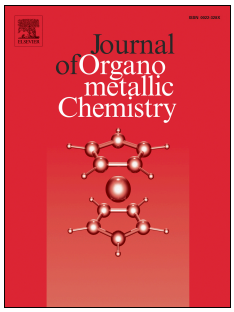
Accepted Manuscript



Synthesis and fluorescence of 3,4,6,7,8,9-hexaphenyl-1H-benzo[g]isochromen-1-one

Dmitry A. Loginov, Alexander P. Molotkov, Nikolay E. Shepel

PII: S0022-328X(17)30706-4

DOI: 10.1016/j.jorganchem.2017.12.021

Reference: JOM 20216

To appear in: *Journal of Organometallic Chemistry*

Received Date: 16 October 2017

Revised Date: 17 December 2017

Accepted Date: 18 December 2017

Please cite this article as: D.A. Loginov, A.P. Molotkov, N.E. Shepel, Synthesis and fluorescence of 3,4,6,7,8,9-hexaphenyl-1H-benzo[g]isochromen-1-one, *Journal of Organometallic Chemistry* (2018), doi: 10.1016/j.jorganchem.2017.12.021.

Synthesis and fluorescence of 3,4,6,7,8,9-hexaphenyl-1H-benzo[g]isochromen-1-one

Dmitry A. Loginov,* Alexander P. Molotkov, Nikolay E. Shepel

A. N. Nesmeyanov Institute of Organoelement Compounds, Russian Academy of Sciences, 28 ul. Vavilova, 119991 Moscow GSP-1, Russian Federation. Fax: +7 499 135 5085; e-mail: dloginov@ineos.ac.ru

Dedicated to the 85th anniversary of Prof. Irina P. Beletskaya in recognition of her contribution to the development of the metal-complex catalysis in Russia.

Abstract

Highly step- and atom-economic synthetic route to 3,4,6,7,8,9-hexaphenyl-1H-benzo[g]isochromen-1-one (**1**) based on the rhodium catalyzed reaction of terephthalic acid with diphenylacetylene was developed. The best catalytic system for this reaction is $[CpRhI_2]_n/Cu(OAc)_2$. Compound **1** shows fluorescent properties with a strong Stokes shift.

Keywords: C–H activation; Fluorescence; Isocoumarins; Metal complex catalysis; Rhodium

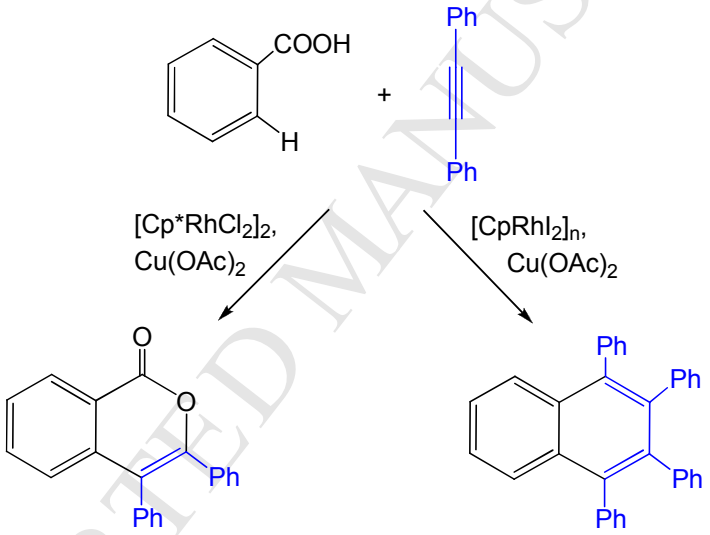
Benzocoumarins and heterocycle-fused coumarin derivatives have found a wide range of applications in the development of fluorescent probes and tags as well as bioactive materials.[1] In particular, π-extended coumarins are shown to provide stronger fluorescence than parent coumarins that is expressed by the longer emission wavelength and the higher quantum yield.[2] These advantageous features are caused by extended conjugation.

