

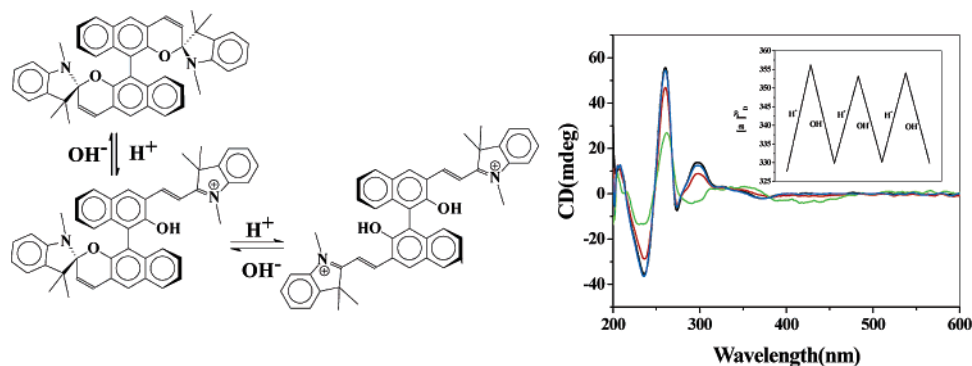
# Tuning the CD Spectrum and Optical Rotation Value of a New Binaphthalene Molecule with Two Spiropyran Units: Mimicking the Function of a Molecular “AND” Logic Gate and a New Chiral Molecular Switch

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With the view to developing new chiral molecular switches and logic gates, a new binaphthalene molecule with two spiropyran units (**1**) was synthesized and characterized. Absorption and <sup>1</sup>H NMR spectral studies of **1** after reaction with acid/base indicate acidichromism can occur to compound **1**. The synergistic actions of acid and UV light irradiation result in a remarkable change for the CD spectrum of the relatively dilute solution of **1**, mimicking the behavior of a chiral “AND” gate, since the “output” is the CD signal. Furthermore, the optical rotation value of the relatively concentrated solution of **1** can be reversibly tuned after sequential reactions with acid and base, and thus a chiral molecular switch with nondestructive “output” signal is realized. The present results not only add a new example of chiral molecular switch with nondestructive readout but also provide a chiral “AND” gate based on the axial chiral binaphthalene to which switchable units are linked.

## Introduction

Reversibly tuning the conformations and the electronic states of organic molecules by external stimulations (input signals) is fundamentally interesting in terms of mechanism and potential applications. When the changes with regard to the conformations and the electronic states are associated with detectable signals (output signals), molecular switches<sup>1</sup> and even logic gates<sup>2–15</sup> can be

established on the basis of these organic molecules. Molecular switches and logic gates are key components of the future molecular level devices, and accordingly they have received significant attention in recent years. Usually, molecular switches are associated with one “input signal”, while molecular logic gates entail two or more “input signals”. When the “output signals” of molecular switches are related to the properties of molecular

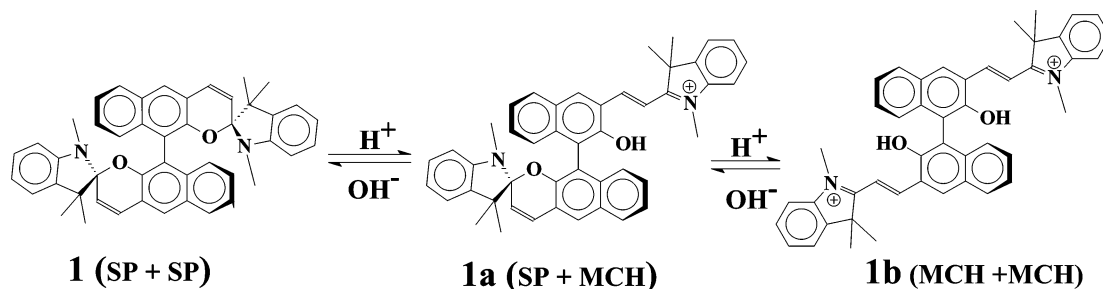
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## SCHEME 1. Illustration of Structure and Transformation of Compound 1 upon Addition of Acid and Base



chirality, they are regarded as chiral molecular switches.<sup>16</sup> Two types of chiral molecular switches have been de-

scribed: one related to the modulation of intrinsic chirality of the system represented by sterically overcrowded chiral alkenes reported first by Feringa et al.,<sup>16a,17</sup> and the other based on the magnitude change of chirality, as reported just recently.<sup>16d,e,18</sup> Herein we report a new chiral molecular switch of the latter type based on the binaphthalene skeleton (*R*-) with two spiroropyran (SP) units (1, Scheme 1). The "output signal" of our chiral molecular switch is the optical rotation value of the solution, and thus it can be addressed in a nondestructive way.<sup>16a,19</sup> Moreover, the circular dichroism (CD) spectrum of 1 can be tuned by the combined actions of acid and UV light irradiation, which mimics the function of an "AND" logic gate.

