analogs of these molecules (**5-8**).[15] If conformational reorganization of the hairpins is required for binding, then BV04-01 should possess a *lower* affinity for the modified sequences, since the disulfide bond renders them resistant to structural changes.[16] However, if preorganization is important for complexation, then the more rigid oligomers should bind with equal or greater affinity than the unmodified ligands.[17]

In preliminary experiments an enzyme-linked immunosorbant assay demonstrated that the hairpin loops were recognized by the antibody.[18] The affinity of BV04-01 for **1-4** was then measured by gel shift assay (Figure 1, top).[19] Hairpin **1** binds more tightly than the other three ligands, which is consistent with solid-phase binding data that indicate a preference for thymidine (Figure 2). When binding to cross-linked hairpins **5-8** was studied, a substantial increase in K_d relative to the unmodified hairpins was observed (Figure 1, bottom). Moreover, the relative affinity of the antibody for the unmodified ligands is different from the specificity displayed toward the cross-linked molecules. This suggests that the mode of binding to the wild-type and cross-linked hairpins may be different.

If the weaker affinity of BV04-01 for **5-8** results from the constraint imposed by the cross-link, then removing this constraint by reduction of the disulfide bond should afford a set of ligands that bind with roughly the same affinity as the unmodified hairpins. Indeed, BV04-01 recognition of **9-12** is nearly indis-

† University of Michigan.
‡ University of Illinois.

(1) *Anti-DNA Antibodies in SLE*; Voss, E. W., Jr., Ed.; CRC Press: Boca Raton, FL, 1988.

(2) Koffler, D.; Miller, T. E.; Faiferman, I. *Human Pathol.* **1983**, *14*, 406-418. Tan, E. M. *Adv. Immunol.* **1989**, *44*, 93-115.

(3) Koffler, D.; Schur, P. H.; Kunkel, H. G. *J. Exp. Med.* **1967**, *126*, 607-617. Schwartz, R. S.; Stollar, B. D. *J. Clin. Invest.* **1985**, *75*, 321-327.

(4) Pollard, K. M.; Jones, J. E.; Tan, E. M.; Theofilopoulos, A. N.; Dixon, F. E.; Rubin, R. L. *Clin. Immunol. Immunopathol.* **1986**, *40*, 197-208.

(5) Getzoff, E. D.; Tainer, J. A.; Lerner, R. A.; Geyson, H. M. *Adv. Immunol.* **1988**, *43*, 1-98.

(6) Stanfield, R. L.; Fieser, T. M.; Lerner, R. A.; Wilson, I. A. *Science* **1990**, *248*, 712-719. Rini, J. M.; Schulze-Gahmen, U.; Wilson, I. A. *Science* **1992**, *255*, 959-965.

(7) Frederick, C. A.; Grable, J.; Melia, M.; Samudzi, C.; Jen-Jacobson, L.; Wang, B.-C.; Greene, P.; Boyer, H. W.; Rosenberg, J. M. *Nature* **1984**, *309*, 327-331. Schultz, S. C.; Shields, G. C.; Steitz, T. A. *Science* **1991**, *253*, 1001-1007.

(8) For a recent example, see: Van Duyne, G. D.; Standaert, R. F.; Karplus, P. A.; Schreiber, S. L.; Clardy, J. *Science* **1991**, *252*, 839-832.

(9) Koshland, D. E., Jr.; Neet, K. E. *Annu. Rev. Biochem.* **1968**, *37*, 359-410. Herschlag, D. *Bioorg. Chem.* **1988**, *16*, 62-96. Wüthrich, K.; von Freyberg, B.; Weber, C.; Wider, G.; Traber, R.; Widmer, H.; Braun, W. *Science* **1991**, *254*, 953-954. Jorgensen, W. L. *Science* **1991**, *254*, 954-955. Davies, D. R.; Padlan, E. A. *Curr. Biol.* **1992**, *2*, 254-256.

(10) Ballard, D. W.; Lynn, S. P.; Gardner, J. E.; Voss, E. W., Jr. *J. Biol. Chem.* **1984**, *259*, 3492-3498. Ballard, D. W.; Voss, E. W., Jr. *J. Immunol.* **1985**, *135*, 3372-3386.

(11) Herron, J. N.; He, X. M.; Ballard, D. W.; Blier, P. R.; Pace, P. R.; Bothwell, A. L. M.; Voss, E. W., Jr.; Edmundson, A. B. *Proteins* **1991**, *11*, 159-175.

(12) Camerman, N.; Fawcett, J. K.; Camerman, A. *J. Mol. Biol.* **1976**, *107*, 601-621.

(13) Structural changes in BV04-01 were also observed upon binding.[11]

(14) The single-stranded and double-stranded regions on DNA hairpins can model the ssDNA and dsDNA molecules that are recognized by anti-DNA. Swanson, P. C.; Glick, G. D., manuscript in preparation.

(15) Glick, G. D. *J. Org. Chem.* **1991**, *56*, 6746-6747. Glick, G. D.; Osborne, S. E.; Knitt, D. S.; Marino, J. P., Jr. *J. Am. Chem. Soc.* **1992**, *114*, 5447-5448.

(16) **5-8** begin to denature at 84 °C, which is >30 °C above the T_m of **1-4** in 1 mM NaCl buffer.

(17) Cram, D. J. *Angew. Chem.* **1986**, *98*, 1041-1060.

(18) The hairpins were covalently linked to BSA and then coated onto microtiter plates. The plates were treated with S1 nuclease to degrade the loops, which decreased BV04-01 binding by >90%. The resulting duplex is still recognized by anti-dsDNA.

(19) Carey, J. *Methods Enzymol.* **1991**, *208*, 103-118, and references therein.

(20) Chrambach, A. In *The Practice of Quantitative Gel Electrophoresis*; Neuhoff, V., Maelicke, A., Eds.; VCH Press: New York, 1988; pp 63-78.

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