FULL PAPER

Novel Azo-Dyes-Modified Isatin Derivatives: Synthesis, UV/VIS Spectroscopic, and Electrochemical Study

by **Lenar I. Musin**[a]), **Ilnur T. Abdullin**[a]), **Alexander E. Vandyukov**[a]), **Dmitry G. Yakhvarov**[a])[b]), **Ruzal G. Zinnatullin**[b]), **Vladimir F. Mironov**[a]), and **Andrei V. Bogdanov***[a])

[a]) A. E. Arbuzov Institute of Organic and Physical Chemistry, Kazan Scientific Center, Russian Academy of Sciences, Kazan, 420088, Russian Federation (phone: +7-843-2727374; fax: +7-843-2732253; e-mail: abogdanov@inbox.ru)
[b]) Kazan Federal University, Kremlyovskaya str., 18, Kazan, 420008, Russian Federation

A high-yield and simple synthesis of certain aminomethylisatins bearing dye fragments *via* the *Mannich* reaction of isatin with amino-containing azobenzenes was reported. It was found that the absence of electron-donating groups in azo-dye molecule prevents aminomethylation of isatin. The effect of the incorporation of an isatin moiety with an azobenzene dye in one molecule on its absorption and electrochemical behavior was studied using UV spectroscopy and cyclic voltammetry.

Keywords: Isatin, Azo-dyes, Isoindigo, UV/VIS spectroscopy, Cyclic voltammetry.

Introduction

Due to their highly conjugated nature, azobenzene derivatives attracts undoubted experimental and theoretical interest [1][2]. These derivatives are used in wide variety of applications, such as photoswitches in biological systems [3], self-assembling amphiphilic photoresponsive polymers [4 – 6], and in coloration technologies [7] because of their conjugated structure. Azobenzenes are also utilized in holographic recording device creation [8], and as colorimetric sensing materials [9] and water-soluble pH-indicators [10]. These structures have also found applications in dye-sensitized solar cell creation [11], as well as to obtain light-absorbing liquid crystals [12]. At the same time, a significant dependence on the absorption, emission, and photochemical properties of azobenzenes on the nature of the ring substituents was established [1][13 – 15]. Recently, these compounds have been proposed as photopharmacological agents [16]. However, several studies of isoindigo derivatives allowed establishing their practically useful properties. High conjugation of two oxindole cycles results in the use of these molecules in various fields of organic electronics such as solar cells, field-effect transistors, and memory device creation [17 – 21]. In the present work, it was revealed that the nature of the substituent in aminoazobenzene also affects the direction of their *Mannich* reaction with isatin. Herein, we describe the peculiarities of the synthesis, spectroscopic, and electrochemical properties of isatin derivatives and one isoindigo-containing azobenzene moiety, which are the first examples in this field, to the best of our knowledge.

Results and Discussion

Target azobenzenes bearing isatin fragment **3a** or **3b** were synthesized by *Mannich* reaction of isatin **1** with 4-aminoazobenzenes **2a** or **2b** in the presence of aqueous HCHO. This reaction proceeds under mild conditions and allows obtaining compounds **3a** or **3b** in pure form with high yields in one step. It was found that the absence of an electron-donating substituent in the aromatic moiety of aminoazobenzene prevents aminomethylation of isatin and leads to the formation of only diaminomethane **3c** as a single reaction product. These data are in good accordance with our ongoing studies on the *Mannich* reaction on isatin scaffold [22] (*Scheme 1*). The structures of products **3a** – **3c** were established from their elemental and spectroscopic analyses including IR, ^{1}H-, and ^{13}C-NMR (NMR spectra of these compounds are shown in *Figs. S1 – S9* in the Supporting Information). Exemplifying on the deoxygenation reaction of azo-containing isatin **3a** with tris(diethylamino) phosphine, the ability of easy and atom-economy synthesis of highly conjugated azo-dyes containing isoindigo derivatives **4** was shown (*Scheme 2*). The presence of N=N bond does not affect dimerization of an intermediate carbene. The downfield shift of the H–C(4) signal in the ^{1}H-NMR spectrum from 7.47 ppm in starting isatin **3a** to 9.18 ppm in isoindigo **4** is observed. As a result of the C=C bond formation, the signal of the C(3) C-atom appears at 133.53 ppm. In addition, the retention of the N=N group is proved by the presence of a characteristic band at 1520 cm^{-1} in IR spectrum of this compound.

The electronic absorption spectra and cyclic voltammetry curves of compounds **3a** – **3c** and **4** are presented in

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Scheme 1. Synthesis of isatin derivatives **3a** – **3c**.

