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Synthesis and Spectroscopic Study of Naphtholic and Phenolic Azo Dyes

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Authors' contributions

This work was carried out in collaboration between the authors. Author OOA designed the scheme, the protocol for synthetic pathway and wrote the first draft. Author OEA carried out the synthesis. Author AOA did the collation of the data and editing of the write-up. Authors AEO and WUA managed the analysis of the study and spectroscopic evaluation. All authors read and approved the final manuscript.

Research Article

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ABSTRACT

Azo dyes are extremely important in variety of industries for variety of technical purposes. Hence, a series of naphtholic azo dyes 1-9 were synthesized via diazotization of substituted aniline derivatives followed by azo coupling with 2-naphthol. In similar manner, diazotization followed by azo coupling with phenol afforded phenolic azo dyes 10-17 in excellent yields. The chemical structures of all synthesized compounds were confirmed using analytical data and spectroscopic technique which include Uv-visible, IR, Mass spectra, ^{1}H- and ^{13}C-NMR.

Keywords: Azo dye; coupling reaction; diazotization; spectral study; naphthol.

1. INTRODUCTION

Over the years, azo compounds constitute one of the largest classes of industrially synthesized organic compounds, potent in drug and cosmetics [1,2]. Of all classes of

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dyestuffs, azo dyes have attained the widest range of usage because variations in chemical structures are readily achievable and methods of application are generally not complex [3]. In fact, 60-70% of all dyes stuff in use and production fall in this group [4]. According to a statistical data survey, one million tons of such dyes are produced annually worldwide [5,6]. It can simply be defined as any class of artificial dyes that contains the azo group (-N=N-). When describing a dye molecule, nucleophiles are referred to as *auxochromes*, while the aromatic groups are called *chromophores*. Together, the dye molecule is often described as a *chromogen* [7]. Synthesis of most azo dyes involves diazotization of a primary aromatic amine, followed by coupling with one or more nucleophiles. Amino-and hydroxy-groups are commonly used coupling components [8].

The traditional application field of the synthetic azo dyes still remains the textile industry, and the finishing of fibrous materials. The emergence of diverse classes of synthetic dyes including azo dyes occurred due to constant effort to find specific dye for application in diverse materials of industrial importance which include, but not limited to textile fabric [9], leather, aluminium sheet, ink-jet printer, paper, electro-optical devices [10]. They are among the compounds which are suitable for biocidal treatment of textile materials due to the fact that some of them exhibit biological activity, as a result of the presence of some bioactive templates that form a definite type of bonding with the molecules of the fibrous material [11]. Azo compounds are known for their medicinal importance and are well recognized for their use as antineoplastics [12], antidiabetics [13], antiseptics [14], antibacterial [15,16], antitumor [17]. They are known to be involved in a number of biological reactions such as inhibition of DNA, RNA and protein synthesis, carcinogenesis and nitrogen fixation [18-19].

Furthermore, azo dye compounds also have a lot of applications in industry and photodynamic therapy as well as photosensitive species in photographic or electro photographic systems and are dominant organic photoconductive materials [17,20]. Azo compounds are important structures in the medicinal and pharmaceutical fields [21] and it has been suggested that the azoimine linkage might be responsible for the biological activities displayed by some reported Schiff bases [22,23]. In addition, Evans blue and Congo Red are azo dyes being studied as HIV inhibitors of viral replications. This effect is believed to be caused by binding of azo dyes to both protease and reverse transcriptase of this virus [24]. The existence of an azo moiety in different types of compounds has caused them to show antibacterial and pesticidal activities. In the recent times, exploration of azo dye as antimicrobial agents has received considerable attention [20,22,25,26]. In the light of variety of diverse applications of azo dyes, it is conceivable to develop synthesis of such naphtholic and phenolic azo dyes and their derivatives in order to unfold many more potentials of such compounds.

2. MATERIALS AND METHODS

2.1 General Conditions

All chemical compounds were obtained from Sigma-Aldrich Chemical, but were made available by the Department of Chemistry, Covenant University. Solvents used were of analytical grade and, when necessary, were purified and dried by standard methods. Melting points were determined in open capillary tubes on a Stuart melting point apparatus and were uncorrected. The IR spectra were run in the single beam Nicolet IR 100 (Fourier-Transform); while UV of all the samples were run in methanol using UV-Genesys spectrophotometer. Their mass spectral data were obtained from waters GCT premier spectrometer. The ^{1}H-

NMR and ^{13}C-NMR spectra were recorded in DMSO-d_6 using NMR Bruker DPX 400 spectrophotometer operating at 400 MHz and 100 MHz respectively. TMS was used as internal standard with the deuterium signal of the solvent as the lock and chemical shifts δ recorded in ppm. The elemental analysis (C, H, N) of the compounds were performed using Flash EA 1112 elemental analyzer while the pH was monitored using Portable pH Meter Model PHB4. Compounds were routinely checked by TLC on silica gel G plates using three different eluting solvents depending on the polarity disparity. The solvent systems are petroleum ether: chloroform (9:1, v/v), petroleum ether: chloroform (6:4, v/v) and chloroform: methanol (9:1, v/v) Also, the developed plates were visualized using UV lamp for the presence of spots and R_f values were duly calculated.

2.2 General Procedure for the Synthesis of Naphtholic Azo Dyes

Concentrated hydrochloric acid (2.5 mL) was added to a solution of corresponding substituted aniline (10.7 mmol) in water (5 mL) in a beaker, swirled thoroughly and the solution was kept in an ice bath prior to use. In another beaker, $NaNO_2$ (1.0 g, 11.8 mmol) was dissolved in water (5 mL) and kept in an ice bath; add this solution drop-wise to the aniline solution with continuous stirring for about 5 minutes within a carefully controlled temperature range (0-5ºC) to generate diazonium salt. The azo coupling was then achieved by adding a solution of 2-naphthol (1.0 g, 6.9 mmol) in 10% NaOH (10 mL) to the diazonium solution slowly at 0-5ºC with continuous stirring for 5 minutes. The resulting solution formed a coloured precipitate which was filtered by suction and purified by column chromatography using three different eluting solvents {Petroleum ether: Chloroform (9:1, v/v) for 1,3-7; Petroleum ether: Chloroform (9:1, v/v) for 2, 9 and Chloroform: Methanol (9:1, v/v)} to give coloured crystalline solid 1-9.

