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Synthesis and characterisation of polymerisable photochromic spiropyrans: towards photomechanical biomaterials

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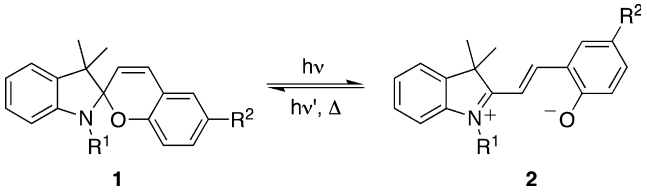
Abstract—A methodology for the synthesis of novel polymerisable spiropyrans with photomechanical properties suitable for subsequent copolymerisation with either vinyl or acrylate-based biomaterials is described. UV–vis spectroscopic characterisation of photoisomerism shows that photochromic behaviour with respect to related non-polymerisable compounds is retained and is solvent dependent. In acetone, conventional spiropyran–merocyanine photochromism is observed for nitro-spiropyran derivatives, whereas in dichloromethane both nitro-spiropyrans and spiropyrans isomerise to merocyanines which rapidly form H-aggregates. The monomers were designed such that an alkyl spacer of variable length, both electronically and sterically, separates the polymerisable moiety from the photochromic core and allows steric aspects of the resulting photomechanical behaviour to be explored.

The development of novel materials which can deliver drugs controllably from matrices represents a major current research drive in biomaterials.[1] There is considerable interest in functional photochromic molecules which undergo externally triggered changes in properties such as optical absorption,[2] or charge,[3] but which remain under-exploited in terms of applications. In particular, the photochromism of spiropyrans[4] (Scheme 1, showing the charged resonance structure of the merocyanine form) is adaptable to biomaterials applications, where the photoinduced generation of a significant dipole in the merocyanine with respect to spiropyran is of primary interest. Such charge generation in hydrogel matrices will alter their osmotic potential, and hence allow a photomechanical response.[5] A positive photomechanical response (i.e., increase in size) increases the porosity, and hence drug diffusion rate, from the polymer matrix. Conversely, the reverse reaction gives a negative photomechanical response, reduces the porosity of the collapsed hydrogel and significantly reduces the drug release rate. The synthesis of such materials is predicated upon the availability of appropriate functional monomers to allow permanent incorporation in biomaterials, many of which are amenable in their preparation to free radical copolymerisation with vinyl monomers. Herein we describe a simple method for the introduction of electronically isolated spiropyrans to a polymerisable moiety and characterise their photoinduced isomerisation and aggregation behaviour in solvents of differing polarity.



1 2

Scheme 1. Photochromism of spiropyrans between spiropyran, **1**, and merocyanine, **2**, forms.

A range of vinyl-functionalised derivatives of 2,3,3-trimethyl-3*H*-indole, **3**, with the vinyl moiety electronically isolated from the photochromic moiety via methylene spacers of various chain lengths, was prepared through N-alkylation of **3** and subsequent treatment with hydroxide, as shown in Scheme 2. The reaction temperatures were maintained below 80 °C to prevent thermal initiation of polymerisation. Alkylation of **3** with allyl bromide, 5-bromo-1-pentene and 11-bromoundecene afforded 2-alkylideneindolines **4** (87%), **5** (86%) and **6** (78%), respectively.[6] The reactions proceeded in an analogous fashion to literature procedures.[7]

Compounds **4**–**6** were subsequently condensed separately with both salicylaldehyde and 5-nitrosalicylaldehyde

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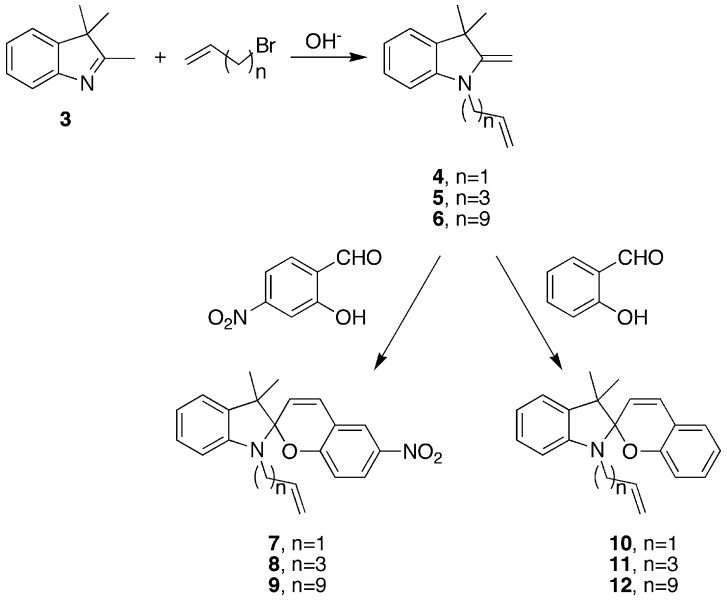