The design rationale is explained as follows: (1) Axially chiral binaphthalenes show strong CD signals and large optical rotation values, which are dependent on the dihedral angle of the two naphthalene moieties,<sup>20</sup> with the latter strongly influenced by the nature of the substituents on the naphthalene rings. Therefore, chiral binaphthalenes are good candidates for the construction of chiral molecular switches and even molecular logic gates. (2) Spiropyran (SP) can be transformed to the corresponding merocyanine (MC) and protonated MC species (MCH) upon external stimulations.<sup>21–27</sup> As SP, MC, and MCH show different electronic structures and can impose different steric hindrances, it is possible to modulate the CD spectrum and optical rotation value

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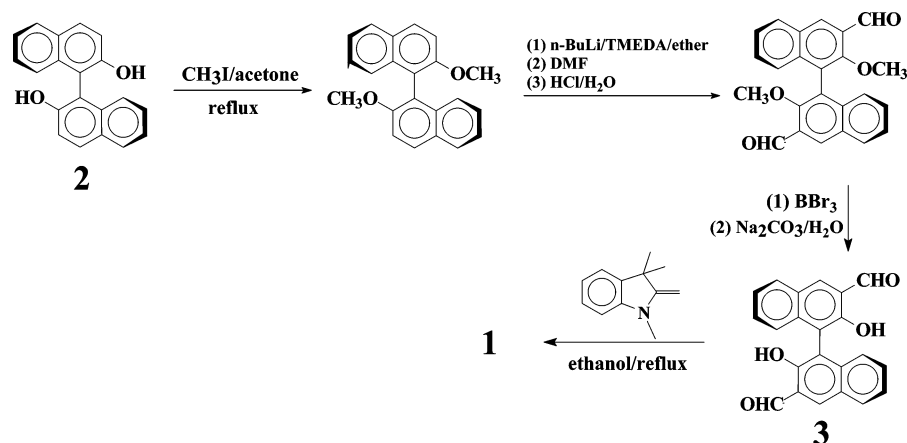
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## SCHEME 2. Synthetic Scheme for Compound 1



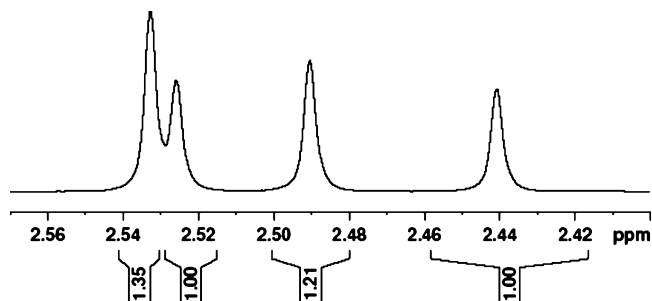
of binaphthalene by external signals when two spiro-pyran units are separately linked to the two naphthalene rings of binaphthalene. It should be mentioned that a few examples of chiral molecular switches based on binaphthalene and photochromic<sup>16e,18</sup> or redox active units<sup>16d</sup> have been described. In this paper, we describe the synthesis and characterization of compound **1** (Scheme 1). Upon reaction with acid or the combined actions of acid and UV light irradiation, the **SP** units in **1** are transformed to the corresponding **MCH** units, leading to the variations of CD spectrum and optical rotation value. The CD spectrum and optical rotation value of the solution can be restored after further reaction with equivalent amounts of base.

## Results and Discussion

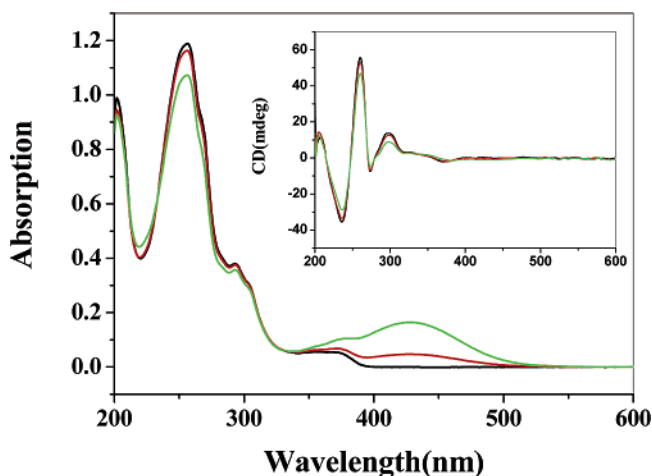
**Synthesis.** Compound **1** was synthesized starting from the commercially available (*R*)-2,2'-dihydroxy-1,1'-binaphthalene (**2**, Scheme 2), from which (*R*)-2,2'-dihydroxy-1,1'-binaphthyl-3,3'-dicarbaldehyde (**3**) was obtained by following the reported procedures.<sup>28</sup> Reaction of compound **3** with 1,3,3-trimethyl-2-methyleneindoline afforded compound **1** in a total yield of 43% after separation. Because of the two spiro-chiral carbon atoms in **1**,<sup>29</sup> there exist four possible steric isomers for **1**, as demonstrated by the four singlet signals of the protons of N-CH<sub>3</sub> in the region of 2.41–2.54 ppm of the <sup>1</sup>H NMR spectrum (Figure 1). By integrating the intensity of each singlet signal, the ratio of the four steric isomers was determined to be about 1:1:1:1, implicating that the axial chiral binaphthalene unit has no direct chiral effect on the formation of the two spiro-carbon atoms in **1**.