In contrast to coumarins, synthesis and fluorescent properties of isocoumarins are still poorly studied. Recently, Makabe with coworkers have developed the synthetic approach to natural isocoumarin compound, legioliulin, which is a fluorescent substance.[3] Legioliulin was synthesized using cyclic acylpalladation with the following chain elongation by Heck reaction. The 4-hydroxyidole fused isocoumarins, which are readily available from ninhydrin and enamines of 1,3-cyclohexanedione, also revealed fluorescent properties with a good quantum yield.[4]

In the last decade, construction of isocoumarin ring via the catalytic C–H activation of benzoic acids has gained traction.[5] The cobalt,[6] ruthenium,[7] rhodium[8] and iridium[9] complexes were

used as catalysts. Using this approach Ackermann with coworkers synthesized the linear π-extended isocoumarin (3,4-diethyl-1H-benzo[g]isochromen-1-one) from 2-naphthoic acid and diethylethyne in 31% yield.[10] Similar reaction of 2-naphthoic acid with isopropenyl acetate gave 3-methyl-1H-benzo[g]isochromen-1-one in 61% yield.[11] Herein, we report the direct synthesis of 3,4,6,7,8,9-hexaphenyl-1H-benzo[g]isochromen-1-one from terephthalic acid and diphenylacethylene as well as its fluorescent properties.

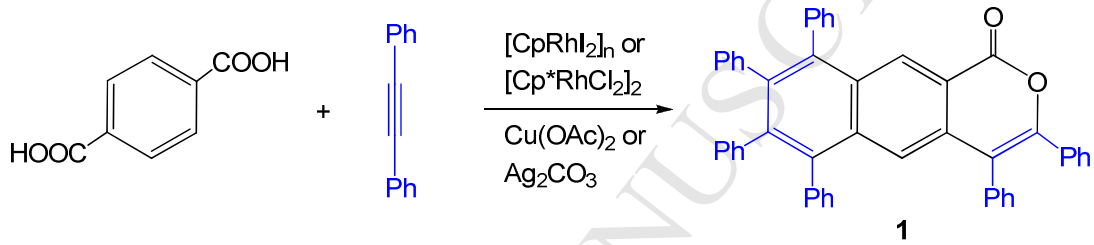
Selectivity of oxidative coupling of benzoic acids with alkynes catalyzed by (cyclopentadienyl)rhodium complexes have shown to strongly depend on substituents in the Cp ring. In particular, the pentamethyl derivative $[Cp^*RhCl_2]_2$ leads to presumably construction of isocoumarin moiety,[8b] whereas the parent unsubstituted complex $[CpRhI_2]_n$ selectively gives only naphthalenes (Scheme 1).[8c]



Scheme 1. Rh-catalyzed coupling of benzoic acid with diphenylacethylene.

We found that both rhodium complexes catalyze reaction of terephthalic acid with diphenylacetylene giving 3,4,6,7,8,9-hexaphenyl-1H-benzo[g]isochromen-1-one (**1**) as a result of formation of the isocoumarin moiety from one carboxylic group and the benzene cycle from another one (Scheme 2, Table 1). $Cu(OAc)_2$ or Ag_2CO_3 were used as cocatalysts (necessary for the regeneration of the initial oxidation state of catalyst). In the case of the $[CpRhI_2]_n/Cu(OAc)_2$ catalytic system, the intermediate formation of 5,6,7,8-tetraphenyl-2-naphthoic acid was detected by mass-spectrometry of the reaction mixture (476.4 $[M]^+$), suggesting that the first stage is construction of the haphthalene moiety. Following annelation of the naphthoic acid formed with the

next molecule of diphenylacetylene gives the target product **1**. The $[CpRhI_2]_n/Cu(OAc)_2$ system was found to provide the best result among the tested combinations giving **1** in 31% yield (Entry 1). The turnover number (TON) is ca. 16. The use of Ag_2CO_3 as a cocatalyst (Entry 2) or $[Cp^*RhCl_2]_2$ as a catalyst (Entries 3 and 4) leads to decrease in yield twice. We considered that low yield of **1** is connected rather with possible side reactions than inactivation of catalyst. In particular, hexaphenylbenzene (534.4 $[M]^+$) was also isolated from this reaction as a side product in 24% yield. To best of our knowledge, the similar reaction with 4-octyne leads to 3,4,8,9-tetrapropylbenzo[1,2-c:4,5-c′]dipyran-1,6-dione as a result of formation of two isocoumarin moieties from both carboxylic groups of terephthalic acid.[12]



Scheme 2. Synthesis of 3,4,6,7,8,9-hexaphenyl-1H-benzo[g]isochromen-1-one (**1**).