Scheme 2. Synthesis of polymerisable spiropyrans.

to give both non-substituted spiropyrans **10** (44%), **11** (50%) and **12** (47%) and nitro-substituted spiropyrans **7** (49%), **8** (50%) and **9** (52%) as shown in Scheme 2.

The yield of related literature procedures, such as the condensation of 5-nitrosalicylaldehyde with 1,3,3-trimethyl-2-methyleneindoline (Fischer's base) did not exceed 60%. To account for this, it has been suggested that unsubstituted salicylaldehydes give bis-condensation products **13**[8] (Fig. 2), while salicylaldehydes bearing polar substituents such as 5-nitrosalicylaldehyde and 3,5-dinitrosalicylaldehyde yield only the mono-condensation product.[9] Although this may be the case under certain reaction conditions, when excess Fischer's base is employed both the mono- and bis-condensation products are formed, with the bis-condensation product predominating when a large excess of Fischer's base is employed.[10] To minimise the yield of bis-condensation product, we therefore employed 1.1 equiv of salicylaldehyde or 5-nitrosalicylaldehyde as appropriate. The reactions require minimal work-up and short reaction times.

The photoisomerism and subsequent physical behaviour of **7**–**12** upon exposure to UV light was characterised[11] to determine the influence of the methylene spacer and polymerisable group on molecular photochemistry and aggregation behaviour. The photoisomerisation of spiropyrans to merocyanines is typically characterised by the appearance of a strong, long-wavelength absorption band, resulting from photoinduced cleavage of the C–O bond at the spiro junction and subsequent increase in conjugation between the two heterocycles (cf. Scheme 1).[12] In acetone, **7**–**9** exhibit conventional spiropyran–merocyanine photochromism. Figure 1 shows overlaid absorption spectra of **7** following irradiation at various times. The evolution of the long-wavelength absorption of the merocyanine form is observed at 577 nm and increases in intensity with increasing total time of irradiation, indicating the progress of the forward photochromic reaction. Compounds **8** and **9** gave almost identical spectra, indicating the number of methylene groups in the polymerisable spacer has a negligible effect on both the nature, and rate, of photoisomerism from spiro to merocyanine forms.

Conversely, in acetone, **10**–**12** showed no light-induction isomerisation on the timescale of the experiment and UV–vis spectra were unchanged over the same periods of irradiation as for **7**–**9**. Compounds **7**–**9** are nitro-substituted on the aromatic pyran ring and, as such, have an electron-withdrawing group which serves to stabilise the merocyanine form. This stabilisation is absent in **10**–**12**. Therefore, upon irradiation, negligible concentrations of the merocyanine form of **10**–**12** arise in the photostationary state due to its short thermal relaxation lifetime at 25 °C.[13] As the solutions remained colourless,

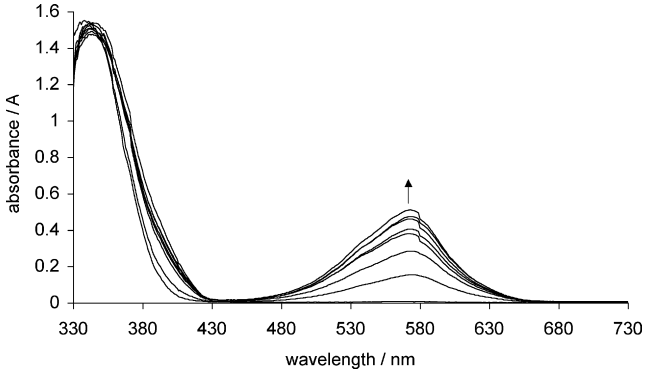

Figure 1. Overlaid absorption spectra of **7** following 312 nm irradiation at various times in acetone. Arrow indicates trends in spectral change with time. The total times of irradiation were 0, 10, 20, 30, 60, 80, 100 and 120 s.

