Tetrahedron 72 (2016) 7796–7804

Contents lists available at ScienceDirect

Tetrahedron

journal homepage: www.elsevier.com/locate/tet

Intra- vs inter-molecular electron transfer processes in C–N bond forming reactions. Photochemical, photophysical and theoretical study of 2′-halo-[1,1′-biphenyl]-2-amines

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ARTICLE INFO

Article history:
Received 30 June 2016
Received in revised form 12 August 2016
Accepted 16 August 2016
Available online 25 August 2016

Keywords:
Electron transfer
Photochemical
Arylation reaction
$S_{RN}1$
Radical anions

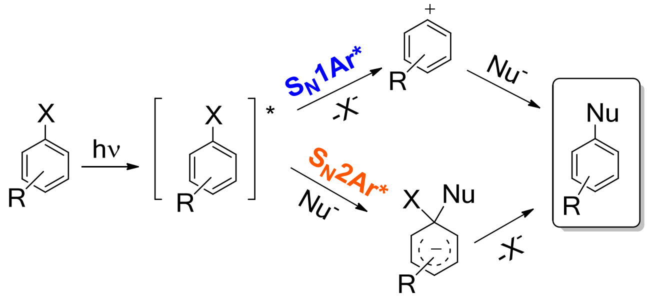
ABSTRACT

N-Arylation reaction is obtained when 2′-halo-[1,1′-biphenyl]-2-amines are irradiated in basic medium. On the basis of photochemical, photophysical experiments and computational studies we propose that carbazoles are formed by intermolecular electron transfer via $S_{RN}1$ mechanism.

In general, biphenylamines with an EDG like Me or OMe behave in the same way as H giving both, cyclized and reduced products. On the other hand, biphenylamines containing EWG like CN, COOEt or CF_3 gave only the corresponding carbazole. Herein, we report for the first time the chain length for the propagation cycle of intramolecular $S_{RN}1$ reactions and explain that differences in the distribution of products suggest differences regarding the overall mechanism involved.

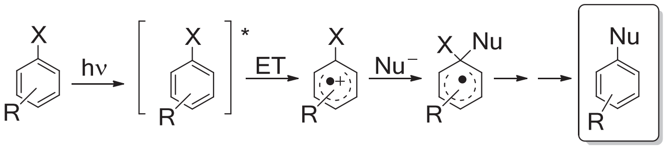
1. Introduction

Aromatic nucleophilic photosubstitution has proven to be a versatile tool in organic synthesis. The photosubstitution reactions between an aromatic substrate and a nucleophile could be achieved by several mechanisms and its classification is based on the key intermediates involved.[1] When the first step involves the excitation of the substrate in photosubstitution mechanisms, the substrate in its excited state could achieve product, for example, by: heterolysis and S_N1Ar^* via cation phenyl intermediate,[2] S_N2Ar^* (addition–elimination mechanisms)[3] (Scheme 1) or via electron transfer process (ET),[4] among others.



Scheme 1. Polar photosubstitution mechanisms.

We could classify the mechanisms involving ET processes in photo-oxidations (via radical cation intermediates, Scheme 2) or photo-reductions (via radical anion intermediates, Scheme 3). The oxidative ET processes are more common with electron-donating substituted aromatics in water or other ionic solvents (unless a good nucleofugal group is present). The resulting radical cation may react with a nucleophile and the resulting radical ends with rearomatization (Scheme 2).[5] A reductive ET commonly requires the presence of donors such as enolate ions, amines, arenes or alkenes. Mechanisms involving reductive ET processes include $S_N(ET)Ar^*$, radical–radical collapse, $S_{RN}1$ chain process[6] or other photochemical processes. The intramolecular version of reductive ET mechanisms was used for ring closure systems (Scheme 3).



Scheme 2. Oxidative electron transfer mechanism.

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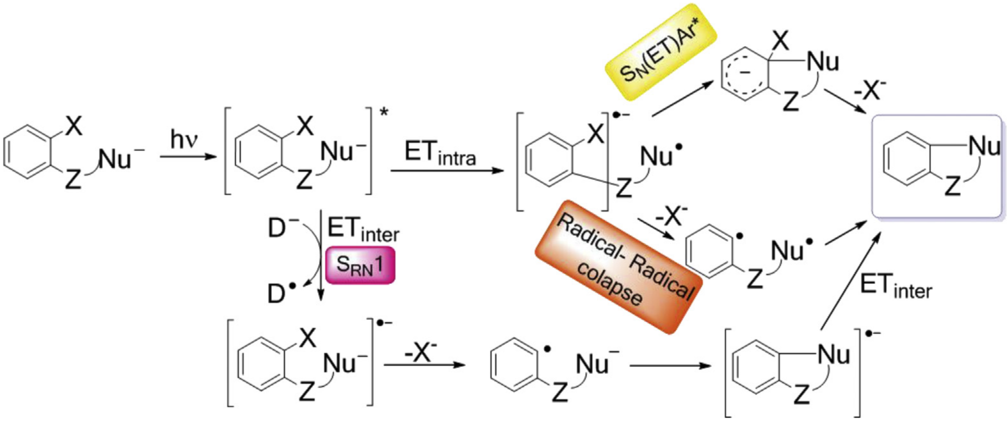
http://dx.doi.org/10.1016/j.tet.2016.08.051



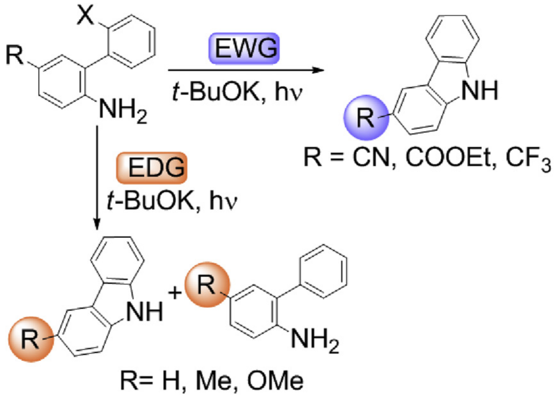
Scheme 3. Aromatic nucleophilic photosubstitution mechanisms by reductive electron transfer.