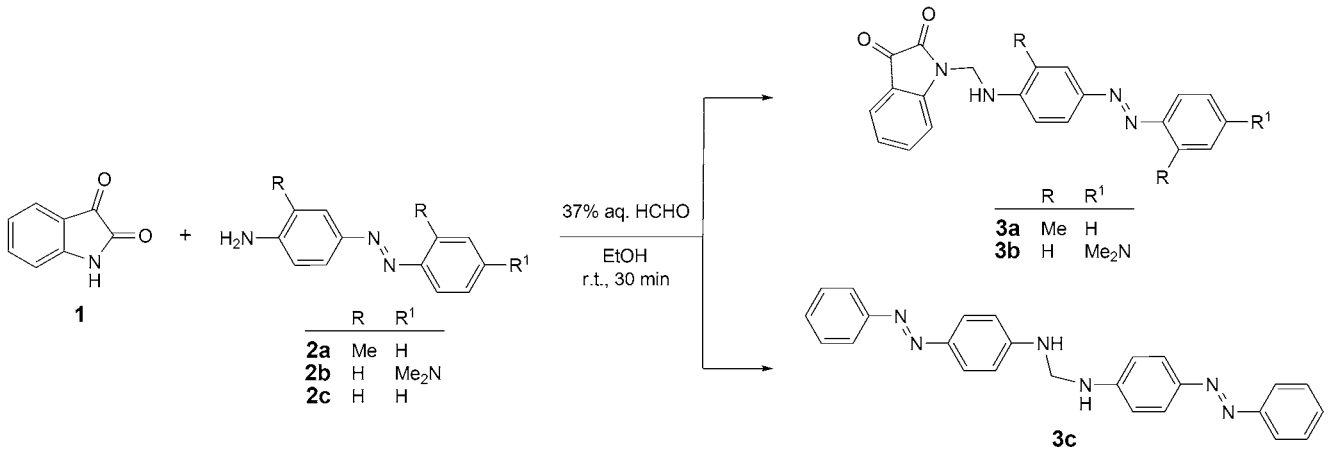

Fig. 1. Being recorded in EtOH at the concentration of 5.0×10^{-5} μM, the absorption spectra have shown two strong bands at 244 – 264 and 381 – 448 nm. By comparing the absorption spectra of initial aminoazobenzenes **2a** – **2c** and unsubstituted isatin **1** (*Fig. SI13*, SI), it can be assumed that far UV bands for **3a**, **3b**, and **4** are due to $\pi - \pi^*$ transitions of heterocyclic fragment. The bands at 380 – 450 nm can be assigned to symmetry-allowed $\pi - \pi^*$ transitions of central N=N group of whole azobenzene moiety. The presence of two azo-fragments in **3c** and **4** molecules did expectedly lead to the increase of the absorption intensity at 380 – 450 nm. Herewith, the replacement of two conjugated C=O groups in **3a** on indigoid fragment in **4** affects only the shape and position of the absorption band (from 244 to 264 nm). In general, it can be stated that the UV/VIS absorption of compounds **3a**, **3b**, and **4** is an additive combination of the absorption of the oxindole and azo moieties integrated in one molecule.

The electrochemical properties of the synthesized compounds **3a** – **3c** and **4** were investigated by cyclic voltammetry (CV; *Fig. 2*). In the cyclic voltammogram of **3a**, **3b**, and **4**, one chemically reversible reduction peak **C1**, having anodic reoxidation peak **A1**, is observed at the first potential scanning from 0.00 to −1.50 V (*Fig. SI16*, *Table S1*, SI). It should be noted that for **3c**, this peak is absent. Thus, it can be concluded that these peaks of reduction (**C1**) correspond to the reduction of the oxindole fragment in the molecule. Moreover, as can be seen from the experimental data, the reduction of **4** proceeds at less negative potentials than compounds **3a** and **3b** due to lower electron density on the isoindigo core. At the anodic potentials, a peaks of oxidation **A2** corresponding to the oxidation of the azo-fragment are present in the CV curves of all investigated compounds. It is interesting to note that in **3b**, the electron-donating effect of Me_2N group results in a strong shift of the oxidation peak **A2** to the cathodic values. Moreover, this peak is chemically reversible in **3b** due to the strong donating effect of Me_2N substituent, which can electrochemically stabilize the generated cationic form. However, in the cases of **3a**, **3c**, and **4**, the electrochemical oxidation proceeds irreversibly and leads to decomposition of the molecule even at the potential scanning up to the first anodic peak.