these systems are undesirable for most photochromic applications[14] and short timescale experiments, including laser or flash photolysis, are required for photoinduced spiropyran–merocyanine equilibrium studies.[15]

In dichloromethane, more complex behaviour was observed upon irradiation and both nitro- and unsubstituted spiropyrans exhibited photochromic behaviour observable on the timescale of these experiments. Figure 3 shows overlaid absorption spectra of **7** following irradiation at various times. The behaviour of **7** is representative of **7**–**9**, with only small spectral differences observed between **7**–**9**, again indicating that the number of methylene groups in the polymerisable spacer has a negligible effect on both the nature and rate of photoisomerism from spiro to merocyanine forms, and that the electronic processes in the spiropyran and merocyanine chromophores are unaffected by the pendant chains. Figure 3 shows that during irradiation, a new band with absorbance centred at 446 nm develops. This is significantly hypsochromically shifted compared to the cognate set of spectra in acetone and cannot be accounted for by differences in solvent polarity.[16] Similar systems have been characterised as aggregates of different types, with the absorption spectrum of the aggregates providing a means of determining the type of ordered structure produced. The molecular assemblies formed generally consist of stacks with deck-of-card type structures.[17] If the dipole–dipole interaction of the stack-forming molecules leads to a parallel orientation of dipoles, the absorption spectrum is red-shifted with respect to the isolated molecules. This type of aggregate with head-to-tail structure is termed the J-stack or J-aggregate.[18] On the other hand, antiparallel dipole interaction leads to the formation of H-stacks with head-to-head stacking,[19] which are characterised by a blue shift in their absorption with respect to the isolated molecules.

In acetone, the merocyanine form was observed at 577 nm, and Figure 3 showed a small peak at this wavelength in spectra where **7** had been irradiated in dichloromethane. It was suspected that this peak was due to free merocyanine, which forms photochemically from spiropyran and subsequently undergoes rapid aggregation. To investigate this, irradiation experiments were repeated using rapid, single wavelength monitoring at both 577 nm and 446 nm. Figure 4 shows the changes in absorbance of **7** following irradiation at various times at these wavelengths. The transient band at 577 nm, due to free merocyanine, was observed to form rapidly, with maximum intensity observed after 30 s of irradiation. As aggregation progresses, the band at 446 nm increased in intensity at the expense of the 577 nm band. Hence there is a kinetically rapid conversion of the conventional merocyanine form into H-aggregates, which have an absorbance centred at the shorter wavelength and which are kinetically stable. The hypsochromic shift of the merocyanine form of 131 nm observed upon aggregation is thus indicative of the formation of H-stacks with head-to-head stacking.

Figure 5 shows the changes in the UV–vis spectrum of **10** upon irradiation for various times. These spectra are typical of **10**–**12**, again indicating that the methylene chain length has little effect on the photochromism or electronic processes in the spiropyran and merocyanine chromophores. A new band with absorbance centred at 469 nm developed with irradiation. This is significantly hypsochromically shifted compared to the cognate set of spectra in acetone and is again attributed to the formation of H-stacks with head-to-head stacking.[19]

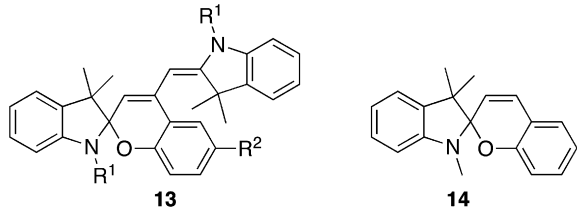

Figure 2.