2.2.1 1-(Phenyldiazenyl) naphthalene-2-ol, 1

Azo coupling afforded a red crystal, 1 (1.7 g, 98.84%). λ_{max} in nm (log ε): 484 (4.38), 424 (4.20), 226 (4.73). IR (KBr, cm^{-1}) ν_{max}: 3402 (OH), 1618 (C=C aromatic), 750 (Ar-H). ^{1}H-NMR (400 MHz, DMSO-d_6) δ: 8.56-8.54 (d, *J* = 8 Hz, 1H, Ar-H), 8.24-8.22 (d, *J* = 8 Hz, 1H, Ar-H), 8.07-8.05 (d, *J* = 8 Hz, 1H, Ar-H), 7.88-7.82 (t, *J* = 9.8 Hz, 1H, Ar-H), 7.74-7.70 (t, *J* = 8 Hz, 2H, Ar-H), 7.65-7.63 (d, *J* = 8 Hz, 2H, Ar-H), 7.51-7.47 (t, *J* = 7.6 Hz, 1H, Ar-H), 7.30-7.27 (t, *J* = 7.4 Hz, 1H, Ar-H), 6.79-6.77 (d, *J* = 8 Hz, 1H, Ar-H). ^{13}C-NMR (100 MHz, DMSO-d_6) δ: 130.7, 130.4, 130.4, 128.4, 128.4, 128.1, 127.5, 126.6, 125.7, 124.3, 123.8, 121.2, 121.2, 119.9, 119.9, 117.4 ppm.

2.2.2 1-((3-nitrophenyl)diazenyl)naphthalen-2-ol, 2

Azo coupling afforded a red crystal, 2 (2.0 g, 98.52%). λ_{max} in nm (log ε): 472 (3.85), 301 (3.68), 223 (4.30). IR (KBr, cm^{-1}) ν_{max}: 3320 (OH), 1614 (C=C aromatic), 1532 (asym. NO_2), 1340 (sym. NO_2), 724 (Ar-H). ^{1}H-NMR (400 MHz, DMSO-d_6) δ: 8.53 (s, 1H, Ar-H), 8.54-8.52 (d, *J* = 8 Hz, 1H, Ar-H), 8.22-8.20 (d, *J* = 8 Hz, 1H, Ar-H), 8.06-8.04 (d, *J* = 8 Hz, 2H, Ar-H), 7.88-7.84 (t, *J* = 9.8 Hz, 1H, Ar-H), 7.74-7.70 (t, *J* = 8 Hz, 2H, Ar-H), 7.65-7.63 (d, *J* = 8 Hz, 1H, Ar-H), 7.51-7.47 (t, *J* = 7.6 Hz, 1H, Ar-H), 7.30-7.27 (t, *J* = 7.4 Hz, 1H, Ar-H), 6.77-6.75 (d, *J* = 8 Hz, 1H, Ar-H). ^{13}C-NMR (100 MHz, DMSO-d_6) δ: 134.5, 130.7, 130.4, 130.4, 128.4, 128.4, 128.1, 127.5, 126.6, 125.7, 124.3, 123.7, 121.1, 121.1, 119.9, 119.9 ppm. MS-EI: m/z (rel. %): 295.10 (M + 2, 3%), 294.09 (20%), 293.07 (99%), 292.07 (24%), 171.05 (37%), 143 (100%), 115.04 (84%), 114.04 (10%), 76.02 (4%).

2.2.3 1-((4-Bromophenyl)diazenyl)naphthalen-2-ol, 3

Azo coupling afforded a red crystal, 3 (2.3 g, 99.56%). λ_{max} in nm (log ε): 476 (3.95), 428 (3.88), 224 (4.63). IR (KBr, cm^{-1}) ν_{max}: 3405 (OH), 1619 (C=C aromatic), 512 (C-Br), 723 (Ar-H). ^{1}H-NMR (400 MHz, DMSO-d_6) δ: 8.56-8.54 (d, *J* = 8 Hz, 1H, Ar-H), 8.10 (d, *J* = 1.7 Hz, 1H, Ar-H), 7.97-7.95 (d, *J* = 9.4 Hz, 1H, Ar-H), 7.80-7.78 (d, *J* = 8 Hz, 2H, Ar-H), 7.64-7.60 (t, *J* = 8 Hz, 2H, Ar-H), 7.51-7.49 (d, *J* = 10 Hz, 1H, Ar-H), 7.48-7.46 (d, *J* = 10 Hz, 1H, Ar-H), 6.96-6.94 (d, *J* = 9.4 Hz, 1H, Ar-H). ^{13}C-NMR (100 MHz, DMSO-d_6) δ: 148.7, 148.7, 148.6, 138.3, 134.5, 132.0, 132.0, 130.5, 130.4, 130.4, 128.4, 128.4, 128.1, 127.5, 126.6, 125.7 ppm.

2.2.4 1-((4-Chlorophenyl)diazenyl)naphthalen-2-ol, 4

Azo coupling afforded a red crystal, 4 (1.5 g, 76.53%). λ_{max} in nm (log ε): 478 (3.92), 370 (3.78), 316 (3.63), 226 (4.35). IR (KBr, cm^{-1}) ν_{max}: 3320 (OH), 1621(C=C aromatic), 826 (C-Cl), 723 (Ar-H). ^{1}H-NMR (400 MHz, DMSO-d_6) δ: 8.56-8.54 (d, *J* = 8 Hz, 1H, Ar-H), 8.10-8.07 (d, *J* = 12 Hz, 1H, Ar-H), 7.97-7.95 (d, *J* = 9.5 Hz, 1H, Ar-H), 7.81-7.79 (d, *J* = 8 Hz, 2H, Ar-H), 7.64-7.60 (t, *J* = 8 Hz, 2H, Ar-H), 7.51-7.49 (d, *J* = 10 Hz, 1H, Ar-H), 7.48-7.44 (d, *J* = 10 Hz, 1H, Ar-H), 6.96-6.94 (d, *J* = 9.5 Hz, 1H, Ar-H). ^{13}C-NMR (100 MHz, DMSO-d_6) δ: 149.0, 148.6, 148.6, 138.4, 134.5, 132.1, 132.1, 130.7, 130.4, 130.4, 128.5, 128.5, 128.1, 127.5, 126.6, 125.7 ppm.

