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Published in:
Journal of the American Chemical Society

DOI:
[10.1021/jacs.7b12871](https://doi.org/10.1021/jacs.7b12871)

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Document Version
Publisher's PDF, also known as Version of record

Publication date:
2018

[Link to publication in University of Groningen/UMCG research database](#)

Citation for published version (APA):

Simeth, N. A., Crespi, S., Fagnoni, M., & König, B. (2018). Tuning the Thermal Isomerization of Phenylazaindole Photoswitches from Days to Nanoseconds. *Journal of the American Chemical Society*, 140(8), 2940-2946. <https://doi.org/10.1021/jacs.7b12871>

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Tuning the Thermal Isomerization of Phenylazoindole Photoswitches from Days to Nanoseconds

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Supporting Information

ABSTRACT: The growing interest in light-driven molecular switches and optical oscillators led to the development of molecules that are able to interconvert from a stable to a metastable configuration upon photochemical triggering and to return to the thermodynamically stable form as soon as the light stimulus is removed. Controlling a wide range of back-isomerization lifetimes in the dark is a crucial goal for potential application of these compounds such as molecular machines. We herein present a novel class of easily synthesizable azo photoswitches based on the arylazoindole core. Most notably, minimal modifications of the core, such as methylation, dramatically change the Z-to-E thermal isomerization rate from days (Me in position 1) to the nanosecond range (Me in position 2). Moreover, fine-tuning of the Z-to-E lifetimes can be achieved choosing a proper dimethyl sulfoxide–water (or buffered water) solvent mixture. The photochemical and thermal mechanisms have been elucidated by a thorough computational and spectroscopic analysis. This allowed to detect three different pathways of thermal isomerization and to identify the hydrazone tautomer of the phenylazoindole as the major actor in the fast Z–E thermal isomerization of the NH-substituted switch in protic media.

INTRODUCTION

Photoswitches have evolved into handy tools to control molecular properties, such as magnetization, fluorescence, or biological activity, or can be exploited as the centerpiece of molecular machines.¹ Thereby, light is applied as an external stimulant. It is easy to handle, unmatched fast and precise in practical usage, and orthogonal to biological systems and most chemical transformations.^{1–3} Within the many classes of photoswitches investigated, azo dyes have emerged as a popular example in the last decades including manifold applications, e.g., in polymers,^{4,5} electronics,⁶ material science,⁷ protein probes, and *in vivo* photocontrol of biomolecules^{8–11} or as light-controllable catalysts.¹² Among them, azobenzene (and its derivatives) is undoubtedly the most prominent scaffold investigated in both fundamental research and modern applications.¹³ The planar azobenzene *E*-isomer can be efficiently converted into its metastable *Z*-isomer via UV irradiation, with a consequent change in the electronic as well as geometrical properties of the molecule.^{14,15} The *Z*-isomer is the main component of the thus formed photostationary state (PSS) and can interconvert to the more stable *E*-isomer through visible light irradiation or through thermal relaxation.¹⁵ Indeed, the ideal thermal lifetime of the metastable *Z*-isomer strongly depends on the application of interest. Highly thermal stable azoswitches are desired for applications such as molecular storage or logic devices, respectively.¹⁶ In contrast, fast relaxing azobenzenes are preferably employed, for instance, in real-time optical information-transmitting materials¹⁷ or in *in vivo* applications due to their temporally limited action.¹⁸ Thus, a lot of effort has been put