The reductive ET mechanisms have been proposed for the synthesis of several heterocycles systems. For example, Park *et al.* proposed an intramolecular S_N(ET)Ar* mechanism (Scheme 3) for the synthesis of 2-pyridinylbenzoxazole from *N*-(2-halophenyl) pyridinecarboxamide[7] and the synthesis of 2-(4-*R*-phenyl)-1,3-benzoxazole and 9-*R*-phenanthridin-6(5*H*)-one from 2′-chloro-4-*R*-benzaniline.[8] The same mechanism was proposed for the synthesis of benzoxazole[3,2-*b*]isoquinolin-11-one from tetrahydroisoquinoline-1,3-diones under basic media.[9] On the other hand, indolo benzoxazoles were prepared from *N*-(2-halophenyl)-indolo-carboxamides,[10] and substituted indazoles from (*Z*)-2-bromoacetophenone *N*-tosylhydrazones with a catalytic amount of *trans*-*N*,*N*′-dimethylcyclohexane-1,2-diamine[11] via radical-radical collapse mechanism (Scheme 3).

An $S_{RN}1$ synthetic strategy (Scheme 3) to obtain heterocyclic compounds has been recently applied to the synthesis of 1-phenyl-1-oxazolinoindan derivatives and their related compounds;[12] tetracyclic isoquinoline derivatives;[13] a series of substituted 9*H*-carbazoles[14,15] and carbolines,[16] pyrroles, indoles, and pyrazoles,[17] pyrido[1,2-*a*]benzimidazoles,[18] dibenzosultams from *N*-aryl-2-halobenzenesulfonamides by intramolecular C–C photoinduced arylation,[19] or by visible-light-promoted denitrogenative cyclization of 1,2,3,4-benzothiatriazine-1,1-dioxides,[20] in addition to other heterocycles.[21] However, studies of photochemical and photophysical properties still remain under script in intramolecular $S_{RN}1$ approach.

The varied panorama illustrates that different pathways could be possible and the actual path followed, as well as efficiency of the overall reaction, will depend on a host of factors such lifetime of the singlet or triplet excited state, their redox properties, chemical reactivity and nature of the nucleophile/electron donor, medium and so on. Developing a comprehensive demonstration of the mechanisms involved is not simple and in many cases computational data appear as a supporting and complementary tool.[22]

We recently reported the intramolecular C–N bond forming reactions of 2′-halo-[1,1′-biphenyl]-2-amines to synthesize different 9*H*-carbazoles (Scheme 4).[15] Even the $S_{RN}1$ reaction was proposed to be in play, a full mechanism description is here reported. In general, biphenylamines with an electron donating group (EDG) like Me or OMe behave in the same way as H giving both, cyclized and reduced products. On the other hand, biphenylamines containing electron-withdrawing groups (EWG) like CN, COOEt or CF_3 gave only the corresponding carbazole. These differences in the distribution of products suggest differences regarding the overall mechanism involved.



Scheme 4. Intramolecular C–N bond forming reaction and reduction of 2′-halo-[1,1′-biphenyl]-2-amines.

Our proposal is to investigate the mechanism of this photosubstitution from the study of experimental reaction conditions, photophysical properties (UV–vis, steady state fluorescence and time-resolved fluorescence), photochemical studies (the quantum yields measured) and computational data (M06-2X DFT functional and 6-311+G* basis set). Herein, we report for the first time the chain length for the propagation cycle of intramolecular $S_{RN}1$ reactions.

2. Results and discussion

The photostimulated reaction (45 min) of 2′-chloro-[1,1′-biphenyl]-2-amine **1a** in the presence of *t*-BuOK (2 equiv) as a base in DMSO afforded 9*H*-carbazol **2a** in 26% yield and [1,1′-biphenyl]-2-amine **3a** in 17% yield, with a ratio of cyclized versus reduced products of 1.5:1 (Table 1, entry 1). The reaction was completed after 180 min and the ratio between cyclic and reduced product went up to 4.4:1 (57% yield of **2a** and 13% yield of **3a**; entry 2). This reaction is completely suppressed in dark conditions, excluding a benzyne and other polar mechanisms (entry 3). The addition of 25 mol % of *m*-dinitrobenzene (*m*-DNB), a well-known electron acceptor, caused 46% of inhibition (14% yield of **2a**, entry 4). The same behavior was observed when 50 mol % of *m*-DNB was added (85% of inhibition, 4% yield of **2a**, entry 5). The reduced product followed the same tendency. Here, the inhibition was proportional to the amount of *m*-DNB used, showing that ET processes are involved in the formation of products **2a** and **3a** and a chain process could be involved for **2a**.