2.2.5 1-((2-Bromo-4-methylphenyl)diazenyl)naphthalen-2-ol, 5

Azo coupling afforded a deep red crystal, 5 (2.2 g, 96.49%). λ_{max} in nm (log ε): 484 (4.33), 310 (3.94), 262 (4.21), 223 (4.97). IR (KBr, cm^{-1}) ν_{max}: 3440 (OH), 1600 (C=C aromatic), 723 (Ar-H), 513 (C-Br). ^{1}H-NMR (400 MHz, DMSO-d_6) δ: 8.54-8.52 (d, *J* = 8 Hz, 1H, Ar-H), 8.09 (s, 1H, Ar-H), 7.98-7.95 (d, *J* = 9.6 Hz, 1H, Ar-H), 7.78-7.76 (d, *J* = 8 Hz, 2H, Ar-H), 7.63-7.61 (d, *J* = 8 Hz, 1H, Ar-H), 7.54-7.51 (m, 2H, Ar-H), 6.99-6.96 (d, *J* = 9.6 Hz, 1H, Ar-H), 2.39 (s, 3H, Ar-H). ^{13}C-NMR (100 MHz, DMSO-d_6) δ: 167.2, 167.2, 145.4, 139.6, 137.4, 132.6, 132.3, 132.3, 128.8, 125.5, 124.8, 123.5, 122.2, 121.1, 118.2, 118.2, 22.4 ppm.

2.2.6 1-((3-bromo-4-methylphenyl)diazenyl)naphthalen-2-ol, 6

Azo coupling afforded a red crystal, 6 (2.0 g, 87.72%). λ_{max} in nm (log ε): 478 (4.14), 310 (3.74), 223 (4.63). IR (KBr, cm^{-1}) ν_{max}: 3410 (OH), 1617 (C=C aromatic), 723 (Ar-H), 513 (C-Br). ^{1}H-NMR (400 MHz, DMSO-d_6) δ: 8.56-8.54 (d, *J* = 8 Hz, 1H, Ar-H), 8.10 (s, 1H, Ar-H), 7.96-7.94 (d, *J* = 9.3 Hz, 1H, Ar-H), 7.80-7.78 (d, *J* = 8 Hz, 2H, Ar-H), 7.62-7.60 (d, *J* = 8 Hz, 1H, Ar-H), 7.51-7.44 (m, 2H, Ar-H), 6.96-6.94 (d, *J* = 9.3 Hz, 1H, Ar-H), 2.39 (s, 3H, Ar-H). ^{13}C-NMR (100 MHz, DMSO-d_6) δ: 166.9, 166.9, 139.7, 137.2, 132.1, 132.1, 129.9, 129.1, 127.9, 125.6, 125.0, 123.4 122.2, 121.2, 118.6, 118.6, 22.4 ppm. MS-EI: m/z (rel. %): 342.02 (M + 2, 65%), 340.02 (M^+, 70%), 261.10 (3%), 171.05 (21%), 143.04 (100%), 115.05 (55%), 89.03 (10%), 77.03 (Ph^+, 5%).

2.2.7 1-((4-Bromo-2-methylphenyl)diazenyl)naphthalen-2-ol, 7

Azo coupling afforded a red crystal, 7 (2.2 g, 99.12%). λ_{max} in nm (log ε): 488 (4.37), 314 (4.14), 260 (4.35), 224 (5.04). IR (KBr, cm^{-1}) ν_{max}: 3448 (OH), 1627 (C=C aromatic), 512 (C-Br), 723 (Ar-H). ^{1}H-NMR (400 MHz, DMSO-d_6) δ: 8.06-8.04 (d, *J* = 8 Hz, 2H, Ar-H), 8.02-8.00 (d, *J* = 7.5 Hz, 1H, Ar-H), 7.80-7.77 (d, *J* = 9.5 Hz, 2H, Ar-H), 7.58 (s, 1H, Ar-H), 7.55-7.53 (t, *J* = 8 Hz, 1H, Ar-H), 7.46-7.44 (t, *J* = 8 Hz, 1H, Ar-H), 7.19-7.17 (d, *J* = 7.5 Hz, 1H,

Ar-H), 2.35 (s, 3H, CH_3-Ar). ^{13}C-NMR (100 MHz, DMSO-d_6) δ: 156.2, 151.0, 145.3, 134.1, 134.1, 129.5, 129.3, 128.9, 128.0, 127.7, 126.8, 126.0, 125.5, 125.5, 125.1, 123.7, 17.9 ppm.

2.2.8 1-((4-Aminophenyl)diazenyl)naphthalen-2-ol, 8

Azo coupling afforded a black crystal, 8 (1.8 g, 97.83%). λ_{max} in nm (log ε): 496 (3.36), 316 (3.15), 271 (3.92), 223 (5.05). IR (KBr, cm^{-1}) ν_{max}: 3402 (OH), 3110 (NH_2), 1628 (C=C aromatic), 723 (Ar-H). ^{1}H-NMR (400 MHz, DMSO-d_6) δ: 8.15-8.13 (d, *J* = 8.5 Hz, 2H, Ar-H), 8.07-8.05 (d, *J* = 8 Hz, 2H, Ar-H), 7.99-7.97 (d, *J* = 7.8 Hz, 1H, Ar-H), 7.56-7.54 (t, *J* = 8 Hz, 1H, Ar-H), 7.47-7.45 (t, *J* = 8 Hz, 1H, Ar-H), 7.18-7.16 (d, *J* = 7.8 Hz, 1H, Ar-H), 6.87-6.89 (d, *J* = 8.5 Hz, 2H, Ar-H), 6.39 (s, 2H, NH_2-Ar).

