Synthesis S. Chuprun et al. Paper

[3+2]-Cycloaddition of α-Diazocarbonyl Compounds with Arenediazonium Salts Catalyzed by Silver Nitrate Delivers 2,5-Disubstituted Tetrazoles

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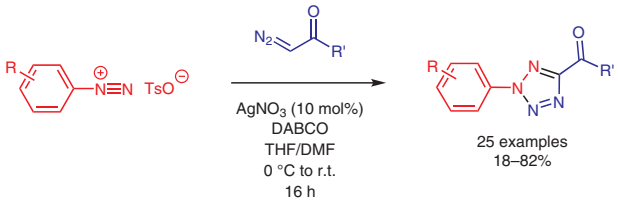

R = H, EWG or EDG, R' = alkyl, (hetero)aryl or 2° amino

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Abstract [3+2]-Cycloaddition of arenediazonium salts with diazo compounds (earlier exemplified only for trimethylsilyldiazomethane and 2,2,2-trifluorodiazoethane) has been developed to include a wide range of readily available α-diazocarbonyl compounds. The resulting 2-aryl-5-acyl-2*H*-tetrazoles are of high value in medicinal chemistry.

Key words α-diazocarbonyl compounds, arenediazonium tosylates, tetrazoles, [3+2]-cycloaddition, silver nitrate

Tetrazoles are important representatives of the azole family of heterocycles with much utility in medicinal chemistry.[3] In particular, 5-substituted 1*H*-tetrazoles are considered classical carboxylic acid isosteres.[4] Disubstituted tetrazoles can be considered suitable amide bond replacements.[3] Moreover, replacement of other five-membered nitrogen heterocyclic cores with tetrazole may significantly alter such molecular characteristics as total polar surface area and hydrophilicity, thus transitioning a compound's properties (in particular, solubility) into a more favorable range.[5] In order to be able to exercise such scaffold-hopping options with facility, there must be a versatile arsenal of synthetic methods to construct tetrazoles with a broad substituent variation. Methods reported to date include azide–nitrile and azide–isocyanide cycloadditions, dimerization of α-diazocarbonyl compounds, diazotization–cyclization of imidohydrazides or amidines, cyclocondensation of acyl hydrazides with arenediazonium salts, and cyclization of amides or imidoyl compounds with azides.[6] A novel approach to constructing 2-aryltetrazoles was presented in 2015/2016 by Ma[7] and Kamenecka[8] and their coworkers. It involves silver-catalyzed cycloaddition of arenediazonium salts with 2,2,2-trifluorodiazoethane (CF_3CHN_2)[7] and trimethylsilyldiazomethane (Me_3SiCHN_2),[8] respectively (Scheme 1). While the method displayed a broad scope with respect to the aromatic groups at *N*[2], the substitution at position 5 attainable by this approach has so far been limited to either a trifluoromethyl group (in compounds **1**) or hydrogen (in compounds **2**). It is worth noting that while preparation of compounds **1** was achieved with a catalytic amount of the silver salt, more than a stoichiometric amount of the latter was required to prepare compounds **2**. We thought it surprising this cycloaddition-based entry into tetrazoles has not been explored further to include other diazo compounds, which would dramatically broaden the range of substituents on the tetrazole carbon atom. Considering, in particular, the diversity of α-diazo ketones available, the resulting 2-aryl-5-acyltetrazoles **3** (EWG = RC(O)) would be a very valuable chemotype to access (Scheme 1). Such cores have been utilized in the design of mGluR5 receptor modulators,[9] fatty acid amide hydrolase inhibitors,[10] antiviral compounds,[11] and compounds endowed with hypoglycemic activity.[12] Thus, we became interested in the opportunity to fill the above-mentioned void in synthetic methodology toward 2,5-disubstituted tetrazoles. Herein, we present the results of our investigation in this regard.

For the initial optimization studies, we selected commercially available benzenediazonium tosylate (**4a**) and 2-diazo-4′-methylacetophenone (**5a**). Our preference for the tosylate counterion was motivated by the recently reported convenient preparation and use of arenediazonium tosylates.[13] Not only are they more stable toward chemical decomposition and explosion compared to conventionally used tetrafluoroborates, they are more cleanly prepared by diazotization of the respective anilines in the presence of *p*-toluenesulfonic acid in a variety of polar organic solvents, and even water.[14] As the silver catalyst, we initially selected the readily available silver nitrate. The initial testing of the