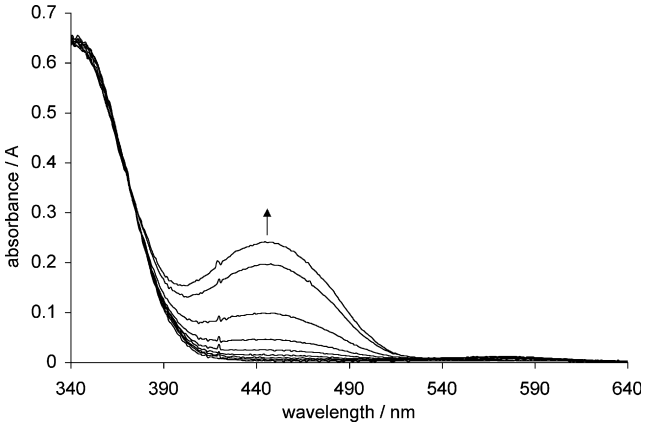

Figure 3. Overlaid absorption spectra of **7** following 312 nm irradiation at various times in dichloromethane. Arrow indicates trends in spectral change with time. The total times of irradiation were 0, 5, 15, 30, 55, 90, 135, 190 and 255 s.

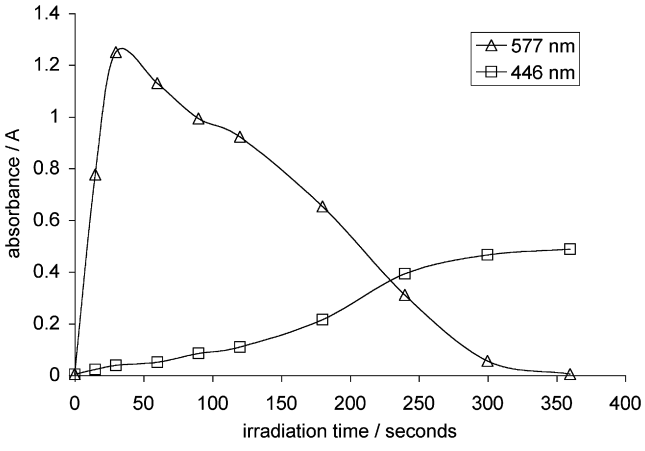

Figure 4. Changes in absorbance at 577 nm (free merocyanine) and 446 nm (aggregate) with total irradiation time for **7** in dichloromethane using rapid, single wavelength monitoring.

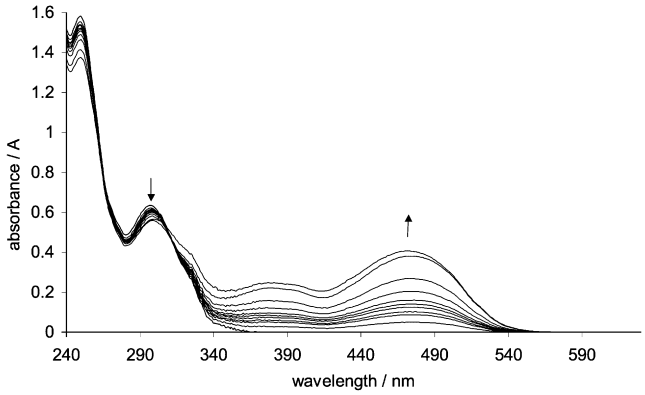

Figure 5. Overlaid absorption spectra of **10** following 312 nm irradiation at various times in dichloromethane. Arrows indicate trends in spectral change with time. The total times of irradiation were 0, 10, 20, 30, 40, 60, 80, 120, 180, 315 and 660 s.

Single wavelength experiments did not show any appreciable evolution of free merocyanine on the timescale of the experiment, indicating that the rate of aggregation is greater than for **7**–**9**, which is attributable to the relative instability of the unsubstituted merocyanine forms of **10**–**12** compared to the nitro-substituted merocyanines formed by **7**–**9**. The band observed for H-aggregates of the merocyanine form centred at 469 nm is bathochromically shifted by 23 nm with respect to that observed for **7**–**9**, which reinforces the conclusion that the unsubstituted merocyanine forms of **10**–**12** are relatively unstable compared to the nitro-substituted merocyanines formed by **7**–**9** in this solvent. The 'parent' spiropyran, 1,3,3-trimethylene indoline-2-spiro-2′-benzopyran, **14**,[9] (Fig. 2) which bears an *N*-methyl, rather than a vinyl-terminated methylene chain, shows a very similar behaviour, with merocyanine bands centred at 382 nm and 469 nm evolving upon irradiation with similar kinetics. This shows that aggregation is not influenced by the length of methylene chain, but is strongly dependent on the evolution of the polar merocyanine.