**UV–Vis and CD Spectral Studies.** UV light irradiation of the solution of **1** ( $1.0 \times 10^{-5}$  M in ethanol) does not lead to any changes of its absorption spectrum.<sup>30</sup> This

is very likely due to the absence of the electron-withdrawing groups in the binaphthalene unit.<sup>31</sup> However, upon the addition of acid (CF<sub>3</sub>COOH) the colorless solution of **1** turns yellow and a new absorption band appears around 427 nm (Figure 2). According to previous studies, this new absorption band can be ascribed to the protonated merocyanine (**MCH**) form of spiro-pyran units of **1**,<sup>26,27,32</sup> indicating that **SP** units of **1** can be transformed into the corresponding **MCH** units upon reaction with acid. Namely, compound **1** can undergo acid-ichromism<sup>33</sup> and can be transformed to **1a**, which can be



**FIGURE 1.** Partial <sup>1</sup>H NMR spectrum of **1** ( $1.0 \times 10^{-2}$  M in CDCl<sub>3</sub>) in the region of 2.41–2.54 ppm (the part for the protons of N-CH<sub>3</sub>).



**FIGURE 2.** UV-vis and CD (inset) spectra of **1** ( $1.0 \times 10^{-5}$  M in ethanol) before (black) and after addition of 10 equiv (red), and 40 equiv (green) of CF<sub>3</sub>COOH.

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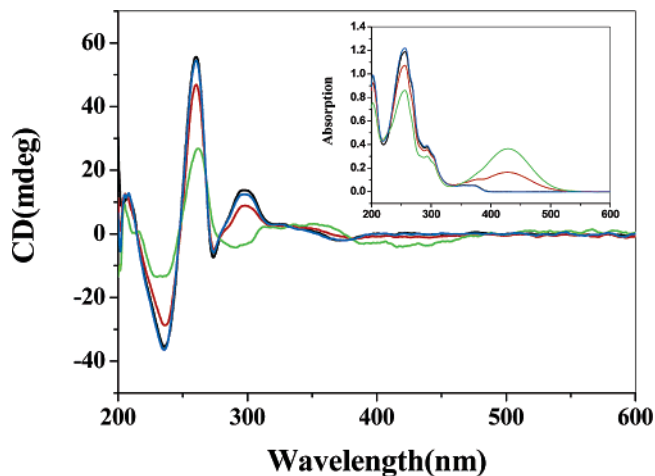
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further converted to **1b** upon exposure to acid. As shown in Figure 2, the absorption intensity around 427 nm increases gradually by increasing the amounts of CF<sub>3</sub>COOH added to the solution, indicating that the amounts of **1** converted to **1a/1b** are dependent on the amounts of acid added to the solution.<sup>34</sup> This is not unexpected since the transformation of **SP** units into **MCH** units should follow a bimolecular mechanism and the reaction process should be dependent on the concentration of acid in the solution. In addition, it is also reasonably assumed that compound **1** is first converted to **1a**, which reacts further with acid to generate **1b** as shown in Scheme 1.

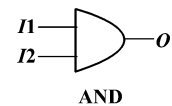
As the **MCH** and **SP** species represent different electronic and steric structures, it can be expected that the dihedral angle of two naphthalene rings of **1** with two **SP** units should be different from that of **1a** with one **SP** and one **MCH** units and that of **1b** with two **MCH** units. Besides, the conjugation in **1a** and **1b** becomes more extended compared with that in **1**. Therefore, the CD spectrum of **1** should be different from that of **1a** and **1b**,<sup>20</sup> namely, the CD spectrum of **1** may be tuned upon reaction with acid. However, the difference between **1** and **1a** in terms of CD spectrum may be small since only one **SP** unit is transformed into **MCH** unit from **1** to **1a**. These expectations are in agreement with the experimental observation as illustrated by the inset of Figure 2, where the CD spectra of **1** in the presence of different amounts of CF<sub>3</sub>COOH are displayed. The CD spectrum (black curve in the inset of Figure 2) of the pure solution of **1** ( $1.0 \times 10^{-5}$  M in ethanol) shows a strong bisignated band at about 235 and 260 nm.<sup>35</sup> Upon reaction with CF<sub>3</sub>COOH, the intensities of the CD signals at about 235 and 260 nm decrease gradually accompanied by slight absorption maximum change and the emergence of a new bisignated band at about 362 and 438 nm. As shown in the inset of Figure 2, the intensities of the new absorptions at 362 and 438 nm (albeit weak) increase by increasing the amounts of CF<sub>3</sub>COOH. Nevertheless, variation of the CD spectrum of **1** ( $1.0 \times 10^{-5}$  M in ethanol) upon reaction with acid is rather small. For instance, the CD signal intensity at 260 nm is only reduced by 14% even after addition of 40 equiv of CF<sub>3</sub>COOH.