toward modifying the thermal lifetime of azobenzenes. Most of these transformations have been achieved through the introduction of different substituents onto the azobenzene core. Ortho-fluoro¹⁹ or ortho-thiol substituents²⁰ have been used to stabilize the thermal lifetime of azobenzenes, whereas 4,4'-push-pull or azophenolic systems (or a combination of both) can lead to extremely fast-relaxing switches.^{17,21} More recently, also heteroaromatic scaffolds were considered to broaden the range of azo dye properties, including their thermal lifetime. Notably, azopyrimidine,²¹ azopyridines,^{22,23} azopyrroles,²⁴ azoimidazole,^{25–29} and azopyrazoles^{30–32} or lately the bicyclic azoindazole scaffold³³ were reported. They were used, for example, to control the assembly of supramolecular systems or as photocontrollable ligands being, depending on the scaffold and its substitution pattern, highly stable (for a pyrazole derivative, the thermal lifetime is reported to be up to 1000 days³²) or fast-relaxing systems (40 ns, for an azopyrimidine²¹). However, a scaffold usually exhibits a certain lifetime, and the tunability is mostly limited to a few orders of magnitude; thus it belongs either to the thermally stable or to the fast back-isomerizing family.

Herein, we present phenylazoindoles as photochromic scaffolds with extremely tunable thermal lifetimes. Indoles are omnipresent in nature and substructures of drugs and various dyes. Although previously employed as antibacterial agents, food dyes,³⁴ or metal complexing ligands,³⁵ arylazoindoles have

Received: December 5, 2017

Published: February 6, 2018

Scheme 1. Synthesis of 3a–c

not been considered as photochromic compounds so far. We investigated both minimal chemical variations of the scaffold (methylation in different positions) and solvent effects on the thermal lifetime of the compounds. We elucidated the mechanism of the isomerizations and take advantage of it to tune the properties of the here presented photoswitches from days to nanoseconds. Thereby, we focus on providing a deep and general understanding of a new class of azo photoswitches to pave the way to further rational developments, using this novel core potentially for all kinds of applications.

RESULTS AND DISCUSSION

Synthesis. The phenylazaindoles **3a–c** were synthesized through azo coupling of diazonium salt **2** and the appropriate

indoles **1a–c** (see Scheme 1 and Section 2 in the [Supporting Information](#)).

Spectroscopy. The absorption and isomerization properties of phenylazaindoles **3a–c** were investigated in various solvents, from nonpolar (aromatic and nonaromatic) to polar aprotic and polar-protic ones. Most prominent is the broad absorption band between 359 and 380 nm. We could assign the aforementioned band to the $\pi \rightarrow \pi^*$ transition of the azo group (see [Table S1](#); for the recorded UV/vis spectra, see Section 3 in the [Supporting Information](#)) owing to the similarities with azobenzene and other azoheteroarenes and TD-DFT simulations (see Section 5.3 in the [Supporting Information](#)).^{15,33} Generally, methylation (**3b** and **3c**) induces a slight bathochromic shift of the band compared to **3a** (between 4 and 11 nm). The weaker $n \rightarrow \pi^*$ band is present between 400 and 500 nm as a tailing of the $\pi \rightarrow \pi^*$ transition. Due to the high variety of lifetimes (τ) of the *Z*-isomer encountered, we decided to study the different kinetics of thermal relaxation processes of **Z-3a–c** using three different experimental setups. In particular, for the slower kinetics, the *E*-to-*Z* isomerization was induced through irradiation with LEDs of 400 or 365 nm, and the back isomerization from the PSS in the dark was recorded through a UV/vis spectrometer (seconds to hours range; see for example [Figure 1A](#)) or a multiplate UV/vis reader (hours to days). The faster kinetics were studied via nanosecond laser flash photolysis with excitation provided by a Nd:YAG laser at 355 nm (full details and pictures of the various experimental setups are included in

Figure 1. (A) Thermal relaxation from the PSS ($\tau = 4.3$ s) of **3a** in DMSO after irradiation with $\lambda_{\text{irrad}} = 400$ nm. (B) Multiple isomerization cycles of **3a** in DMSO (black bars: dark, blue bars: irradiation with $\lambda_{\text{irrad}} = 400$ nm; the observed wavelength corresponds to $\lambda_{\text{obs}} = 375$ nm) indicating a good fatigue resistance. (C) Transient signal registered for **3b** in DMSO. The disappearing of the $n \rightarrow \pi^*$ band belonging to **Z-3b** is accompanied by the restoration of the $\pi \rightarrow \pi^*$ band of **E-3b**. (D) Transient signal registered for **3b** in a DMSO/water (1:2) mixture (detailed spectrometric data and kinetics in Section 3.3 in the [Supporting Information](#)). The decay of the $n \rightarrow \pi^*$ band of **Z-3b** is followed by the formation of a hypsochromically shifted transient signal. Then, the $\pi \rightarrow \pi^*$ band of **E-3b** reappears.