Conclusions

We have described the synthesis of novel azo-dyes containing isoindigo derivatives. The effect of the substituent in aminoazobenzene on the possibility of aminomethylation of isatin has been disclosed. An additive character of absorption in the UV/VIS region and the reversibility of reduction/oxidation of aminoazobenzenes bearing isatin or isoindigo fragments were established using UV/VIS spectroscopy and CV. Further studies to determine UV/VIS and electrochemical properties of both isatin and isoindigo containing different dyes, as well as any computational studies, are underway.

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Supplementary Material

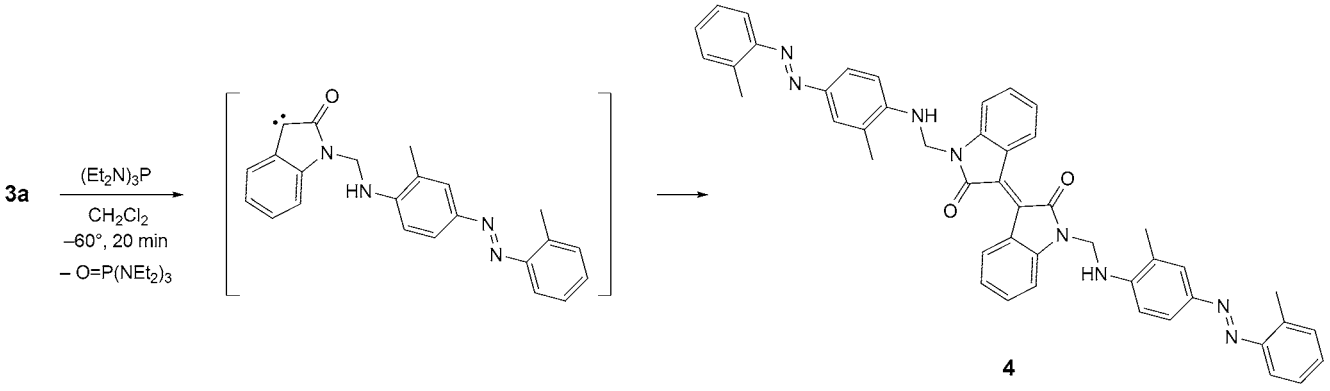
Supporting Information for this article is available on the WWW under http://dx.doi.org/10.1002/hlca.201600032.

Experimental Part

General

4-Amino-4′-(dimethylamino)azobenzene and 2-aminoazotoluene were obtained from *Acros Organics* (Geel, Belgium). 4-Aminoazobenzene was purchased from *TCI Europe N.V* (Zwijndrecht, Belgium). EtOH was distilled before use. UV/VIS Spectra: *Lambda 35* (*PerkinElmer*;

Scheme 2. Synthesis of isoindigo-bridged azo-dye **4** *via* deoxygenation reaction.



Waltham, Massachusetts, USA) UV/VIS spectrophotometer; λ_{max} (log ε) in nm. Cyclic voltammograms were recorded with a glassy carbon electrode (working surface 3.14 mm^2) in a thermostatically controlled (T = 20°C) three-electrode electrochemical cell under N_2 in the presence of Bu_4NBF_4 (0.1M). A Ag electrode $Ag/AgNO_3$ (0.01M soln. in MeCN) was used as a reference electrode and a Pt wire served as an auxiliary electrode. Curves were recorded at a constant potential scan rate of 50 mV/s at T = 20°C using a potentiostat/galvanostat model *PI-50-1* (*Bourevestnik Inc.*, St. Petersburg, USSR). IR Spectra: *Bruker Vector-22* (*Billerica*, Massachusetts, USA) FT-IR spectrophotometer in KBr pellets; $\tilde{\nu}$ in cm^{-1}. ^{1}H- and ^{13}C-NMR spectra: *Bruker AVANCE-400* spectrometer (400.1 MHz (^{1}H), 100.6 MHz (^{13}C)). Chemical shifts are reported in the δ [ppm] scale relative to the residual ^{1}H and ^{13}C signals of $CHCl_3$ or DMSO, J in Hz. Elemental analysis (C, H, and N): *EuroVector 2000 CHNS-3* (Milan, Italy) instrument; in %.

UV/VIS Spectra of isatin, azo-dyes, and compounds **3a** – **3c**, **4** were recorded at concentration 50 μM in EtOH at 20°C. CV Curves of **3a** – **3c** and **4** were recorded in DMF (5×10^{-3}M) in the presence of Bu_4NBF_4 (0.01M) without IR compensation at the first scan at constant potential scan rate 50 mV/s from 0.00 to −1.50 V then to anodic potentials and back to 0.00 V. Peak potentials are referred to $Ag/AgNO_3$ (0.01M in MeCN) reference electrode.