Interestingly, further UV light irradiation of the solution of **1** ( $1.0 \times 10^{-5}$  M in ethanol) that had been treated with CF<sub>3</sub>COOH resulted in large CD spectrum change as illustrated in Figure 3. Significant change was also observed for the absorption spectrum of **1** under identical conditions (see the inset of Figure 3). The UV light irradiation alone could not induce any CD spectrum



**FIGURE 3.** CD and UV-vis (inset) spectra of **1** ( $1.0 \times 10^{-5}$  M in ethanol) before (black) and after addition of 40 equiv of CF<sub>3</sub>COOH (red), after addition of 40 equiv of CF<sub>3</sub>COOH followed by UV light irradiation for 5 min (green), and after combined actions of CF<sub>3</sub>COOH and UV light, followed by addition of 40 equiv of NaOH (blue); the black and blue curves are almost overlapped.

Input		Output
<i>I</i> 1	<i>I</i> 2	<i>O</i> 1
0	0	0
0	1	0
1	0	0
1	1	1



**FIGURE 4.** Truth table (left) and logic circuit (right) corresponding to the truth table. *I*1, *I*2, and *O*1 are UV light (365 nm, 120 W, 5 min), acid (40 equiv of CF<sub>3</sub>COOH), and CD value at 235 or 260 nm, respectively. The output signal (*O*1) is off when the CD value at 235 nm is smaller than -20 mdeg and it is on when the CD value is larger than -20 mdeg, or *O*1 is off when the CD value at 260 nm is larger than 30 mdeg and it is on when the CD value is smaller than 30 mdeg.

change of **1**, and addition of CF<sub>3</sub>COOH to the solution of **1** only led to small change of its CD spectrum. The results in Figure 3 indicate that large CD spectrum change can occur to the solution of **1** only after the synergistic actions of CF<sub>3</sub>COOH and UV light irradiation. These spectral changes can be understood as follows. Because of the lack of electron-withdrawing groups on the two naphthalene rings of **1**, the open form of **SP** units cannot be stabilized. As a result, variation of the absorption spectrum was not observed for **1** upon UV light irradiation. Upon reaction with acid, the **SP** units can be converted to the corresponding **MCH** units, leading to the transformation of **1** into **1a**, which was confirmed by <sup>1</sup>H NMR spectral studies as discussed below. In **1a**, the nitrogen atom of the indoline ring (**MCH** unit) possesses positive charge, i.e., implying that the **MCH** unit of **1a** can function as an electron-withdrawing group to stabilize the open form of **SP** unit. Accordingly, UV light irradiation would facilitate the transformation of **1a** into **1b** in the presence of acid. Such behavior of **1** mimics the function of an “AND” logic gate (Figure 4) when CF<sub>3</sub>COOH (*I*1), UV light (365 nm) (*I*2), and the CD signal intensity at 235 or 260 nm (*O*1) are regarded as the two input signals and output signal, respectively. As the “output signal” is CD signal

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(34) The reaction of compound **1** with CF<sub>3</sub>COOH was carried out in the dark.

(35) The CD signals should be due to the axial chirality of binaphthalene unit rather than the spiro-carbon chirality since four steric isomers of **1** are equally present in the solution based on the <sup>1</sup>H NMR data.

intensity, this “AND” gate may be regarded as a chiral “AND” gate. To the best of our knowledge, such a chiral “AND” gate was not described previously.

Both the absorption spectrum and CD spectrum of **1** can be restored if equal amounts of base (NaOH) were added to the solution of **1** that had been treated with CF<sub>3</sub>COOH alone or treated by both CF<sub>3</sub>COOH and UV light irradiation (see Figure 3). This is due to the fact that the transformation of spiropyran units from **MCH** species to the corresponding **SP** ones of **1**, namely, the interconversion between **1** and **1a** (**1a** and **1b**) (Scheme 1), can reversibly proceed upon reaction with acid (and UV light irradiation) and base. Therefore, the “AND” gate based on compound **1** can be easily reset by reaction with equal amounts of base and thus can be reversibly performed.

The interconversion between **SP** and **MCH** units is accompanied by the disappearance and reformation of spiro-chiral carbon centers in **1**. However, they cannot account for the variation of CD spectra of **1** discussed above, because (1) the four steric isomers are equally present in the solution according to the <sup>1</sup>H NMR spectrum as shown in Figure 1, and (2) the axial chiral binaphthalene unit has no direct chiral effect on the formation of the spiro-carbon atoms in **1** synthesized from (*R*)-2,2'-dihydroxy-1,1'-binaphthyl-3,3'-dicarbaldehyde and 1,3,3-trimethyl-2-methyleneindoline. Thus, it cannot be expected that the axial chiral binaphthalene unit has chiral induction effect on the formation of the spiro-carbon atoms during the transformation between **SP** and **MCH** units.