the [Supporting Information](#), Section 1). Multiple isomerization cycles can be achieved by pulsed irradiation of a single wavelength (see for example [Figure 1B](#), concerning the pulsed irradiation with 400 nm of **3a** in DMSO).

The results are summarized in [Table 1](#) (see [Table S2](#) for a wider number of entries, spectra, and isomerization kinetics).

Table 1. Z-to-E Isomerization Lifetimes for 3a–c

entry	solvent ^a	lifetime, τ		
		3a	3b	3c ^c
1	cyclohexane	42.5 ms ^b	116.8 ms ^b	1.1 h
2	dioxane	84.9 ms ^b	1.9 s ^c	17.6 h
3	mesitylene	12.3 ms ^b	3.3 ms ^b	1.13 d
4	benzene	78.5 ms ^b	167 ms ^b	6.0 min
5	toluene	47.5 ms ^b	60.2 ms ^b	17.1 min
6	aqueous toluene ^d		1.4 ms ^b	
7	MeOH	6.8 ms ^b	454 μ s (51%), 78 μ s (49%) ^e	2.4 h
8	MeOD	37.7 ms ^b		
9	MeOH–water 9:1	14.8 ms ^b	41.9 μ s ^b	
10	MeOH–water 1:1	2.9 ms ^b	41.4 μ s ^b	
11	MeOH ^f	4.7 ms ^b		
12	MeCN (dry)	4.3 s ^c	1.9 μ s ^b	1.2 d
13	DMSO (dry)	6.5 s ^c	1.3 ms ^b	2.6 d
14	DMSO–water 9:1	266 μ s ^b	111.2 μ s ^b	
15	DMSO–water 1:1	187.9 μ s ^b	32.1 μ s ^b	
16	DMSO–buffered water (pH = 4) ^f 1:1	2.2 μ s ^b	743 ns ^b	
17	DMSO–water 1:1 + 25 μ L DBU	31 ns	46 ns	

^aThe concentration was adjusted to 50 μ M for all the measurements. ^bDetermined via nanosecond laser flash photolysis. ^cDetermined via UV/vis spectroscopy. ^dToluene saturated with water (15 μ L of water was added to 2 mL of a 50 μ M solution of **3b** in toluene; the emulsion thus formed was sonicated for 1 h). ^eThe decay is biexponential. In parentheses is shown the contribution of the single lifetimes to the whole decay. ^fConcentration of **3a** = 75 μ M. ^gpH = 4.00 $\pm$ 0.02 (20 °C) (citric acid = 0.056 M; NaOH = 0.11 M; HCl = 0.044 M).

Compounds **Z-3a** and **Z-3b** exhibited thermal isomerization lifetimes comparable with or far lower than the second range. Laser flash photolysis allowed us to describe the transient absorption signal belonging to the Z-form of **3a** and **3b**. In particular, in **3b** a broad absorption band appeared around 450 nm immediately after the laser shot, attributable to the $n \rightarrow \pi^*$ transition of its Z-isomer ([Figure 1C](#)). On the other hand, only the bleaching of the $\pi \rightarrow \pi^*$ of the E-isomer can be observed in **3a**. TD-DFT UV/vis absorption simulations of the most stable Z-isomers of **3a,b** allowed us to conclude that the geometry of **Z-3b** is causing the $n \rightarrow \pi^*$ transition to be more symmetry-allowed than the one in **Z-3a** (cf. Section 5.3 in the [Supporting Information](#)).