2.2.9 1-((2-Aminophenyl)diazenyl)naphthalen-2-ol, 9

Azo coupling afforded a grey crystal, 9 (1.5 g, 81.97%). λ_{max} in nm (log ε): 329 (4.29), 272 (4.86), 227 (5.35). IR (KBr, cm^{-1}) ν_{max}: 3447 (OH), 3180 (NH_2), 1630 (C=C aromatic), 723 (Ar-H). ^{1}H-NMR (400 MHz, DMSO-d_6) δ: 8.19-8.17 (d, *J* = 8 Hz, 1H, Ar-H), 8.12-8.10 (d, *J* = 7.8 Hz, 1H, Ar-H), 8.04-8.02 (d, *J* = 8.7 Hz, 1H, Ar-H), 7.78-7.76 (d, *J* = 9.5 Hz, 1H, Ar-H), 7.56-7.54 (t, *J* = 8 Hz, 1H, Ar-H), 7.47-7.45 (t, *J* = 7.8 Hz, 1H, Ar-H), 7.41-7.38 (d, *J* = 12 Hz, 1H, Ar-H), 7.21-7.19 (d, *J* = 8.7 Hz, 1H, Ar-H), 7.04-7.02 (t, *J* = 9.5 Hz, 1H, Ar-H), 6.86-6.83 (d, *J* = 12 Hz, 1H, Ar-H), 6.52 (s, 2H, NH_2-Ar).

2.3 General Procedure for the Synthesis of Phenolic Azo Dyes

To a mixture of substituted aniline (10.7 mmol) and water (5 mL) was added conc. hydrochloric acid (2.5 mL) prior to use. $NaNO_2$ (1.0 g, 11.8 mmol) was dissolved in water (5 mL) and kept in an ice bath; this solution was added drop-wise to the aniline solution at 0-5 ºC with continuous stirring for about 5 minutes. In the coupling reaction, a solution of phenol (1 mL) in 10% NaOH (10 mL) was added slowly to the diazonium solution obtained above, with continuous stirring for 5 minutes (0-5ºC). The resulting solution formed a precipitate which was filtered by suction and purified by column chromatography using various eluting solvents Petroleum ether: Chloroform (6:4, v/v) for 10, 11; Petroleum ether: Chloroform (9:1, v/v) for 12-16; Chloroform: Methanol (9:1, v/v) for 17} to give coloured crystalline solid 10-17.

2.3.1 4-(Phenyldiazenyl)phenol, 10

Azo coupling afforded a black crystal, 10 (2.5 g, 87.1%). λ_{max} in nm (log ε): 344 (4.81), 230 (4.56). IR (KBr, cm^{-1}) ν_{max}: 3160 (OH), 1589 (C=C aromatic), 723 (Ar-H). ^{1}H-NMR (400 MHz, DMSO-d_6) δ: 8.26-8.23 (d, *J* = 10.5 Hz, 2H, Ar-H), 7.84-7.82 (d, *J* = 8 Hz, 2H, Ar-H), 7.65-7.68 (t, *J* = 10.5 Hz, 2H, Ar-H), 7.28-7.26 (t, *J* = 10.5 Hz, 1H, Ar-H), 7.01-7.03 (d, *J* = 8 Hz, 2H, Ar-H), 5.35 (s-br, IH, OH). ^{13}C-NMR (100 MHz, DMSO-d_6) δ: 160.2, 152.6, 145.3, 130.8, 129.1, 129.1, 124.5, 124.5, 123.0, 123.0, 116.4, 116.4 ppm.

2.3.2 4-((3-Nitrophenyl)diazenyl)phenol, 11

Azo coupling afforded a red crystal, 11 (3.5 g, 99.43%). λ_{max} in nm (log ε): 356 (4.27), 245 (4.24), 206 (4.35). IR (KBr, cm^{-1}) ν_{max}: 3423 (OH), 1637 (C=C aromatic), 1590 (asym.NO_2), 1350 (sym. NO_2), 723 (Ar-H). ^{1}H-NMR (400 MHz, DMSO-d_6) δ: 8.68 (s, 1H, Ar-H), 8.39-8.38 (d, *J* = 4.9 Hz, 1H, Ar-H), 8.20-8.19 (d, *J* = 5.5 Hz, 1H, Ar-H), 7.94-7.91 (m, 1H, Ar-H), 7.85-7.83 (d, *J* = 8 Hz, 2H, Ar-H), 7.01-6.99 (d, *J* = 8 Hz, 2H, Ar-H), 5.34 (s-br, IH, OH). ^{13}C-NMR

(100 MHz, DMSO-d_6) δ: 152.0, 151.6, 150.7, 129.4, 129.4, 129.1, 129.1, 129.0, 125.0, 125.0, 123.7, 122.9 ppm.

2.3.3 4-((4-Bromophenyl) diazenyl) phenol, 12

Azo coupling afforded a brown crystal, 12 (2.7 g, 67.33%). λ_{max} in nm (log ε): 352 (4.04), 238 (3.28). IR (KBr, cm^{-1}) ν_{max}: 3398 (OH), 1617 (C=C aromatic), 723 (Ar-H), 521 (C-Br). ^{1}H-NMR (400 MHz, DMSO-d_6) δ: 7.81-7.79 (d, *J* = 8 Hz, 1H, Ar-H), 7.75-7.73 (m, 2H, Ar-H), 7.67-7.65 (m, 2H, Ar-H), 7.58-7.56 (m, 1H, Ar-H), 7.40-7.38 (m, 1H, Ar-H), 6.96-6.94 (m, 1H, Ar-H). ^{13}C-NMR (100 MHz, DMSO-d_6) δ: 152.4, 152.0, 132.3, 132.1, 132.1, 131.9, 126.1, 125.0, 123.9, 123.7, 123.1, 116.1 ppm. MS-EI: m/z (rel. %): 276.99 (M + 1, 37%), 275.99 (M^+, 37%), 172.96 (90%), 170.97 (100%), 121.04 (59%), 93.03 (89%), 65.03 (40%), 43.98 (24%).

2.3.4 4-((4-Chlorophenyl)diazenyl)phenol, 13

Azo coupling afforded a black crystal, 13 (1.2 g, 37.04%). λ_{max} in nm (log ε): 346 (4.69), 238 (4.20). IR (KBr, cm^{-1}) ν_{max}: 3394 (OH), 1576 (C=C aromatic), 829 (C-Cl), 723 (Ar-H). ^{1}H-NMR (400 MHz, DMSO-d_6) δ: 8.03-8.02 (d, *J* = 4 Hz, 1H, Ar-H), 7.84-7.79 (m, 2H, Ar-H), 7.74-7.72 (d, *J* = 8 Hz, 1H, Ar-H), 7.63-7.61 (d, *J* = 8 Hz, 1H, Ar-H), 7.56-7.51 (m, 2H, Ar-H), 6.97-6.95 (d, *J* = 8 Hz, 1H, Ar-H). ^{13}C-NMR (100 MHz, DMSO-d_6) δ: 152.6, 152.0, 132.3, 132.1, 132.1, 131.9, 126.0, 125.0, 123.9, 123.7, 123.1, 116.2 ppm. MS-EI: m/z (rel. %): 234.04 (M + 2, 11%), 232.04 (M^+, 70%), 218.99 (29%), 130.99 (5%), 121.04 (41%), 93.03 (100%), 68.99 (22%), 67.99 (20%), 43.98 (12%).