#### <sup>1</sup>H NMR Spectral and Optical Rotation Studies.

The transformation of **1** to **1a** (**1a** to **1b**) was also confirmed by <sup>1</sup>H NMR spectra of **1** (in CDCl<sub>3</sub>, 1.0 × 10<sup>-4</sup> M and 1.0 × 10<sup>-2</sup> M) in the presence of acid (CF<sub>3</sub>COOH) (Figure 5). Upon addition of CF<sub>3</sub>COOH, a new singlet signal around 4.3 ppm appeared, which can be ascribed to the protons of N<sup>+</sup>-CH<sub>3</sub> of **1a/1b** (Scheme 1), by reference to the <sup>1</sup>H NMR spectra of **MCH** species of similar spiropyran molecules.<sup>32</sup> As shown in Figure 5, the integration intensity for the signal around 4.3 ppm increased, while that in the region of 2.4–2.6 ppm (N-CH<sub>3</sub>) decreased by increasing the amounts of CF<sub>3</sub>COOH added to the CDCl<sub>3</sub> solution of **1** (Figure 5b–d). These results implied that the amounts of **1** transformed to **1a/1b** increased by adding more CF<sub>3</sub>COOH to the solution of **1**. When 1.0 or 2.0 equiv of CF<sub>3</sub>COOH was added (Figure 5b–c), four singlet signals were observed in the region of 2.4–2.6 ppm (N-CH<sub>3</sub>), indicating the presence of **1** in the solution besides **1a/1b** since there should exist only two signals for **1a** and no signal for **1b** in this region. If we assumed that the amounts of **1b** can be neglected in the solution of **1** containing 1.0 equiv of CF<sub>3</sub>COOH, the molar ratio of **1** and **1a** was estimated to be about 85/15 based on the integration intensity ratio between the signal around 4.3 ppm and that in the region of 2.4–2.6 ppm. When 10.0 equiv of CF<sub>3</sub>COOH was used, the signals around 2.4–2.6 ppm due to the protons of N-CH<sub>3</sub> almost disappeared (Figure 5d), indicating that the **SP** units of **1** were nearly transformed to **MCH** units under this condition.<sup>36</sup>

The <sup>1</sup>H NMR spectra of **1** in the presence of different amounts of CF<sub>3</sub>COOH were also measured in the relatively concentrated solution of **1** (in CDCl<sub>3</sub>, 1.0 × 10<sup>-2</sup> M, Figure 5e,f). Interestingly, it was found that the

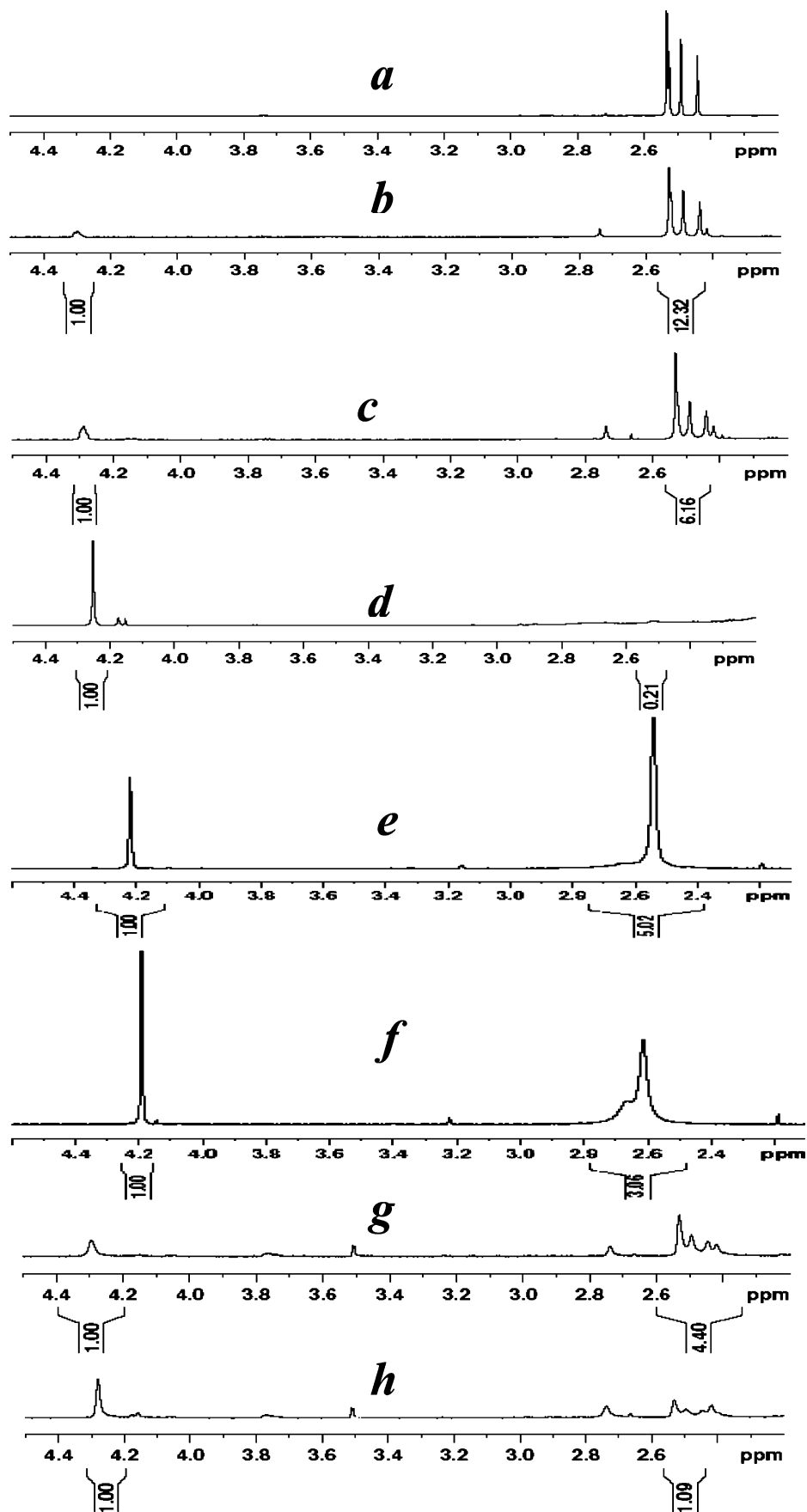
amounts of the **SP** units of **1** that were transformed to **MCH** units was larger for the more concentrated solution of **1** when the same amounts of CF<sub>3</sub>COOH were used. For instance, the integration intensity ratio between the signal around 4.3 ppm and that in the region of 2.4–2.6 ppm increased from 1:12.3 to 1:5.0 after addition of 1.0 equiv of CF<sub>3</sub>COOH when the concentration of the solution of **1** was changed from 1 × 10<sup>-4</sup> M to 1 × 10<sup>-2</sup> M (see Figure 5, b and e).<sup>37</sup> This result is not unexpected since the transformation of **SP** units to **MCH** units follows a bimolecular reaction mechanism, and thus the reaction process must be affected by the concentrations of both compound **1** and CF<sub>3</sub>COOH.