Moving from apolar to polar-aprotic solvents in **3a** led to τ shifting from the millisecond to the second range (entries 1–5, 12, 13, [Table 1](#)). This trend becomes less discernible with **Z-3b**, which only in dioxane has a $\tau > 1$ s (entry 2, [Table 1](#)). In **3a,b** it seems that the increased speed of the thermal Z-to-E relaxation goes hand in hand with the proton availability (compare entries 7 and 13 for **Z-3a**). A striking example is **3a** in mixtures of MeOH or DMSO with water. While the addition of water in methanol does not drastically modify the lifetime (cf. [Table 1](#), entries 7, 9, 10 for **Z-3a**), the increased protic environment in aprotic DMSO lowers τ from seconds to microseconds (cf. [Table 1](#), entries 13–15). This allowed tuning the lifetime only

by changing the water content in DMSO. Similar observations can be made for **Z-3b**. Here, 1:1 mixtures of water and MeOH or DMSO afford lifetimes of 41.4 or 32.1 μ s, respectively. Moreover, in a mixture of acidic water and DMSO, the relaxation time decreases to 2.2 μ s for **Z-3a** and even reaches the nanosecond range (743 ns) for **Z-3b** (entry 16). A similar result was obtained for both **3a** and **3b** when 1,8-Diazabicyclo[5.4.0]undec-7-ene (DBU) was used as additive (entry 17), suggesting a proton-transfer mechanism contributes to the speed of the thermal isomerization. Reaching the submicrosecond scale is crucial for applications requiring real-time information transmission, and up to now, this goal was achieved in azobenzene cores only in one case by using phenolic push–pull systems.²¹ The dependency on a protic environment becomes more evident comparing the lifetimes of **Z-3a** in MeOH and MeOD, which show a significant kinetic isotope effect (KIE) (entries 7 and 8 in [Table 1](#)). A KIE = 5.5 indicates that a proton transfer is involved in the rate-determining step in this solvent. Increasing the concentration of **3a** in MeOH leads to faster isomerization kinetics (entry 11). In anhydrous toluene no concentration effect on τ was found; see [Table S2](#). The presence of an intermolecular interaction in **3a** can be followed by NMR (see Section 4.3 in the [Supporting Information](#)). In contrast to the other experiments, **Z-3b** in methanol relaxes with biexponential kinetics. This suggests, compared with the previous findings, that the presence of a protic environment modifies the mechanism of the dark reaction for **Z-3a** and **Z-3b**. Indeed, for the specific case of **3b** in MeOH, two mechanisms of thermal relaxation are in competition (cf. entry 7 for **3b**). A detailed kinetic analysis of the thermal isomerization reaction is presented in Section 7 of the [Supporting Information](#). In particular, a dependency both on concentration of the photoswitch and on water was found for the N–H-containing photoswitch **3b**. The kinetic law that was derived is similar to the one obtained for the arylazimidazoles, compounds that are supposed to isomerize through an intermolecular proton transfer leading to the formation of a hydrazone intermediate ([Chart 1](#)).^{17,26,32}

Chart 1. Formula of the s-trans Hydrazone Tautomer of 3a,b

The water content dependency led to an interesting saturation kinetics, which is another evidence of a mechanism characterized by an intermolecular proton transfer that is mediated by the presence of a protic medium.

Moreover, we observed notable differences in the transient spectra of **3a,b**. In the absence of protic media, the transient signal of the Z-isomer directly interconverts to the E-form (that exhibits an isosbestic point in **3b**, where the $n \rightarrow \pi^*$ absorption band of the Z-form can be clearly discerned; see [Figure 1C](#)). However, in a protic environment, the signal of **Z-3b** shifts hypsochromically, giving rise to a second band, which belongs to an intermediate of the Z-to-E thermal conversion that eventually collapses with the restoration of the E-isomer (cf. [Figure 1D](#)). In **3a** a new band arises at a similar wavelength to the comparable one in **3b**, before the **E-3a** $\pi \rightarrow \pi^*$ is restored). To prove our theory and to generalize the effect of a protic medium on the isomerization reaction of **3a,b**, we saturated toluene with