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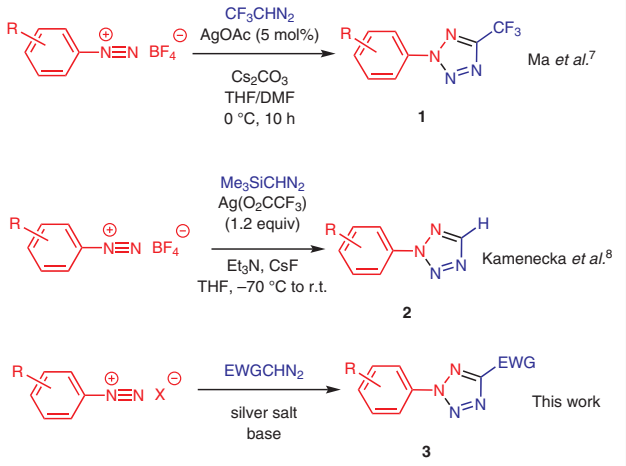
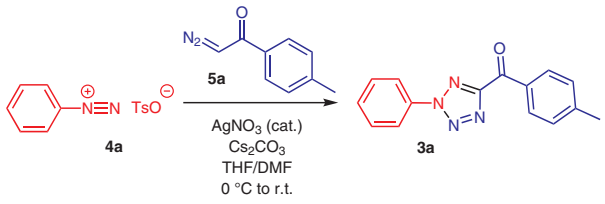


Scheme 1 Cycloaddition-based routes from diazo compounds to tetrazoles reported previously and investigated in this work

conditions described by Ma and co-workers[7] (employing a twofold excess of the diazo compound relative to the diazonium salt) gave, gratifyingly, a 48% yield of the anticipated product **3a** (Table 1, entry 1). The yield of **3a** was improved to 66% by altering the reagent ratio and doubling the amount of the catalyst (Table 1, entry 4).

Having identified the optimal reagent and catalyst ratio, we screened for a possible better solvent, base or catalyst (Table 2). The only improvement, however, that we were able to achieve was the replacement of the base with equally workable (yet significantly less expensive and easier to dose) DABCO. THF/DMF mixture and silver nitrate were only confirmed to be the best catalysts for the transformation.

Table 1 Reagent Ratio Screening for the Preparation of **3a**



Entry	Equiv of **4a**	Equiv of Cs_2CO_3	Equiv of $AgNO_3$	Yield (%) of **3a**
1	0.5	2.0	0.05	48
2	2.0	2.0	0.05	65
3	1.1	2.0	0.05	61
4	1.1	1.5	0.1	**66**
5	1.1	1.2	0.1	59

With the optimized reaction conditions at hand, we proceeded to investigate the scope of the tetrazole synthesis for a range of substituted arenediazonium tosylates (**4a–k**, prepared by diazotization of the respective anilines) and (hetero)aromatic (**5a–g**, **5i–k**, **5n–q**) and aliphatic (**5h**) diazo ketones, as well as α-diazo acetamides (**5l**, **5m**), all of which are commercially available and can be conveniently prepared by the literature protocols (Figure 1).

As follows from the results presented in Scheme 2, the silver-catalyzed, DABCO-promoted cycloaddition of diazo compounds **5** with arenediazonium salts **4** (likely analogous, from the mechanistic perspective, to the earlier described cycloaddition of diazo compounds with isocyanides[15]) gave moderate to good yields of the diversely substituted tetrazoles **3a–y**. The reaction did not appear to be

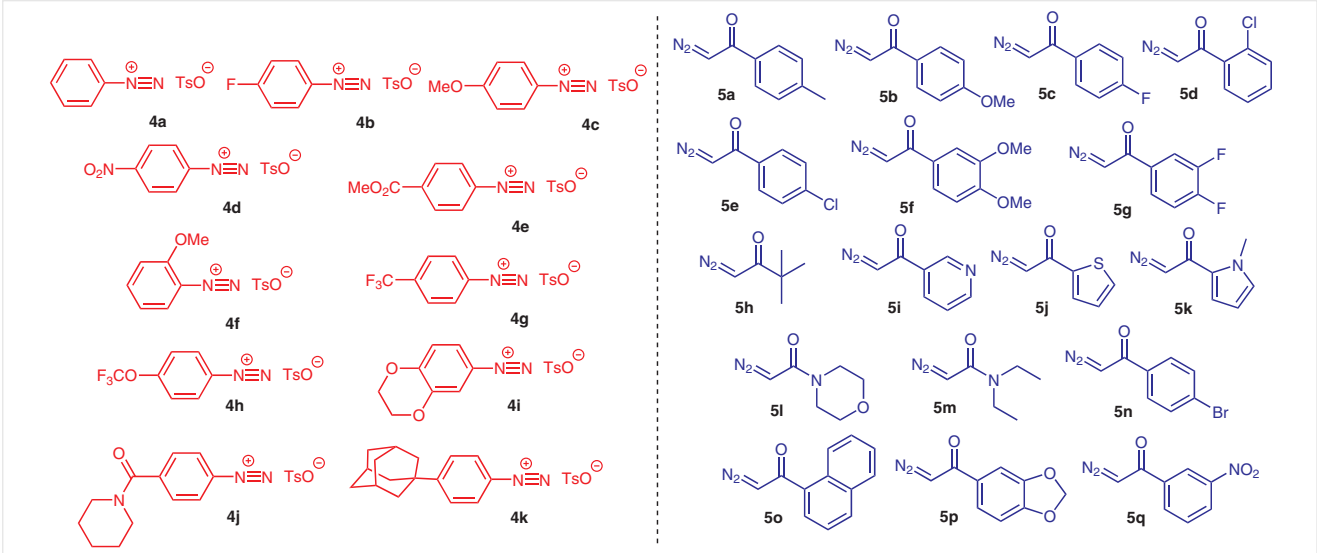


Figure 1 Arenediazonium tosylates **4** and diazo compounds **5** employed in the scope investigation of the [3+2]-cycloaddition toward tetrazoles **3**. All diazonium salts were used directly as obtained in the crude form from the diazotization reaction, without further purification.