In summary, we have successfully demonstrated an efficient route for the synthesis of both nitro- and unsubstituted polymerisable spiropyrans, with a variable chain length methylene spacer between the functional spiropyran and polymerisable moiety. The spacer is shown to have no electronic effect on the photochromic behaviour of the resulting spiropyrans in a range of solvents. The monomers comprise building blocks for the synthesis of novel photomechanical biomaterials due to the long-lived photoinduced charge generation in the merocyanine form.

Acknowledgements

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References and notes

1. Langer, R. *Science* **2001**, *293*, 58–59.
2. Bulanov, A. O.; Luk'yanov, B. S.; Kogan, V. A.; Stankevich, N. V.; Lukov, V. V. *Russ. J. Coord. Chem.* **2002**, *28*, 46–49.
3. Dürr, H.; Bouas-Laurent, H. *Photochromism, Molecules and Systems*; Elsevier: Amsterdam, 1990; Bouas-Laurent, H.; Dürr, H. *Pure Appl. Chem.* **2001**, *73*, 639–665.
4. Brown, G. H. *Photochromism*; Wiley: New York, 1971.
5. Gonzalez-de los Santos, E. A.; Lozano-Gonzalez, M. J.; Johnson, A. F. *J. Appl. Polym. Sci.* **1999**, *71*, 262–272.
6. General procedure for the preparation of 3,3-dimethyl-2-methylene-1-(2-alkenyl) indolines **4**–**6**. A solution of the appropriate bromoalkene (35.5 mmol) in 2,3,3-trimethylindoline (36.1 mmol) was heated under reflux for 72 h. After cooling and removal of excess bromoalkene via evaporation under reduced pressure, the resulting viscous purple material was dissolved in chloroform (100 mL) and washed with water (3 × 30 mL). The chloroform layer was dried over anhydrous magnesium sulfate and the solvent removed under reduced pressure. The residue was resuspended in ethanol (50 mL) and shaken with aqueous sodium hydroxide solution (2.0 M, 19.3 mL). The solution was reduced under vacuum to approximately 20 mL and the product extracted into ether (3 × 30 mL). The ethereal layer was dried over anhydrous magnesium sulfate and the solvent removed under reduced pressure to give the product as a red oil (87% for **4**, 86% for **5** and 78% for **6**).The resulting compounds were used immediately in the preparation of **7**–**12** as appropriate. Spectroscopic data for **4**: δ_H (500 MHz, $CDCl_3$): 6.50–7.11 (m, 2H, C-5′H, C-7′H); 6.76 (dd, $J = 7.4$, 7.6 Hz, 1H, C-6′H); 6.50 (d, $J =$ 7.4 Hz, 1H, C-4′H); 5.83–5.77 (m, 1H, NCH_2CHCH_2); 5.15 (d, $J = 13.9$ Hz, 2H, NCH_2CHCH_2); 4.10 (d, $J =$ 3.8 Hz, 2H, $=CH_2$); 3.86 (d, $J = 10.8$ Hz, 2H, NCH_2-$CHCH_2$); 1.34 (s, 6H, $2 \times CH_3$). Spectroscopic data for **5**: δ_H (500 MHz, $CDCl_3$): 7.04 (dd, $J = 7.4$ Hz, 7.6 Hz, 1H C-5′H); 7.01 (d, $J = 7.3$ Hz, 1H, C-7′H); 6.67 (dd, $J = 7.4$, 7.3 Hz, 1H, C-6′H); 6.45 (d, $J = 7.8$ Hz, 1H, C-4′H); 5.70–5.80 (m, 1H, $NCH_2CH_2CH_2CHCH_2$); 4.98 (dd, $J = 18.8$, 1.7 Hz, 1H, =CH *trans*); 4.93 (dd, $J = 10.2$, 1.7 Hz, 1H, =CH *cis*); 3.77 (d, $J = 18.9$ Hz, 2H, $=CH_2$); 3.43 (t, $J = 7.4$ Hz, 2H, $NCH_2CH_2CH_2CHCH_2$); 2.05 (dt, $J = 7.4$, 7.2 Hz, 2H, $NCH_2CH_2CH_2CHCH_2$); 1.74 (tt, $J = 7.4$, 7.6 Hz, 2H, $NCH_2CH_2CH_2CHCH_2$); 1.26 (s, 6H, $2 \times CH_3$). Spectroscopic data for **6**: δ_H 8.3 (500 MHz, $CDCl_3$): 7.09–7.05 (m, 2H, C-5′H, C-7′H); 6.72 (dd,$J = 8.3$, 8.0 Hz, 1H, C-6′H); 6.50 (d, $J = 8.3$ Hz, 1H, C-4′H); 5.82–5.77 (m, 1H, n-$C_9H_{18}CHCH_2$); 4.98 (dd, $J = 15.7$, 1.6 Hz, 1H, =CH *trans*); 4.92 (dd, $J = 10.2$, 1.6 Hz, 1H, =CH *cis*); 3.87 (d, $J = 18.9$ Hz, 2H, $=CH_2$); 3.46 (t, $J = 7.4$ Hz, 2H, NCH_2); 2.04–1.27 (m, 22H, $2 \times CH_3$ and 16 alkyl H). General procedure for the preparation of polymerisable spiropyrans **7**–**12**. A solution of either 5-nitrosalicylaldehyde (for **7**–**9**) or salicylaldehyde (for **10**–**12**) (20 mmol) in methanol (15 mL) was heated to reflux. The appropriate 3,3-dimethyl-2-methylene-1-(2-alkenyl)indoline, **4**–**6** (19.7 mmol), in methanol (6 mL) was added dropwise via a pressure-equalising dropping funnel over 45 min. After the addition, reflux was continued for 20 h. The reaction mixture was cooled, the resulting yellow precipitate was collected by filtration and washed with cold methanol. The product was then recrystallised from hot methanol to give colourless to pale yellow crystals (**7**–**9** and **11**) or pale yellow oils (**10** and **12**) (yields as in the main text). Spectroscopic data for **7**: mp 124–125 °C; ^{1}H NMR (500 MHz, $CDCl_3$): 7.98–8.03 (m, 2H, C-5H, C-7H); 7.16 (dd, $J = 7.7$, 7.4 Hz, 1H, C-5′H); 7.09 (d,