General Procedure for the Reactions of Isatin (**1**) *with Azobenzenes* (**2a** – **2c**). To a mixture of isatin (0.2 mmol) and corresponding azobenzene (0.2 mmol) in abs. EtOH (20 ml) at 20°C, HCHO (37% aq. soln., 0.2 mmol) was added dropwise under constant vigorous stirring. After 1 h, precipitated products **3a** – **3c** that formed were filtered off, washed with cold EtOH, and dried *in vacuo* (12 Torr).

1-[({2-Methyl-4-[(*E*)-(2-methylphenyl)diazenyl]phenyl}amino)methyl]-1*H*-indole-2,3-dione (**3a**). Yield: 98%. Orange powder. M.p. 210 °C. IR: 3441 (N–H), 1729 (C=O), 1607 (C=C), 1522 (N=N), 1320 (C–N). ^{1}H-NMR ((D$_6$)DMSO): 7.71 – 7.70 (*m*, 2 H); 7.65 (*dd*, *J* = 7.5, 2.3, 1 H); 7.62 (br. *s*, 1 H); 7.57 (*d*, *J* = 7.2, 1 H); 7.47 (*dd*, *J* = 7.9, 1.0, 1 H); 7.36 – 7.30 (*m*, 2 H); 7.27 – 7.23 (*m*, 1 H); 7.14 – 7.18 (*m*, 1 H); 6.96 (*d*, *J* = 8.7, 1 H); .76 (*t*, *J* = 6.0, 1 H); 5.26 (*d*, *J* = 6.0, CH_2); 2.60 (*s*, Me), 2.22 (*s*, Me). ^{13}C-NMR ((D$_6$)DMSO): 183.2; 158.0; 150.2; 150.1; 146.9; 144.3; 138.0; 136.2; 131.1; 129.7; 126.4; 124.4; 124.2;

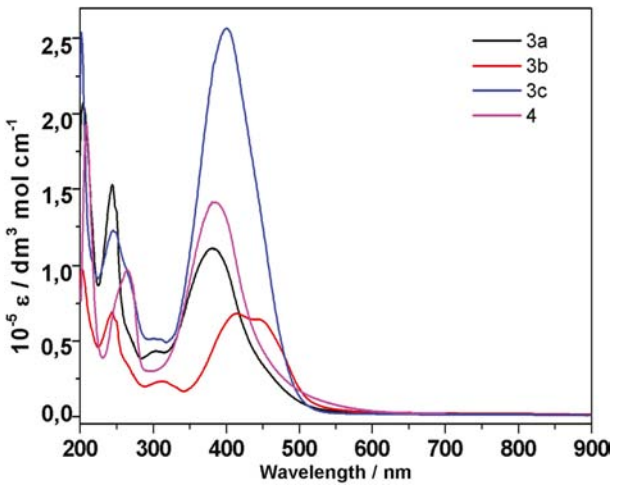


Fig. 1. UV/VIS Absorption spectra of compounds **3a** – **3c** and **4**.

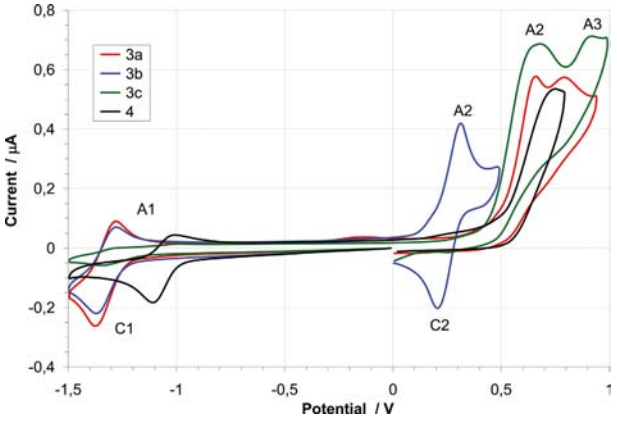


Fig. 2. Cyclic voltammetry curves of compounds **3a** – **3c** and **4**.

123.7; 123.5; 122.6; 117.6; 112.1; 109.7; 49.2; 17.8; 17.1. Anal. calc. for $C_{23}H_{20}N_4O_2$ (384.43): C 71.86, H 5.24, N 14.57; found: C 71.59, H 5.09, N 14.37.