2.3.5 4-((2-Bromo-4-methylphenyl)diazenyl)phenol, 14

Azo coupling afforded a yellow crystal, 14 (2.3 g, 56.93%). λ_{max} in nm (log ε): 361 (4.79), 247 (4.46), 205 (4.44). IR (KBr, cm^{-1}) ν_{max}: 3325 (OH), 1589 (C=C aromatic), 723 (Ar-H), 518 (C-Br). ^{1}H-NMR (400 MHz, DMSO-d_6) δ: 7.83-7.81 (d, *J* = 8 Hz, 2H, Ar-H), 7.66 (s, 1H, Ar-H), 7.55-7.53 (d, *J* = 8 Hz, 1H, Ar-H), 7.29-7.27 (d, *J* = 8 Hz, 1H, Ar-H), 7.00-6.97 (dd, J_1 = 4 Hz, J_2 = 12 Hz, 2H, Ar-H), 2.37 (s, 3H, Ar-H). ^{13}C-NMR (100 MHz, DMSO-d_6) δ: 146.8, 145.2, 142.2, 133.5, 129.2, 125.2, 125.2, 124.1, 117.1, 116.3, 116.3, 114.1, 20.5 (CH_3) ppm. MS-EI: m/z (rel. %): 292.00 (M + 2, 82%), 290.00 (M^+, 91%), 170.96 (24%), 168.96 (30%), 121.03 (97%), 93.02 (100%), 90.04 (15%), 89.03 (12%), 65.03 (22%), 63.02 (3%).

2.3.6 4-((3-Bromo-4-methylphenyl)diazenyl)phenol, 15

Azo coupling afforded an orange crystal, 15 (1.7 g, 42.1 %). λ_{max} in nm (log ε): 355 (5.30), 241 (5.02), 205 (5.06). IR (KBr, cm^{-1}) ν_{max}: 3290 (OH), 1589 (C=C aromatic), 723 (Ar-H), 582 (C-Br). ^{1}H-NMR (400 MHz, DMSO-d_6) δ: 7.83-7.81 (d, *J* = 8 Hz, 2H, Ar-H), 7.72 (s, 1H, Ar-H), 7.54-7.52 (d, *J* = 8 Hz, 1H, Ar-H), 7.29-7.27 (d, *J* = 8 Hz, 1H, Ar-H), 7.00-6.97 (dd, J_1 = 4 Hz, J_2 = 12 Hz, 2H, Ar-H), 2.37 (s, 3H, Ar-H). ^{13}C-NMR (100 MHz, DMSO-d_6) δ: 146.8, 145.2, 142.2, 133.5, 129.2, 125.2, 125.2, 124.1, 117.1, 117.1, 116.3, 114.1, 20.1 (CH_3) ppm.

2.3.7 4-((4-Bromo-2-methylphenyl)diazenyl)phenol, 16

Azo coupling afforded a brown crystal, 16 (g, 44.55%). λ_{max} in nm (log ε): 361 (5.14), 241 (4.91), 205 (4.96). IR (KBr, cm^{-1}) ν_{max}: 3337 (OH), 1586 (C=C aromatic), 723 (Ar-H). ^{1}H-NMR (400 MHz, DMSO-d_6) δ: 7.95-7.93 (d, *J* = 8 Hz, 2H, Ar-H), 7.87-7.84 (d, *J* = 12 Hz, 2H, Ar-H), 7.67 (s, 1H, Ar-H), 7.16-7.14 (d, *J* = 8 Hz, 2H, Ar-H), 5.35 (s-br, 1H, OH), 2.38 (s, 3H,

CH_3-Ar). ^{13}C-NMR (100 MHz, DMSO-d_6) δ: 158.7, 151.2, 143.5, 134.2, 133.5, 128.9, 125.3, 125.2, 124.4, 124.4, 116.7, 116.7, 21.3 ppm.

2.3.8 4-((4-Aminophenyl)diazenyl)phenol, 17

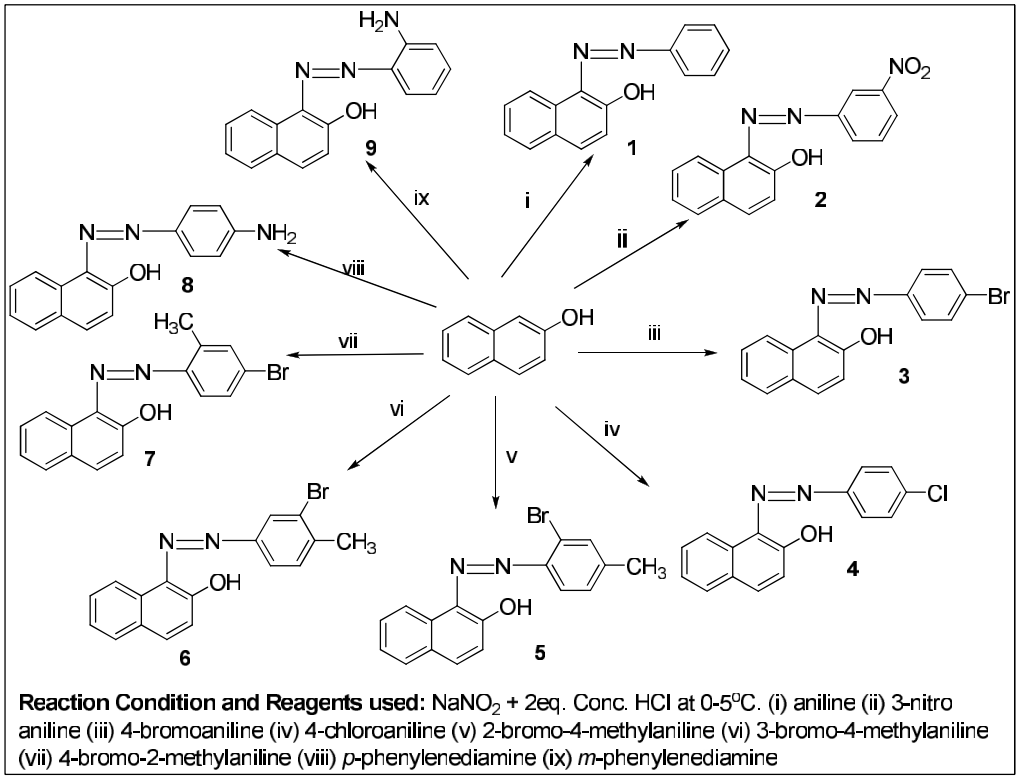
Azo coupling afforded a black crystal, 17 (0.7 g, 30.84%). λ_{max} in nm (log ε): 595 (2.60), 568 (2.60), 394 (3.83), 205 (4.00). IR (KBr, cm^{-1}) ν_{max}: 3261 (OH), 3100 (NH_2), 1589 (C=C aromatic), 723 (Ar-H). ^{1}H-NMR (400 MHz, DMSO-d_6) δ: 8.78-8.75 (d, *J* = 12 Hz, 2H, Ar-H), 7.86-7.84 (d, *J* = 8 Hz, 2H, Ar-H), 7.22-7.20 (d, *J* = 8 Hz, 2H, Ar-H), 7.02-6.99 (d, *J* = 12 Hz, 2H, Ar-H), 6.75 (s, 2H, NH_2), 5.35 (s-br, IH, OH). ^{13}C-NMR (100 MHz, DMSO-d_6) δ: 159.3, 150.7, 148.2, 148.2, 125.1, 125.1, 124.4, 124.4, 116.5, 116.5, 113.9, 113.9 ppm.