$J = 7.4$ Hz, 1H, C-7′H); 6.86–6.91 (m, 2H, C-4H, C-6′H); 6.74 (d, $J = 8.9$ Hz, 1H, C-8H); 6.57 (d, $J = 7.7$ Hz, 1H, C-4′H); 5.80–5.90 (m, 2H, C-3H, NCH_2CHCH_2); 5.18 (dd, $J = 17.2$, 1.7 Hz, 1H, =CH *trans*); 5.09 (dd, $J = 10.3$, 1.7 Hz, 1H, =CH *cis*); 3.91 (d, $J = 17.2$ Hz, 1H, NCH); 3.69 (d, $J = 17.2$ Hz, 1H, NCH); 1.30 (s, 3H, CH_3); 1.21 (s, 3H, CH_3); IR υ_{max}/cm^{-1}: 3062, 2961 (C–H), 1650 (spiro C=C), 1610, 1508 (–NO_2), 1482, 1334, 1274, 1027 (spiro COC=C), 914 (C=CH_2), 749; *m*/*z* (EI) (%): 349 (MH^+, 100), 118 (20), 87 (8); Anal. Calcd for $C_{21}H_{20}N_2O_3$: C, 72.40; H, 5.79; N, 8.04. Found: C, 72.32; H, 5.49; N, 7.81. Spectroscopic data for **8**: mp 97 °C; ^{1}H NMR (500 MHz, $CDCl_3$): 7.92–8.20 (m, 2H, C-5H, C-7H); 7.12 (dd, $J = 7.7$, 7.4 Hz, 1H, C-5′H); 7.02 (d, $J = 7.7$ Hz, 1H, C-7′H); 6.85–6.77 (m, 2H, C-6′H, C-4H); 6.67 (d, $J = 8.4$ Hz, 1H, C-8H); 6.51 (d, $J = 7.7$ Hz, 1H, C-4′H); 5.79 (d, $J = 10.4$ Hz, 1H, C-3H); 5.75–5.64 (m, 1H, C*H*CH_2); 4.95–4.87 (m, 2H, =CH_2); 3.16–3.04 (m, 2H, NCH_2); 2.04–1.89 (m, 2H, $NCH_2CH_2CH_2CHCH_2$); 1.73–1.57 (m, 2H, $NCH_2CH_2CH_2CHCH_2$); 1.21 (s, 3H, CH_3); 1.11 (s, 3H, CH_3); IR υ_{max}/cm^{-1}: 2925 (C–H), 1650 (spiro C=C), 1610, 1510 (–NO_2), 1480, 1335, 1276, 1022 (spiro COC=C), 917 (C=CH_2), 747; *m*/*z* (EI) (%): 376 (M^+, 58), 361 (24), 346 (8), 335 (19), 307 (30), 158 (97), 144 (44), 130 (32), 115 (28), 103 (8), 84 (46), 77 (13), 49 (64), 41 (100); HRMS (ESI): *m*/*z* Calcd for $C_{23}H_{24}N_2O_3$: 376.1787. Found: 376.1791. Spectroscopic data for **9**: mp 85 °C (sharp): ^{1}H NMR (500 MHz, $CDCl_3$): 7.99–8.02 (m, 2H, C-5H, C-7H); 7.18 (dd, $J = 7.6$, 7.4 Hz, 1H, C-5′H); 7.07 (d, 1H, $J = 7.20$ Hz); 6.89 (m, 2H, C-4H, C-6′H); 6.74 (d, $J = 8.9$ Hz, 1H, C-8H); 6.56 (d, $J = 7.6$ Hz, 1H, C-4′H); 5.85 (d, 1H, $J = 10.4$ Hz, C-3H); 5.83–5.78 (m, 1H, *n*-C_9H_{18}C*H*CH_2); 4.99 (dd, 1H, $J = 17.1$, 1.7 Hz, =CH *trans*); 4.94 (dd, 1H, $J = 10.2$, 1.7 Hz, =CH *cis*); 3.17–3.11 (m, 2H, NCH_2); 2.01–2.05 (m, 2H, *n*-$C_8H_{16}CH_2CHCH_2$); 1.63–1.17 (m, 20H, $2 \times CH_3$, 14 alkyl H); IR υ_{max}/cm^{-1}: 2924 (C–H), 1651 (spiro C=C), 1611, 1511 (–NO_2), 1481, 1336, 1275, 1024 (spiro COC=C), 920 (C=CH_2), 