1-{[(4-{(*E*)-[4-(Dimethylamino)phenyl]diazenyl}phenyl) amino]methyl}-1*H*-indole-2,3-dione (**3b**). Yield 96%. Red powder. M.p. 212 °C. IR: 3359 (N–H), 1743 (C=O), 1726 (C=O), 1600 (C=C), 1518 (N=N), 1323 (C–N). ^{1}H-NMR ((D$_6$)DMSO): 7.73 – 7.68 (*m*, 1 H); 7.66 (*d*, *J* = 9.1, 2 H); 7.62 (*d*, *J* = 8.8, 2 H); 7.56 (*d*, *J* = 7.4, 1 H); 7.48 (*d*, *J* = 8.0, 1 H); 7.33 (*t*, *J* = 6.5, 1 H); 7.18 – 7.15 (*m*, 1 H); 6.85 (*d*, *J* = 8.9, 2 H); 6.78 (*d*, *J* = 9.2, 2 H); 5.17 (*d*, *J* = 6.5, CH$_2$), 3.01 (*s*, 2 Me). ^{13}C-NMR ((D$_6$)DMSO): 183.4; 158.0; 151.6; 150.1; 147.7; 144.5; 142.8; 138.0; 124.5; 123.7 (2 C); 123.6; 117.6; 112.5; 111.9; 111.6; 49.1; 39.6. Anal. calc. for $C_{23}H_{21}N_5O_2$ (399.45): C 69.16, H 5.30, N 17.53; found: C 69.05, H 5.18, N 17.37.

***N*,*N*′-Bis{4-[(*E*)-phenyldiazenyl]phenyl}methanediamine** (**3c**). Yield 97%. Yellow solid. M.p. 155 °C. IR: 3379 (N–H), 1598 (C=C), 1511 (N=N), 1334 (C–N). ^{1}H-NMR ((D$_6$) DMSO): 7.78 – 7.74 (*m*, 4 H); 7.54 – 7.50 (*dd*, *J* = 7.9, 7.3, 2 H); 7.44 (*d*, *J* = 7.3, 1 H); 7.41 (*t*, *J* = 5.8, 1 H, NH); 6.88 (*d*, *J* = 8.9, 2 H); 4.69 (*t*, *J* = 5.8, CH$_2$). ^{13}C-NMR ((D$_6$)DMSO): 152.4; 150.8; 143.4; 129.6; 129.1; 124.8; 121.7; 112.3; 51.53. Anal. calc. for $C_{25}H_{22}N_6$ (406.48): C 73.87, H 5.46, N 20.67; found: C 73.65, H 5.38, N 20.49.

Synthesis of **(3*E*)-3-{1,2-Dihydro-1-[({2-methyl-4-[(*E*)-2-(2-methylphenyl)diazenyl]phenyl}amino)methyl]-2-oxo-3*H*-indol-3-ylidene}-1,3-dihydro-1-[({2-methyl-4-[(*E*)-2-(2-methylphenyl)diazenyl]phenyl}amino)methyl]-2*H*-indol-2-one** (**4**). To a soln. of compound **3a** (0.7 g, 1.8 mmol) in CH_2Cl_2 (15 ml) under bubbling of Ar at −60 °C, tris(diethylamino)phosphine (0.52 ml, 1.8 mol) was slowly added dropwise followed by spontaneous warming to r.t. The solvent was rotary evaporated and a residue was grinded in Et$_2$O/hexane (1:1) mixture. The precipitate that formed was filtered off and dried *in vacuo* (12 Torr). Yield 92%. Purple solid. M.p. 208 °C. IR: 3458 (N–H), 2927 (C–H), 1697 (C=O), 1603 (C=C), 1520 (N=N), 1329 (C–N). ^{1}H-NMR ($CDCl_3$): 9.18 (*d*, *J* = 7.8, 1 H); 7.77 (*dd*, *J* = 8.8, 2.1, 1 H); 7.68 (br. *d*, *J* = 1.4, 1 H); 7.52 (*d*, *J* = 7.8, 1 H); 7.41 (*m*, 1 H); 7.27 – 7.26 (*m*, 3 H); 7.15 – 7.12 (*m*, 2 H); 7.01 (*d*, *J* = 7.8, 1 H); 5.40 (br. *s*, CH$_2$); 2.64 (*s*, Me); 2.23 (*s*, Me). ^{13}C-NMR ($CDCl_3$): 168.0; 151.1; 146.0; 145.8; 143.7; 137.0; 133.5; 132.7; 131.0; 130.1; 129.7; 126.3; 124.9; 124.0; 122.8; 121.8; 115.4; 110.7; 108.2; 49.8; 17.6; 17.5. Anal. calc. for $C_{46}H_{40}N_8O_2$ (736.86): C 74.98, H 5.47, N 15.21; found: C 74.79, H 5.29, N 15.02.

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