3. RESULTS AND DISCUSSION

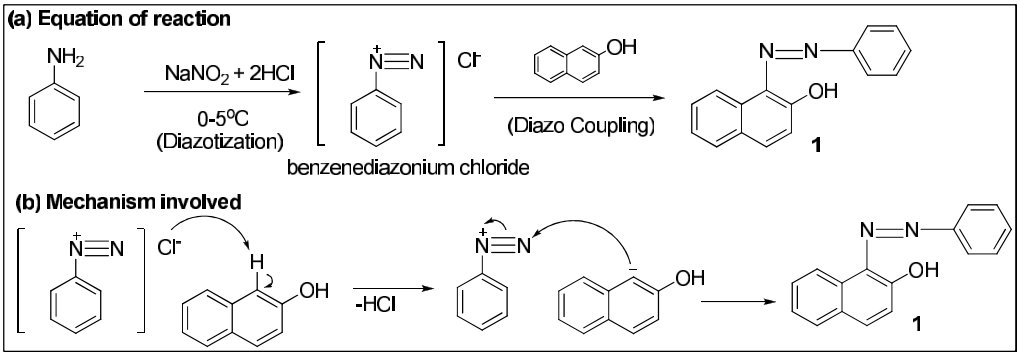
3.1 Synthetic Pathway to the Azo Dyes

In the recent times, considerable attention has been devoted to antimicrobial application of azo dye. In fact, numerous literatures are available recently to supplement this paradigm shift in azo dyes utilization [20,21,24-26]. First and foremost, it is important to note that the azo dyes synthesized were of two forms based on the nature of the starting material common to each group. The rational for choosing these dyes is to be able to get various scaffolds of this nature by derivatization which will in turn help in the future SAR study of these compounds. The first set of these series have naphtholic group common to them; hence, they are referred to as the naphtholic azo dyes 1-9, while the second set are called the phenolic azo dyes 10-17 because they have phenolic group in common. However, the two sets were prepared using the same procedure as reported by Liebermann (1883) but in modified version [27]. In a nutshell, to understand the detail of the observed reaction, it is essential to explain the formation of compound 1 as a representative of the naphtholic azo dyes. The naphtholic azo dye 1 was prepared in excellent yield by coupling of 2-naphthol with aniline. The same procedure was repeated with substituted aniline derivatives to afford other eight naphtholic azo dyes 2 - 9. Generally speaking, the naphtholic azo dyes, 1-9 were prepared in good to excellent yield (76.53 - 99.56%) by the diazo coupling of the aniline and substituted anilines with 2-naphthol at 0-5ºC as shown in Scheme 1.