Table 1. Catalyst screening in oxidative coupling of terephthalic acid with diphenylacetylene.[a]

Entry	Catalyst	Cocatalyst (mmol)	Yield of **1**, %
1	$[CpRhI_2]_n$	$Cu(OAc)_2 \cdot H_2O$ (1.12)	31
2	$[CpRhI_2]_n$	Ag_2CO_3 (0.56)	17
3	$[Cp^*RhCl_2]_2$	$Cu(OAc)_2 \cdot H_2O$ (1.12)	15
4	$[Cp^*RhCl_2]_2$	Ag_2CO_3 (0.56)	19

[a] Reaction conditions: [terephthalic acid]/[diphenylacetylene]/[catalyst] = 0.25:1.0:0.01 (in mmol, quantity of catalyst is given for monomeric species), in boiling o-xylene under argon.

Solution of **1** in CH_3CN demonstrates an intense absorption band with a maximum at 305 nm (ε_{305}=50354 $L \times mol^{-1} \times cm^{-1}$) and also has bands with low intensity at 264 nm (ε_{264}=35569 $L \times mol^{-1} \times cm^{-1}$), 350 nm ($\varepsilon_{350}$=16182 $L \times mol^{-1} \times cm^{-1}$), 400 nm ($\varepsilon_{400}$=3467 $L \times mol^{-1} \times cm^{-1}$) (Figures 1 and 2).

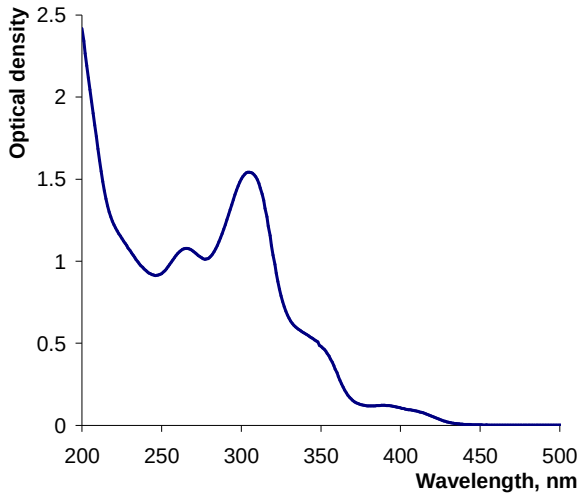


Figure 1. The absorption spectrum of **1** in CH_3CN, $C=3\cdot10^{-5}$ M, L=1 cm.

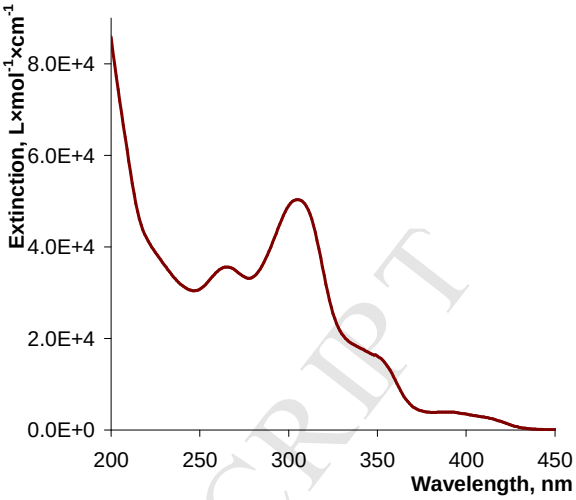
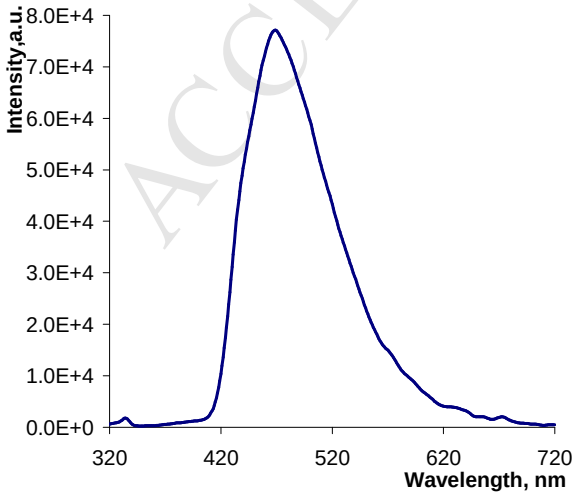


Figure 2. The extinction spectrum of **1**, [$L\times mol^{-1}\times cm^{-1}$], CH_3CN.