750; *m*/*z* (EI) (%): 460 (M^+, 97), 445 (46), 430 (42), 419 (29), 405 (13), 391 (9), 377 (24), 363 (15), 349 (28), 335 (73), 321 (78), 307 (72), 291 (83), 261 (84), 246 (100), 217 (80); Anal. Calcd for $C_{29}H_{36}N_2O_3$: C, 75.61; H, 7.87; N, 6.08. Found: C, 75.32; H, 7.65; N, 5.91. Spectroscopic data for **10**: ^{1}H NMR (500 MHz, $CDCl_3$): 7.13–7.65 (m, 9H, 8Ar, C-4H); 5.84–5.92 (m, 1H, NCH_2CHCH_2); 5.68 (d, $J = 10.2$ Hz, 1H, C-3H); 5.19 (dd, $J = 17.2$, 1.6 Hz, 1H, =CH *trans*); 5.07 (dd, $J = 10.2$, 1.6 Hz, 1H, =CH *cis*); 3.95–3.85 (m, 1H, NCH); 3.70–3.60 (m, 1H, NCH); 1.31 (s, 3H, CH_3); 1.19 (s, 3H, CH_3); IR υ_{max}/cm^{-1}: (C–H), 1645 (spiro C=C), 1608, 1484, 1031 (spiro COC=C), 925 (C=CH_2), 743; *m*/*z* (EI) (%): 303 (M^+, 90), 288 (50), 246 (31), 217 (28), 158 (53), 144 (67), 115 (60), 41 (100); HRMS (ESI): *m*/*z* Calcd for $C_{21}H_{21}NO$: 303.1621. Found: 303.1623. Spectroscopic data for **11**: mp 76 °C (sharp); ^{1}H NMR (500 MHz, $CDCl_3$): 7.15–6.50 (m, 9H, 8Ar, C-4H); 5.79–5.74 (m, 1H, $NCH_2CH_2CH_2CHCH_2$); 5.67 (d, $J = 10.2$ Hz, 1H, C-3H); 5.02–4.92 (m, 2H, =CH_2); 3.27–3.16 (m, 1H, NCH); 3.16–3.09 (m, 1H, NCH); 2.20–1.94 (m, 2H, $NCH_2CH_2CH_2CHCH_2$); 1.80–1.60 (m, 2H, $NCH_2CH_2CH_2CHCH_2$); 1.37 (s, 3H, CH_3); 1.16 (s, 3H, CH_3); IR υ_{max}/cm^{-1}: 2928 (C–H), 1642 (spiro C=C), 1606, 1484, 1023 (spiro COC=C), 919 (C=CH_2), 744; *m*/*z* (EI) (%): 331 (M^+, 73), 316 (25), 290 (51), 276 (25), 262 (32), 246 (36), 230 (9), 158 (64), 144 (78), 114 (63), 84 (86), 49 (100). Anal. Calcd for $C_{23}H_{25}NO$: C, 83.34; H, 7.60; N, 4.23. Found: C, 83.40; H, 7.60; N, 4.32. Spectroscopic data for **12**: ^{1}H NMR (500 MHz, $CDCl_3$): 7.23–6.51 (m, 9H, 8Ar, C-4H), 5.85–5.75 (m, 1H, C*H*CH_2), 5.66 (d, $J = 10.2$ Hz, 1H, C-3H); 5.00–4.91 (m, 2H, =CH_2); 3.27–3.18 (m, 1H, NCH); 3.11–3.04 (m, 1H, NCH); 2.04–2.01 (m, 2H, NCH_2CH_2); 1.86–1.10 (m, 20H, $2 \times CH_3$, 14 alkyl H); IR υ_{max}/cm^{-1}: 2922 (C–H), 1642 (spiro C=C), 1608, 1484, 1030 (spiro COC=C), 909 (C=CH_2), 743; *m*/*z* (EI) (%): 415 (M^+, 39), 400 (15), 276 (27), 262 (20), 158 (79), 144 (56), 131 (33), 55 (70), 41 (100); HRMS (ESI): *m*/*z* Calcd for $C_{29}H_{37}NO$: 416.2950. Found: 416.2953.