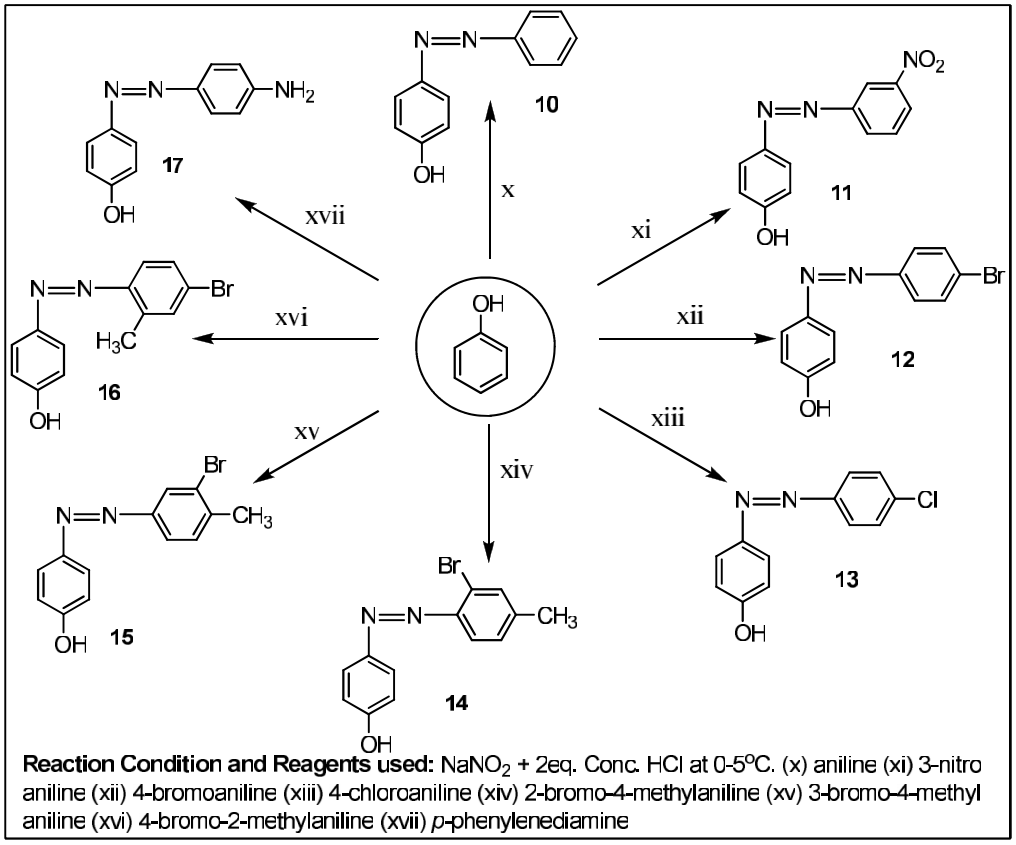
The formation of 1, involved two steps reaction as shown in Scheme 2a while the detail mechanism was as presented in Scheme 2b. The first step involved the diazotization of aniline to form a reactive intermediate, benzene diazonium chloride while the second step involved the formation of carbanion of 2-naphthol by a nucleophilic attack initiated by the chloride ion. The nucleophilic 2-naphthol generated, then attacks the diazonium nitrogen to form the naphtholic azo dye 1 (Scheme 2b). This mechanism was also adopted for the coupling of substituted aniline ii to ix to afford the corresponding naphtholic azo dyes 2 to 9 respectively. In a similar manner, to understand the detail of the observed reaction above, it is also essential to explain the formation of compound 10 as a representative of the phenolic azo dyes. The formation of 10 involved two steps reactions. The first step involved the diazotization of aniline to form a reactive intermediate, benzene diazonium chloride while the second step involved the formation of carbanion of phenol by a nucleophilic attack initiated by the chloride ion. The nucleophilic phenol generated, then attacks the diazonium nitrogen to form the phenolic azo dye 10. This mechanism was also adopted for the coupling of substituted aniline xi to xvii to afford phenolic azo dyes 11 to 17 respectively as shown in Scheme 3.



Scheme 1. Synthesis of naphtholic azo dyes 1 - 9



Scheme 2. Equation and mechanism for the formation of naphtholic azo dye, 1



Scheme 3. Synthesis of phenolic azo dyes 10 – 17

3.2 Physico-Chemical Parameter Analysis

The physico-chemical parameters in terms of the report of the molecular formula, molecular weight, percentage yields, melting points, R_f values as well as the elemental analysis results are as shown in Table 1. The molecular weights of the compounds range from the highest 341 which was obtained for compounds 5, 6, 7 to the lowest 198 which could be found in compound 10. The entire compounds were synthesized in good (56.93%) to excellent yield (99.56%) except for compounds 13, 15, 16, 17 where-in arbitrarily low yields of 37.04%, 42.10%, 44.60% and 30.84% were observed respectively. The melting points of the entire compounds ranged between 134-136ºC for compound 2 and 269-271ºC, for compound 17. The low melting point observed in 2 might be as a result of inductive effect generated by the $-NO_2$ at the meta position of the ring, while the high melting point experienced in 17 might be as a result of electron donating power contributed by the para-positioned -OH and $-NH_2$ to strengthen the azo functionality. The TLC spotting was done in order to monitor the progress of the reaction and to confirm the purity level of the products obtained. The R_f values of all the compounds ranged from 0.18 to 0.94 using petroleum ether/chloroform solvent system. Although, the solvent systems are the same for all the compounds but in varying ratio (See Table 1) except 8 and 17 (Chloroform/methanol $\rightarrow$ 9:1), the eluting ratio varies depending on the polarity disparity of the synthesized compounds. The calculated values for the C, H, N elemental analysis was also reported in Table 1 to be in agreement with the found values

within the limit of ±0.20. The colours of the synthesized compounds ranges from red to black except for compounds 9, 14 and 15 in which the colour are grey, yellow and orange respectively (Experimental). It is noteworthy to distinguish the novel compounds from the existing ones. Hence, according to comprehensive literature search, it was observable that compounds 1, 8, 10 and 17 were earlier reported [27-30] while all other compounds are new. The *o*- and *p*-nitronaphtholic azo dyes have been synthesized by Chakraborty et al. [10] and Morhig et al. [31] respectively but the *m*-nitronaphtholic azo dye reported herein, 2 has not been synthesized before to the best of our knowledge.

3.3 Spectral Studies

The structures of newly synthesized compounds were elucidated by IR, UV, NMR, mass spectral studies, and elemental analysis. Generally speaking, from the spectroscopic study, the ultraviolet absorption and infrared data of all compounds were listed in the experimental section. The electronic transition of uv-visible spectra in methanol gave rise to wavelength (λ_{max}) ranging from 205 nm to 595 nm. The first wavelength (λ_{max}) for all the compounds were found between 205 - 227 nm as a result of $\pi \rightarrow \pi^*$ transition of the compounds indicating the presence of C=C peculiar to benzene nucleus. This is in agreement with earlier report by Mielgo et al., as per benzenoid uv-visible absorption [32]. The uv-visible absorption spectrum of 1-(phenyldiazenyl) naphthalene-2-ol, 1, as a representative of naphtholic azo dye, showed a peak at λ_{max} = 226 nm (log ε = 4.73) and two other bathochromic shifts at λ_{max} = 424 nm (log ε_{max} = 4.20) and λ_{max} = 484 nm (log ε = 4.38). All the wavelength (λ_{max}) above benzenoid region (i.e. between 424 nm to 484 nm) was as a result of $\pi \rightarrow n$ transition and extended conjugation contributed by the C=C and the conjugative linkage performed by the N=N group. An incomparably strong bathochromic shift occurred in compound 17 that resulted in wavelength at far visible region of light at λ_{max} of 595 nm (log ε = 2.60) was due to the presence of an auxochrome (-NH_2) in the skeletal framework of compound 17 which improved the colour deepening attribute by delocalization of the lone pair of electron present on the nitrogen atom.