To obtain fluorescent spectrum, compound **1** was excited at λ_{ex} corresponding to position near the maximum of a peak with maximum absorption (λ_{ex}=305 nm). Emission band in air-saturated CH_3CN solution has its maximum at λ_{em}=470 nm (Figure 3) with shoulder at 430 nm. Fluorescence spectrum's shape and its maximum's position is not excitation wavelength depended (Figure 4). The shoulder at 400 nm in spectrum (line 1) appears due to the presence of a microimpurity in the sample. Stokes shifts for emission spectra (lines 1–4) of compound **1** (Figure 4) are 206, 165, 120 and 70 nm for excitation 264, 305, 350 and 400 nm, correspondingly. In accordance with extended conjugation in structure of **1**, those shifts are big enough in comparison to the Stokes shift of quinine sulphate (108 and 138 nm) in 1N H_2SO_4 solution (absorption bands 315 and 350 nm, fluorescence band: 453 nm). Noteworthy, the coumarine-6 Stokes shift is only about 50 nm.[13]



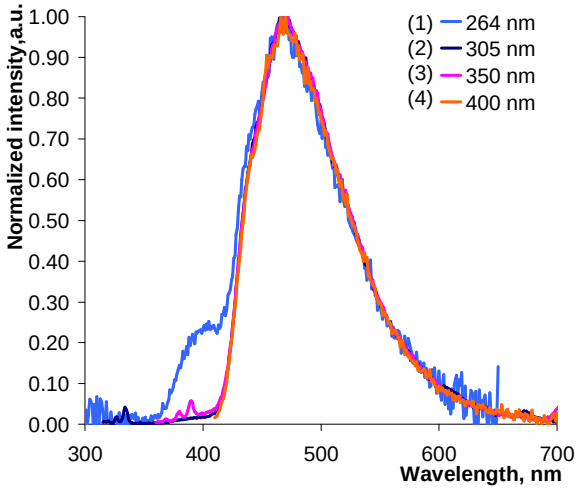


Figure 3. Fluorescence spectrum of **1** in CH_3CN, C=2·10^{-6} M, $\lambda_{ex.}$=305 nm, 20°C.

Figure 4. Fluorescence spectra dependence of **1** in CH_3CN, C=2·10^{-6} M; 20°C upon excitation wavelength. $\lambda_{ex.}$=264 nm – (1), 305 nm – (2) 350 nm – (3), 400 nm – (4).

The quantum yield of compound **1** in air-saturated CH_3CN is φ_{em}=7.3% upon excitation at $\lambda_{ex.}$= 305 nm and φ_{em}=6.4% for λ_{ex}= 350 nm. The difference in values can be explained by the error of the method.

Excitation spectrum (Figure 5) has analogous bands as in absorption spectrum (Figure 1), suggesting that **1** is individual compound. There are bands with maxima at 311, 350 nm and series of low intensity band near 400 nm.

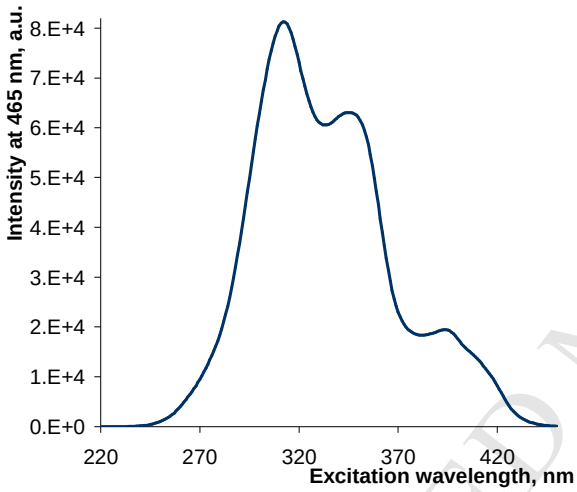


Figure 5. Excitation spectrum of **1**, C=2·10^{-6} M, CH_3CN. Emission wavelength λ_{em}=465 nm.

In conclusion, we successfully developed a catalytic step-economic protocol for synthesis of the linear π-extended isocoumarin derivative **1** directly from readily available reactants (terephthalic acid and diphenylacethylene). Compound **1** reveals strong Stokes shift (by 165 nm) of fluorescence emission.

Experimental

General: The catalytic reactions were carried out under an inert atmosphere in dry *o*-xylene. Catalysts $[CpRhI_2]_n$[14] and $[Cp^*RhCl_2]_2$[15] were prepared as described in the literature. ^{1}H and ^{13}C{^{1}H} NMR spectra (δ in ppm) were recorded on a Bruker Avance-400 spectrometer operating at 400.13 and 100.61 MHz, respectively.