Figure 2. (A) Thermal *Z*–*E* isomerization of compound **3b** in toluene. An isosbestic point can be observed, indicating the monomolecular decay of the $n \rightarrow \pi^*$ band of *Z*-**3b** in favor of the formation of the $\pi \rightarrow \pi^*$ of *E*-**3b**. (B) The addition of water to toluene induces a change in the transient spectra. Like in DMSO, a new species, blue-shifted compared to the $n \rightarrow \pi^*$ band of *Z*-**3b**, can be detected by laser flash photolysis. This intermediate contributes to the restoration of the $\pi \rightarrow \pi^*$ band of *E*-**3b**. (C) Transient signal of the restoration of the $\pi \rightarrow \pi^*$ band of *E*-**3b** ($\lambda_{\text{obs}} = 370$ nm) in toluene and water-saturated toluene. A forced protic environment inside toluene increases the overall *Z*-to-*E* isomerization rate.

water (cf. Figure 2 and Table 1, entry 6, for **3b**). Consequently, the isomerization rate increased 60-fold, and a transient signal, similar to the intermediate signal observed above, appears. Furthermore, the importance of the NH moiety in the thermal *Z*-to-*E* relaxation was proven studying compound **3c**. Indeed, the methylation of the indole-nitrogen (in **3c**) causes significant changes of the relaxation properties with respect to the N–H-containing derivatives (**3a,b**). Compound **3c** exhibits longer lifetimes (minutes to days; see Table 1) compared to **3a,b**. Moreover, in polar-aprotic solvents (DMSO and MeCN) as well as in mesitylene, **3c** shows a τ larger than 1 day. Owing to their stable photostationary state, we were able to determine the PSS population of **3c** in DMSO (Figure 3) and MeCN applying ^1H NMR spectroscopy (85:15 and 61:39 *Z*:*E* ratio, respectively; see Section 4.4 in the Supporting Information).

However, to the best of our knowledge, spectroscopic observations similar to the ones we witnessed have not been made so far. Phenylazindoles themselves are known to give rise to a hydrazone tautomerism.³⁶ Thus, we aimed to explain the involvement of an azo-hydrazone and why minimal modifications of the indolic core lead to a surprisingly wide span of thermal relaxation rates through a detailed computational study.

Computational Studies. To look for similarities to the azobenzene core, we endeavored to analyze both the photochemical *E*-to-*Z* and thermal *Z*-to-*E* interconversion pathways. Representing the most general scaffold, **3a** was selected for the study. Hence, we performed an MS-CASPT2/CASSCF calculation of the *E*-to-*Z* pathway, both from the first (S_1 , $n \rightarrow \pi^*$ in

Figure 3. Thermal relaxation from the PSS (85:15 *Z*:*E* ratio, $\tau = 2.6$ d) of **3c** in DMSO after irradiation with $\lambda_{\text{irrad}} = 400$ nm.

character; cf. Figure 4A) and from the second excited state (S_2 , $\pi \rightarrow \pi^*$). The analysis of the molecular structure, its electronic distribution, and the g and h vectors defining the branching space of the conical intersections (CoIns) (cf. Figure 4A and B) helped us to assign the photochemical decay pathways (a complete analysis of the CoIns is presented in Section 5.2.2 in the Supporting Information).³⁷ Similarly to azobenzene, population of the $n \rightarrow \pi^*$ singlet excited state leads to a rotational conical intersection ($S_0 \leftarrow S_1$, CoIn_A), which generates the *Z*-isomer.¹⁴ This process is barrierless. Excitation to the S_2 level is followed by a