7. Hirschberg, Y. *J. Am. Chem. Soc.* **1956**, *78*, 2304–2312.
8. Balny, C.; Hinnen, A.; Mossé, M. *Tetrahedron Lett.* **1968**, *49*, 5097–5099.
9. Koelsch, C. F.; Workman, W. R. *J. Am. Chem. Soc.* **1952**, *74*, 6288–6289.
10. Keum, S. R.; Kazmaier, P. M.; Cheon, K. S.; Manderville, R. A.; Buncel, E. *Bull. Kor. Chem. Soc.* **1996**, *17*, 291–393.
11. A typical photochemical experiment employed a 1.3×10^{-4} M solution of spiropyrans in either acetone or dichloromethane. Solutions were exposed to 312 nm light from a 15 W UV source (BDH, VL215LM) at a distance of 1 cm at 25 °C for various durations prior to the acquisition of UV–vis spectra using a Pye-Unicam UV1 spectrophotometer.
12. Pimienta, V.; Lavabre, D.; Levy, G.; Samat, A.; Guglielmetti, R.; Micheau, J. C. *J. Phys. Chem.* **1996**, *100*, 4485–4490.
13. Chibisov, A. K.; Görner, H. *Phys. Chem. Chem. Phys.* **2001**, *3*, 424–431.
14. Kießwetter, R.; Pustet, N.; Brandl, F.; Mannschreck, A. *Tetrahedron: Asymmetry* **1999**, *10*, 4677–4687.
15. Zhang, J. Z.; Schwartz, B. J.; King, J. C.; Harris, C. B. *J. Am. Chem. Soc.* **1992**, *114*, 10921–10927.
16. Tagaya, H.; Kuwahara, T.; Sato, S.; Kadokawa, J.; Karasu, M.; Chiba, K. *J. Mater. Chem.* **1993**, *3*, 317–318.
17. Eckhardt, H.; Bose, A.; Krongauz, V. A. *Polymer* **1987**, *28*, 1959–1964.
18. Berkovic, G.; Krongauz, V.; Weiss, V. *Chem. Rev.* **2000**, *100*, 1741–1753.
19. Hachisako, H.; Ihara, H.; Kamiya, T.; Hirayama, C.; Yamada, K. *Chem. Commun.* **1997**, 19–20.