Synthesis of 3,4,6,7,8,9-hexaphenyl-1H-benzo[g]isochromen-1-one (1): A mixture of terephthalic acid (42 mg, 0.25 mmol), diphenylacetylene (178 mg, 1.0 mmol), $[CpRhI_2]_2$ (4.2 mg, 0.01 mmol), $Cu(OAc)_2 \cdot H_2O$ (223 mg, 1.12 mmol) was refluxed in *o*-xylene (2 ml) with vigorous stirring for 6 h. The solvent was removed in vacuo, and the residue was extracted with diethyl ether. The extract was chromatographed on a silica column (1 × 15 cm). Unreacted diphenylacetylene was washed off with petroleum ether. Then the first yellow band was collected using mixture of petroleum ether/CH_2Cl_2 (2:1) as the eluent, giving hexaphenylbenzene (43 mg, 24%) after removal of solvents in vacuo. The second yellow band was collected using CH_2Cl_2 as the eluent. After the removal of the solvent in vacuo, the residue was washed with petroleum ether (3 × 4.5 ml) and dried in vacuo to give **1** as a white solid. Yield 50 mg (31%). EI-MS; m/z: 652.5 [M^+]. ^{1}H NMR ($CDCl_3$) δ: 8.86 (s, 1H), 7.39–7.40 (m, 3H), 7.20–7.33 (m, 12H), 7.02–7.13 (m, 6H), 6.86–6.91 (m, 10H). $^{13}C\{^1H\}$ NMR ($CDCl_3$) δ: 162.24, 149.00, 141.83, 139.95, 139.85, 139.75, 139.69, 138.54, 138.25, 138.13, 135.29, 134.19, 133.61, 132.93, 131.05, 130.99, 130.79, 130.65, 130.68, 130.71, 129.07, 128.61, 128.54, 127.78, 127.66, 127.44, 127.29, 126.99, 126.59, 126.28, 125.59, 125.51, 124.33, 118.50, 116.88. Found (%): C, 90.28; H, 5.08. Calc. for $C_{49}H_{32}O_2$ (%): C, 90.16; H, 4.94.

Absorption and fluorescence spectroscopy: Spectroscopic grade acetonitrile (HPLC-S, Biosolve, #01200702) was used for recording of the absorption and fluorescence spectra. Stock solution of substance **1** with concentration 1×10^{-3} M was prepared using optically pure acetontrile as a solvent.

Electronic absorption spectrum was measured on a two-channel spectrophotometer Varian-Cary 300, fluorescence spectra were recorded on spectrofluorimeter FluoroLog-3-221 at 20±1°C in standard 1 cm quartz cell. The observed fluorescence was detected at a direct angle relative to the excitation beam. The fluorescence spectra were corrected for the nonuniformity of detector spectral sensitivity. Fluorescent quantum yield of sample was determined at 20±1°C in solutions of CH_3CN compared to quinine sulphate in 0.5M H_2SO_4 water solution as a standard (φ=0.55±0.03)[16]. The quantum yield was calculated from the equation[17]:

$$\varphi_i^{\mathrm{fl}} = \varphi_0^{\mathrm{fl}} \times \frac{(1-10^{-D_0}) \times S_i \times n_i^2}{(1-10^{-D_i}) \times S_0 \times n_0^2}$$

where φ_i^{fl} and φ_0^{fl} are the quantum yields of the test solution and the standard; D_i and D_0 are the absorptions of the test solution and the standard, S_i and S_0 are areas underneath the fluorescence spectrum curves for the test solution and the standard, n_i and n_0 are refraction factors of solvents of the test compound and the standard compound, respectively.

Acknowledgements

The work was financially supported by the Russian Science Foundation (Grant No. 17-73-30036).

References

[1] M. Tasior, D. Kim, S. Singha, M. Krzeszewski, K. H. Ahn, D. T. Gryko, J. Mater. Chem. C 3 (2015) 1421–1446, and references therein.

[2] a) C. Murata, T. Masuda, Y. Kamochi, K. Todoroki, H. Yoshida, H. Nohta, M. Yamaguchi, A. Takadate, Chem. Pharm. Bull. 53 (2005) 750–758; b) J. A. Key, S. Koh, Q. K. Timerghazin, A. Brown, C. W. Cairo, Dyes Pigm. 82 (2009) 196–203; c) I. Kim, D. Kim, S. Sambasivan, K. H. Ahn, Asian J. Org. Chem. 1 (2012) 60–64; d) D. Kim, Q. P. Xuan, H. Moon, Y. W. Jun, K. H. Ahn, Asian J. Org. Chem. 3 (2014) 1089–1096.