Figure 4. (A) Photochemical *E*-to-*Z* isomerization pathways calculated at the CASSCF(10,8)/6-31G(d) level of theory, showing the different pathways 3a can cover after excitation to the first or second excited state. (B) Branching space of conical intersection A ($CoIn_A$) represented in panel A. The derivative coupling (g) and gradient difference vectors (h), removing the degeneracy between S_1 and S_0 , are highlighted with green arrows on the geometry at which the conical intersection occurs. (C) Thermal reaction coordinates (RC) restoring *E*-3a from *Z*-3a. In particular, the rotation, inversion, and hydrazone formation mechanisms are compared. In the box, the spectroscopically detectable hydrazone of 3a is represented. (D) Thermal relaxation kinetics of 3a in MeCN at different temperatures. The related Eyring–Polanyi plot is depicted in the inset. (E) (TD)-PBE0/6-311+G(2d,p)-simulated UV/vis spectrum of the *s-trans* conformer of the azo-hydrazone of 3b in DMSO. In the inset, the optimized structure of the same species is shown.

deactivation to S_1 via a conical intersection topologically similar to the $S_0 \leftarrow S_1$ one ($CoIn_C$). The molecule has now enough potential energy either to go through $CoIn_A$ relaxing to *Z*-3a or to funnel through another conical intersection to the sole *E*-3a isomer ($CoIn_B$). $CoIn_B$ is accessible only in this way, because it

is located energetically uphill compared to the Franck–Condon geometry of the S_1 .

In accordance with our experiments, the simulated photochemical behavior of 3a, and in general of phenylazindole cores, does not differ drastically compared to the parent

azobenzene photoswitch.¹⁴ In contrast, the thermal Z-to-E pathway was studied via broken symmetry (BS)-density functional theory (DFT) taking into account three different mechanisms, viz., the inversion, the rotation (both of them typical of azobenzene),³⁸ and the intermolecular hydrazone formation (with and without water-assisting molecules). We found that the indole moiety lowers the rotational activation barrier with respect to the inversion in **3a,b** ($\Delta E^\ddagger = 20.3$ and 30.7 kcal/mol for the rotation and inversion mechanism, respectively, at the ω B97XD/6-31G(d) level of theory; Figure 3C; comparable findings were recently reported on arylazoindazoles³³), while N-Me indole (**3c**) increases it ($\Delta E^\ddagger = 33.8$ and 30.7 kcal/mol for the rotation and inversion mechanism, respectively, at the ω B97XD/6-31G(d) level of theory). That could be an explanation for the higher lifetimes encountered in aprotic solvents for **3c** compared to **3a** and **3b**, where other pathways, apart from monomolecular relaxation, were not detected. The computed thermochemical values we have in hand ($\Delta H^\ddagger = 14$ kcal/mol at the (C-PCM)-B3LYP/6-31G(d) in MeCN) are comparable with the experimental Eyring–Polanyi plot obtained for **3a** in MeCN ($\Delta H^\ddagger = 12$ kcal/mol; Figure 4D).

Most interestingly, using DFT calculations we proved the participation of a hydrazone intermediate in a third relaxation pathway. We reasoned that the hydrazone formation in azoindoles is only feasible intermolecularly, due to the impossibility for the indolic proton to reach the azo group intramolecularly (see Scheme 2; Section 5.4 in the Supporting Information; for a

Scheme 2. Simplified Intermolecular Hydrazone Mechanism

Level of theory: CPCM(DMSO)-B3LYP/6-31G(d)

Energies of the species compared to the Z-isomer, taken as a reference.

more detailed representation of the mechanism see Section 8 of the Supporting Information).