Furthermore, the IR spectra of all the compounds were run in nujol using single beam FT-IR. The infrared spectra of the compounds 1-17 showed absorption bands due to the stretching vibrations of OH of phenol and 2-naphthol, C=C of aromatic and Ar-H bending vibration at 3160- 3448 cm^{-1}, 1589 - 1637 cm^{-1} and 723 - 750 cm^{-1} respectively. Specifically speaking, using IR spectrum of 7 as representative example of the azo dyes, the highest but broad band observed at 3402 cm^{-1} was as a result of OH functionality of phenol. The absorption bands at 1618 cm^{-1} and 750 cm^{-1} depicted the present of C=C and Ar-H respectively. The ^{1}H- and ^{13}C-NMR analysis of 1 was run at 400 MHz and 100 MHz respectively using deuterated DMSO. The ^{1}H-NMR spectrum of compound 1 showed signals down field in the aromatic region of the TMS scale which was between δ 8.56-8.54 and 6.79-6.77 ppm as one proton doublet each with coupling constant of 8 Hz. Other prominent signals include one proton doublet each at δ 8.24-8.22 and 8.07-8.05; two proton doublets at 7.65-7.63; two proton triplet at δ 7.74-7.70 and one proton triplet each at δ 7.88-7.82, 7.51-7.47 and 7.30-7.27 respectively. The ^{13}C-NMR spectrum of 1 showed it to have sixteen aromatic carbon atoms ranging from 130.7 ppm to 117.4 ppm.

Table 1. Physico-chemical properties of compounds synthesized

Com no	Molecular formula	Mol. wt.	Yield (%)	Melting pt. (°C)	R_f^*	Elem. Anal: %Calcd. (%Found) C	H	N
1	$C_{16}H_{12}N_2O$	248	98.84	138-140	0.27[a]	77.40(77.36)	4.87(4.89)	11.28(11.32)
2	$C_{16}H_{11}N_3O_3$	293	98.52	134-136	0.89[b]	65.53(65.47)	3.78(3.89)	14.33(14.27)
3	$C_{16}H_{11}BrN_2O$	327	99.56	206-208	0.49[a]	58.74(58.59)	3.39(3.46)	8.56(8.72)
4	$C_{16}H_{11}ClN_2O$	282	76.53	169-171	0.21[a]	67.97(68.07)	3.92(4.04)	9.91(9.82)
5	$C_{17}H_{13}BrN_2O$	341	96.49	231-233	0.21[a]	59.84(59.99)	3.84(3.67)	8.21(8.13)
6	$C_{17}H_{13}BrN_2O$	341	87.72	217-219	0.24[a]	59.84(59.77)	3.84(3.97)	8.21(8.30)
7	$C_{17}H_{13}BrN_2O$	341	99.12	219-221	0.54[a]	59.84(59.91)	3.84(3.69)	8.21(8.34)
8	$C_{16}H_{13}N_3O$	263	97.83	248-250	0.94[c]	72.99(73.12)	4.98(5.11)	15.96(16.09)
9	$C_{16}H_{13}N_3O$	263	81.97	237-239	0.20[b]	72.99(73.15)	4.98(4.81)	15.96(15.79)
10	$C_{12}H_{10}N_2O$	198	87.10	162-164	0.18[b]	72.71(72.89)	5.08(4.88)	14.13(13.99)
11	$C_{12}H_9N_3O_3$	243	99.43	167-169	0.18[b]	59.26(59.21)	3.73(3.62)	17.28(17.33)
12	$C_{12}H_9BrN_2O$	277	67.33	216-218	0.63[a]	52.01(51.96)	3.27(3.41)	10.11(10.21)
13	$C_{12}H_9ClN_2O$	232	37.04	188-190	0.60[a]	61.95(62.02)	3.90(4.08)	12.04(11.99)
14	$C_{13}H_{11}BrN_2O$	291	56.93	252-254	0.53[a]	53.63(53.51)	3.81(3.69)	9.62(9.76)
15	$C_{13}H_{11}BrN_2O$	291	42.10	248-250	0.60[a]	53.63(53.77)	3.81(3.89)	9.62(9.51)
16	$C_{13}H_{11}BrN_2O$	291	44.60	223-225	0.67[a]	53.63(53.52)	3.81(3.74)	9.62(9.49)
17	$C_{12}H_{11}N_3O$	213	30.84	269-271	0.94[c]	67.59(67.68)	5.20(5.11)	19.71(19.89)

**Solvent System: Petroleum ether: $CHCl_3$ (9:1, v/v)[a]; Petroleum ether: $CHCl_3$ (6:4, v/v)[b]; $CHCl_3$: CH_3OH (9:1, v/v)[c]. Com. No = Compound Number. Mol. Wt. = Molecular Weight. Elem. Anal. = Elemental Analysis. Literature melting points for 1 is 133ºC [Ref. 28]; for 8 is 245-247ºC [Ref. 29]; for 10 is 160-163ºC [Ref. 30]; for 17 is 270-272ºC [Ref. 30].*

In addition, the result of the mass spectral data of some selected compounds which include compounds 2, 6, 12, 13 and 14 was as reported in the experimental section. The molecular ion peaks obtained from all the spectra were consistent with the molecular mass of the proposed structures while some other daughter ions and base peaks were observed based on some fragmentation patterns. The mass spectral data of 6, for instance, showed molecular ion peak at m/z 340.02 (70%) which was in concordance with the molecular mass (340.02) of the compound ($C_{17}H_{13}BrN_2O$) while base peak was observed at m/z 143.04 (100%). A highly intense peak with m/z 342.02 was as a result of (M + 2) pattern. Other prominent peaks that appeared at m/z 261.10, 171.05, 115.05 and 89.03 with relative intensities of 3% 21%, 55% and 10% respectively as reported in the experimental section were due to some fragmentation processes. Specifically, the fragmentation that led to phenylium cation (Ph^+) was responsible for m/z of 77.03; although, with low relative intense (5%).

4. CONCLUSION

In summary, the synthesis of series of naphtholic azo dyes 1 – 9 and phenolic azo dyes 10 – 17 was successfully achieved using various substituted aniline derivatives as the coupling agents. Apart from compounds 1, 8, 10 and 17 earlier reported, all other compounds are new and could be a good yardstick for monitoring of trend in activity of the functionalized azo dyes as a result of difference in substituent; structure activity relationship (SAR) study, in the nearest future. Thus, the azo dyes herein synthesized are good candidates for further study in terms of the investigation of their biological activities. This might create a new vista of opportunity in new drug discovery and medicinal research.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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