[3] M. Asai, Y. Hattori, H. Makabe, Tetrahedron Letters 57 (2016) 3942–3944.

[4] S. Pathak, D. Das, A. Kundu, S. Maity, N. Guchhait, A. Pramanik, RSC Adv. 5 (2015) 17308–17318.

[5] a) T. Satoh, M. Miura, Chem. Eur. J. 16 (2010) 11212–11222; b) G. Song, F. Wang, X. Li, Chem. Soc. Rev. 41 (2012) 3651–3678; c) F. W. Patureau, J. Wencel-Delord, F. Glorius, Aldrichimica Acta 45 (2012) 31–41; d) D. A. Loginov, V. E. Konoplev, J. Organomet. Chem., doi: 10.1016/j.jorganchem.2017.11.013.

[6] R. Mandal, B. Sundararaju, Org. Lett. 19 (2017) 2544−2547.

[7] a) L. Ackermann, J. Pospech, K. Graczyk, K. Rauch, Org. Lett. 14 (2012) 930–933; b) R. K. Chinnagolla, M. Jeganmohan, Chem. Commun. 48 (2012) 2030–2032; c) L. Ackermann, J. Pospech, H. K. Potukuchi, Org. Lett. 14 (2012) 2146–2149; d) S. Warratz, C. Kornhaass, A. Cajaraville, B. Niepötter, D. Stalke, L. Ackermann, Angew. Chem. Int. Ed. 54 (2015) 5513–5517.

[8] a) K. Ueura, T. Satoh, M. Miura, Org. Lett. 9 (2007) 1407–1409; b) K. Ueura, T. Satoh, M. Miura, J. Org. Chem. 72 (2007) 5362–5367; c) D. A. Loginov, A. O. Belova, A. R. Kudinov, Izv. Akad. Nauk, Ser. Khim. (2014) 983−986 [Russ. Chem. Bull. 63 (2014) 983−986 (Engl. Transl.)]; d) E. Kudo, Y. Shibata, M. Yamazaki, K. Masutomi, Y. Miyauchi, M. Fukui, H. Sugiyama, H. Uekusa, T. Satoh, M. Miura, K. Tanaka, Chem. Eur. J. 22 (2016) 14190–14194.

[9] a) D. A. Frasco, C. P. Lilly, P. D. Boyle, E. A. Ison, ACS Catal. 3 (2013) 2421−2429; b) D. A. Loginov, A. O. Belova, A. V. Vologzhanina, A. R. Kudinov, J. Organomet. Chem. 793 (2015) 232–240.

[10] M. Deponti, S. I. Kozhushkov, D. S. Yufit, L. Ackermann, Org. Biomol. Chem. 11 (2013) 142–148.

[11] M. Zhang, H.-J. Zhang, T. Han, W. Ruan, T.-B. Wen, J. Org. Chem. 80 (2015) 620–627.

[12] M. Shimizu, K. Hirano, T. Satoh, M. Miura, J. Org. Chem. 74 (2009) 3478–3483.

[13] U. S. Raikar, C. G. Renuka, Y. F. Nadaf, B. G. Mulimani, A. M. Karguppikar, M. K. Soudagar, Spectrochimica Acta Part A 65 (2006) 673–677.

[14] D. A. Loginov, M. M. Vinogradov, Z. A. Starikova, P. V. Petrovskii, A. R. Kudinov, Izv. Akad. Nauk, Ser. Khim. (2004) 1871−1874. [Russ. Chem. Bull. 53 (2004) 1949−1953 (Engl. Transl.)].

[15] C. White, A. Yates, P. M. Maitlis, Inorg. Synth. 29 (1992) 228–234.

[16] J. N. Demas "Measurement of Photon Yields" Optical Radiation Measurements, Academic Press, 1982, Vol. 3, p. 195.

17 S. P. Nighswander-Rempel, J. Riesz, J. Gilmore, P. Meredith, J. Chem. Phys. 123 (2005) 194901.

Highlights

- The linear π-extended isocoumarin was synthesized from readily available terephthalic acid and diphenylacethylene.
- Oxidative coupling of benzoic acids with alkynes was extended for terephthalic acid.
- The obtained isocoumarin reveals strong Stokes shift of fluorescence emission.