However, without the assistance of water (representing the simplest proton donor) the interaction of two molecules of **3a** is characterized by high energy barriers, which make this pathway not competitive with the previously analyzed monomolecular thermal isomerizations. On the other hand, two explicit molecules of water bridging two Z-conformers of **3a** lower the energetic barriers for the hydrazone formation, thus explaining the increase of rate observed with protic solvents in N–H-containing azoindoles (Section 7 in the Supporting Information). We

propose the following mechanism. The first step involves a water-mediated proton transfer from the indole nitrogen of one molecule of Z-**3a** onto the azo moiety of the second one (β -nitrogen atom with respect to the indole; see Figure 4C). The barrier for the formation of this complex is only 17.3 kcal/mol due to the stabilizing action of the water molecules. The ensuing generation of the two *s-cis* hydrazones is defined by a low activation energy ($\Delta E^\ddagger = 3.5$ kcal/mol) and is slightly exothermic (ca. 1 kcal/mol). After the rotation around the newly formed N–N single bonds (characterized by ($\Delta E^\ddagger = 8.6$ and 10.2 kcal/mol), the *s-trans* hydrazone dimer is formed, which is located inside a potential well (ca. 30 kcal/mol more stable than the initial water-bridged Z-**3a** dimer; see Figure 4C). Due to this fact, the transient signal of the intermediate present in protic media can be assigned to the *s-trans* hydrazone (compare Figure 4E, showing the simulated TD-DFT UV/vis spectra of the azohydrazone of **3b** with the experimentally observed band, Figure 1D).

Then, the system undergoes two consecutive water-mediated proton transfers leading to the E-isomer of **3a**. The hydrazone pathway possesses a slightly lower activation energy in protic media than the rotation or the inversion ones. This explains the surprisingly fast isomerization kinetics found with increased proton availability of the medium for **3a,b**. With this mechanism in hand, we also expect **3a** and **3b** to be able to switch faster at higher concentrations, nicely explaining the concentration-dependent behavior we found in our experiments (entry 11, Table 1; Section 7 in the Supporting Information).

Moreover, the competition between the hydrazone and the rotation pathway can be recognized for **3b** in MeOH for its biexponential decay. In contrast, due to its methylated nitrogen atom, the azo-hydrazone formation is precluded to **3c**.

CONCLUSIONS

In summary, the photochromic properties of phenylazoindoles have been investigated for the first time. We synthesized compounds **3a–c**, representing three very basic derivatives of this class of azo dyes. All compounds photoisomerize applying light of 355, 365, and 400 nm wavelength. Thereby, N-methylated **3c** showed the typical behavior of an azobenzene (τ between several minutes and 2 days). In contrast to these findings, N-H azoindoles exhibit shorter lifetimes, strongly dependent on the protic character of the solvent. We took further advantage of this relationship and tuned the reaction kinetics, increasing the proton content of the solvents. Best results were obtained in mixtures of DMSO and water (1:1) using DBU as an additive, giving rise to lifetimes between 33.9 and 46 ns for **3a** and **3b**, respectively. The surprisingly short lifetimes are explained by a thorough mechanistic study, assuming the intermolecular formation of a hydrazone. Such a mechanism was studied in detail for the first time, spectroscopically, kinetically, and computationally. Compared to the canonical inversion and rotation pathways, this conversion is energetically favored in protic media. Thus, faster Z-to-E relaxation rates can be achieved for **3a,b** in contrast to **3c**. Hence, only slight changes of the substituent position or the solvent composition can drastically tune the properties of phenylazoindoles. Such extremely versatile properties render this core structure a suitable candidate for the wide range of applications of photoswitches.

ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available free of charge on the ACS Publications website at DOI: 10.1021/jacs.7b12871.

General procedures, synthesis of compounds **3a–c**, spectroscopic experiments, NMR experiments, computational analysis kinetic analysis, mechanism proposal (PDF)

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Notes

The authors declare no competing financial interest.

ACKNOWLEDGMENTS

We are grateful to Regina Hoheisel and Julia Zach for technical support and to Prof. S. M. Bonesi (University of Buenos Aires) for his help with the kinetic analysis. This work was supported by CINECA SCAI, with computer time granted by ISCRA projects (project codes: HP10CBEIAU and HP10C8U1NY). N.A.S. thanks the Studienstiftung des Deutschen Volkes for a doctoral scholarship. S.C. gratefully thanks P. Sbazzeguti, Prof. S. Protti, and Dr. D. Ravelli for their help and fruitful discussions.

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