<sup>1</sup>H NMR spectra of **1** were also measured after combined actions of CF<sub>3</sub>COOH and UV light (Figure 5g,h). Compared with the cases where only CF<sub>3</sub>COOH was added, the integration intensity ratio between the signal around 4.3 ppm and that in the region of 2.4–2.6 ppm increased after further UV light irradiation: from 1:12.3 to 1:4.4 for the addition of 1.0 equiv of CF<sub>3</sub>COOH and from 1:6.2 to 1:1.1 for the addition of 2.0 equiv of CF<sub>3</sub>COOH. These results show that the combined actions of CF<sub>3</sub>COOH and UV light facilitate the conversion of **SP** units to **MCH** units, which is consistent with the CD and absorption spectral studies as discussed above.

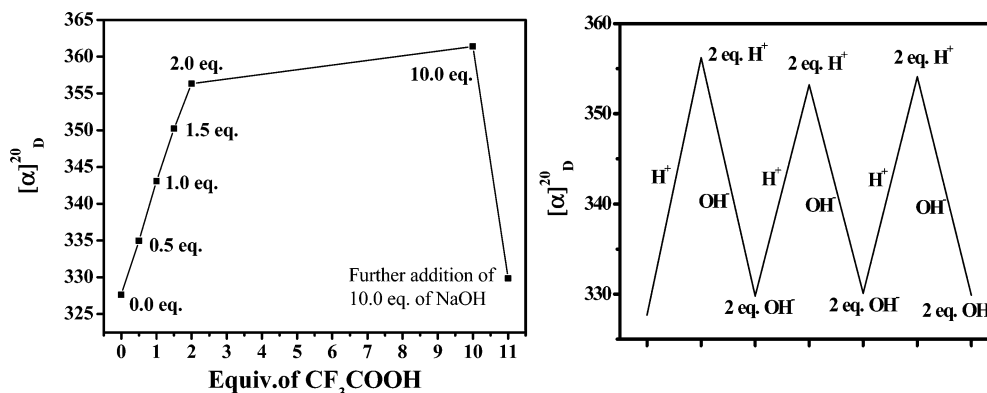
The concentrated solution of **1** showed such a strong absorption around 260 nm that it was difficult to measure a reliable CD spectrum for **1** under this condition, but the optical rotation value of the concentrated solution of **1** in the presence of CF<sub>3</sub>COOH could be measured. As illustrated in Figure 6 (left), the optical rotation value of the solution of **1** (*c* = 0.66, 1.0 × 10<sup>-2</sup> M in ethanol, 20 °C) increased by increasing the amounts of CF<sub>3</sub>COOH added to the solution and reached maximum when about 10 equiv of CF<sub>3</sub>COOH was added. As for the CD spectrum, the optical rotation value can return to the initial magnitude (for the pure solution of **1**) after equal amounts of NaOH were added to the CF<sub>3</sub>COOH-treated solution of **1**. More interestingly, the optical rotation value of solution of **1** can be reversibly tuned after sequential reaction with acid and base as shown in Figure 6 (right). Therefore, a new chiral molecular switch with the optical rotation value as the “output signal” is realized. On the basis of the fact that the light wavelength used in the optical rotation measurement is longer than the absorption region of **1**, our chiral molecular switch is attractive because of its nondestructive read-out.<sup>16a,19</sup>

(36) When 10.0 equiv of CF<sub>3</sub>COOH was added to the solution of **1** (ethanol, 1.0 × 10<sup>-5</sup> M), only minor change was observed in the CD spectrum of the solution. However, there is no disagreement between the CD and <sup>1</sup>H NMR (CDCl<sub>3</sub>, 1.0 × 10<sup>-4</sup> M) spectral studies of **1** in the presence of CF<sub>3</sub>COOH because the transformation of **SP** units to **MCH** units follows a bimolecular reaction mechanism, and thus the reaction process must be affected by the concentrations of both compound **1** and CF<sub>3</sub>COOH. The transformation process may also be affected by solvent effects.

(37) The signals for the protons of N-CH<sub>3</sub> in the region of 2.4–2.6 ppm became singlet (four singlet signals before addition of acid) after reaction with CF<sub>3</sub>COOH for the (relatively concentrated) CDCl<sub>3</sub> solution of **1** (1.0 × 10<sup>-2</sup> M). This is likely due to the aggregation of **1** (**1a** and **1b**) or, alternatively, intermolecular proton transfer from the **MCH** unit of **1** to the **SP** unit of surrounding molecules of **1**, leading to formation of a new **MCH** unit and a **MC** unit, which may be in the quinonoid form in CDCl<sub>3</sub>. As expected, the protons of N-CH<sub>3</sub> of the quinonoid form show a singlet signal in <sup>1</sup>H NMR spectrum. This may also contribute to the collapse of the signals in the 2.4–2.6 ppm region into a single signal.



**FIGURE 5.**  $^1\text{H}$  NMR spectra of  $\text{N-CH}_3$  and  $\text{N}^+\text{-CH}_3$  region of **1**, **1a**, and **1b** ( $\text{CDCl}_3$ , *a-d,g,h*  $1.0 \times 10^{-4}$  M and *e, f*  $1.0 \times 10^{-2}$  M) before (*a*) and after addition of 1.0 equiv (*b,e*), 2.0 equiv (*c,f*), and 10 equiv (*d*) of  $\text{CF}_3\text{COOH}$ ; after addition of 1.0 equiv (*g*) and 2.0 equiv (*h*) of  $\text{CF}_3\text{COOH}$  followed by UV light irradiation for 5 min.



**FIGURE 6.** (left) The optical rotation values  $[\alpha]^{20}_D$  ( $c$  0.66 ( $1.0 \times 10^{-2}$  M), ethanol) of **1** before and after addition of 0.5, 1.0, 1.5, 2.0, and 10.0 equiv of  $\text{CF}_3\text{COOH}$ , and after addition of 10.0 equiv of  $\text{CF}_3\text{COOH}$  followed by injection of 10.0 equiv of NaOH. (right) Illustration of the switchable behavior with optical rotation values as “output signal” after sequential addition of 2 equiv of  $\text{CF}_3\text{COOH}$  and NaOH.

## Conclusion

A new binaphthalene with two spiropyran units (**1**) was synthesized and characterized. Absorption and  $^1\text{H}$  NMR spectral studies of the solution of **1** indicate the reversible transformation between the **SP** units and the corresponding **MCH** units in **1** after sequential reaction with acid/base. The reversible transformation of the **SP** units to the corresponding **MCH** units in **1** leads to the reversible modulation of the CD spectra, but the variation of the CD spectrum is rather small. However, the synergistic actions of acid and UV light irradiation result in a large CD spectrum change for the relatively dilute solution of **1**, which mimics the behavior of an “AND” gate that may be regarded as a chiral “AND” gate since the “output” signal is the CD signal intensity. Furthermore, the optical rotation value of the relatively concentrated solution of **1** can be reversibly tuned after sequential reaction with acid and base, and thus a chiral molecular switch with nondestructive “output” signal is realized. The present results not only add a new example of chiral molecular switch but also provide a chiral “AND” gate based on the axial chiral binaphthalene to which switchable units are linked. Further investigations will be directed toward fully light-driven chiral switches that are analogues of compound **1** with electron-withdrawing functional groups on the binaphthalene rings.

## Experimental Section

**General Experimental Methods.** All chemicals are commercially available. Ethanol was distilled over Mg and tetrahydrofuran (THF) over Na with benzophenone as indicator.

**Synthesis of Compound 1.** Compound **1** was prepared from (*R*)-2,2'-dihydroxy-1,1'-binaphthyl-3,3'-dicarbaldehyde, which was synthesized according to the literatures in a total yield of 69%,<sup>28</sup> and 1,3,3-trimethyl-2-methyleneindoline.

(*R*)-2,2'-Dihydroxy-1,1'-binaphthyl-3,3'-dicarbaldehyde (**3**) (0.50 g, 1.5 mmol) and 0.5 mL (0.51 g, 3.0 mmol) of 1,3,3-trimethyl-2-methyleneindoline were dissolved in 120 mL of anhydrous ethanol under nitrogen atmosphere. The mixture was stirred magnetically and heated to reflux. After 3 h, solvents were removed under reduced pressure to give a red oil. The residue was subjected to column chromatography (silica gel) with dichloromethane/petroleum ether (60–90 °C) (1:2, v/v) as eluent to give **1** (0.61 g, 62%) as a white solid.

As mentioned above, the obtained sample of **1** contained four equally present steric isomers. For this reason, its melting

point shows a relatively long melting range (155–160 °C), and  $^1\text{H}$  NMR and  $^{13}\text{C}$  NMR display more signals.  $[\alpha]^{20}_D$  327.6 ( $c$  0.66, ethanol).  $^1\text{H}$  NMR ( $\text{CDCl}_3$ , 600 MHz):  $\delta$  7.72 (d,  $J$  = 8.4 Hz, 2H/4), 7.67 (d,  $J$  = 8.4 Hz, 2H/4), 7.63 (d,  $J$  = 7.8 Hz, 2H/4), 7.59 (d,  $J$  = 7.8 Hz, 2H/4), 7.55 (s, 2H/4), 7.51 (s, 2H/4), 7.48 (s, 2H/4), 7.45 (s, 2H/4), 7.07–7.22 (m, 20H/4), 6.94–7.04 (m, 16H/4), 6.81–6.87 (m, 4H/4), 6.78 (d,  $J$  = 6.6 Hz, 2H/4), 6.72 (d,  $J$  = 7.2 Hz, 2H/4), 6.66 (d,  $J$  = 6.6 Hz, 2H/4), 6.65 (s, 2H/4), 6.54–6.59 (m, 6H/4), 6.50 (t,  $J$  = 7.5 Hz, 2H/4), 6.33 (d,  $J$  = 7.8 Hz, 2H/4), 6.23 (d,  $J$  = 7.2 Hz, 2H/4), 6.05 (d,  $J$  = 7.8 Hz, 2H/4), 6.00 (d,  $J$  = 7.8 Hz, 2H/4), 5.78 (d,  $J$  = 10.2 Hz, 2H/4), 5.73 (d,  $J$  = 10.2 Hz, 2H/4), 5.69 (d,  $J$  = 9.6 Hz, 2H/4), 5.67 (d,  $J$  = 10.2 Hz, 2H/4), 2.52 (s, 6H/4), 2.51 (s, 6H/4), 2.47 (s, 6H/4), 2.43 (s, 6H/4), 1.08 (s, 6H/4), 1.07 (s, 6H/4), 1.06 (s, 6H/4), 0.97 (s, 6H/4), 0.88 (s, 6H/4), 0.83 (s, 6H/4), 0.66 (s, 6H/4), 0.62 (s, 6H/4).  $^{13}\text{C}$  NMR ( $\text{CDCl}_3$ , 150.9 MHz):  $\delta$  149.4, 149.3, 148.8, 147.4, 147.1, 136.6, 136.5, 136.3, 134.5, 134.4, 134.2, 129.2, 129.0, 128.7, 128.7, 128.6, 128.3, 128.2, 128.1, 127.6, 127.1, 127.0, 126.9, 125.9, 125.8, 125.6, 125.5, 125.4, 123.4, 123.2, 123.1, 122.0, 121.4, 121.3, 121.0, 120.3, 120.1, 119.8, 118.2, 118.0, 115.8, 106.2, 106.0, 105.9, 50.9, 49.8, 49.6, 49.4, 31.0, 29.1, 28.9, 28.6, 28.5, 25.3, 24.9, 24.6, 24.5, 22.0, 21.7, 21.4, 21.0. MS (MALDI-TOF):  $m/z$  652.5 ( $\text{M}^+$ ). FT-IR (KBr): 1608  $\text{cm}^{-1}$  (C=C). Anal. Calcd for  $\text{C}_{46}\text{H}_{40}\text{N}_2\text{O}_2$ : C, 84.63; H, 6.18; N, 4.29. Found: C, 84.69; H, 6.56; N, 4.16.

**Experimental Details for the Chiral Switch and “AND” Logic Gate.** (1) To a solution of **1** ( $1.0 \times 10^{-2}$  M in ethanol) was added 2.0 equiv of  $\text{CF}_3\text{COOH}$ , and then the optical rotation value of the solution was measured. After that, 2.0 equiv of NaOH was added to the above solution, and again the rotation value was measured. The experiments were repeated by following the sequences. The reactions with  $\text{CF}_3\text{COOH}$  and NaOH were carried out in the dark. (2) A solution of **1** ( $1.0 \times 10^{-5}$  M in ethanol) in quartz cell was first treated with 40 equiv of  $\text{CF}_3\text{COOH}$ , followed by UV light irradiation (120-W high pressure Hg lamp) for 5.0 min.; after that, the CD spectrum of the solution was recorded.

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