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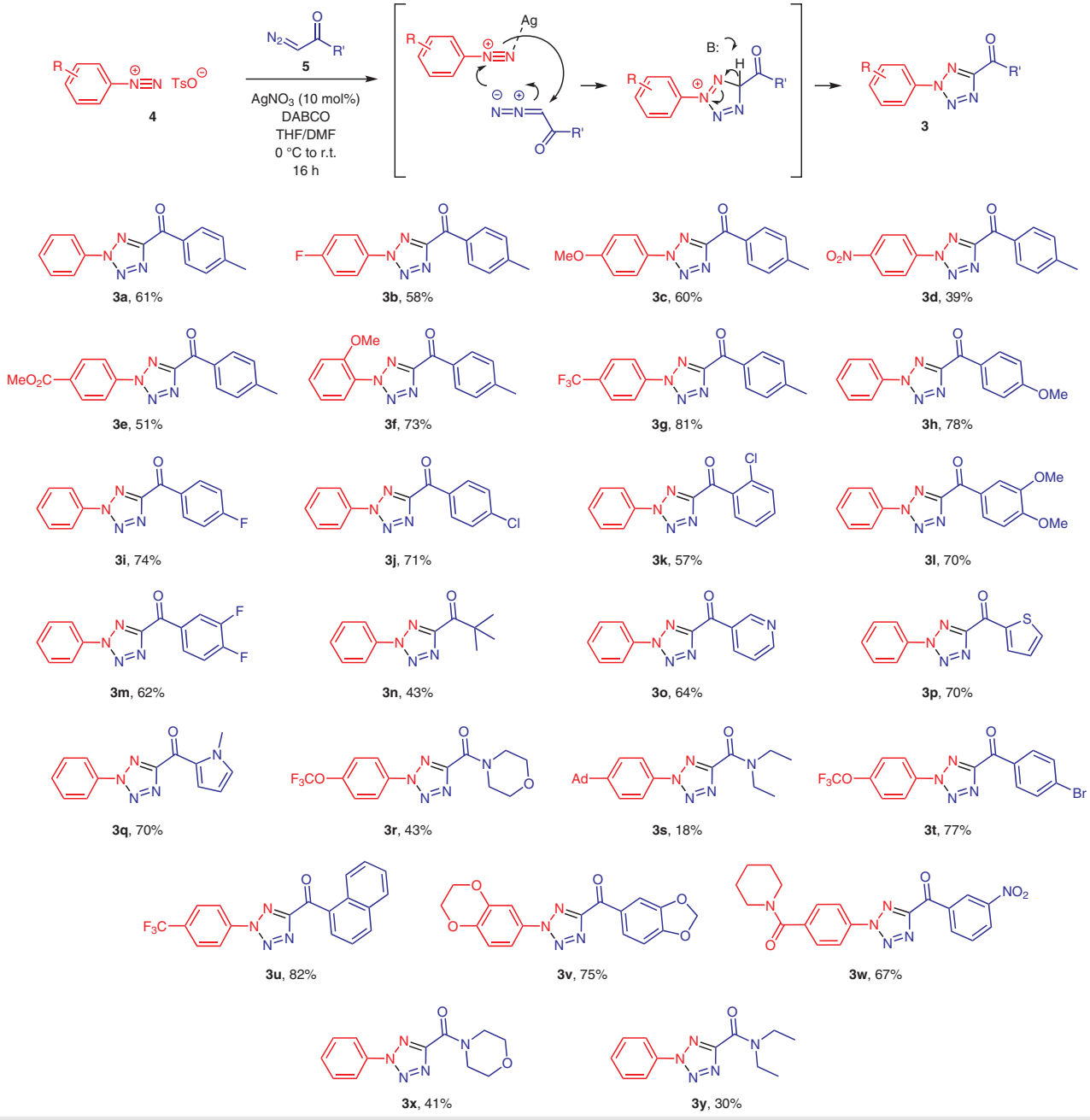

Scheme 2 Tetrazoles **3a–y** prepared in this work

particularly sensitive to substituent effects in the diazonium portion. However, the yields were markedly lower for α-diazo acetamides (cf. **3r**, **3s**, **3x**, **3y**) compared to diazo ketones. Reassuringly, the yields for aromatic and heteroaromatic ketones were comparable, thus allowing access to intriguing combinations of three different aromatic motifs in a single molecule (e.g., benzene/tetrazole/pyridine in **3o**).

To conclude, we have described a novel variant of the [3+2]-cycloaddition of arenediazonium tosylates with structurally diverse α-diazocarbonyl compounds which employs the readily available silver nitrate as a catalyst and significantly expands the range of druglike tetrazoles accessible from a broader range of reagents than has been reported to date. We are in the process of investigating other diazo compounds as partners in these reactions and will report the results in due course.

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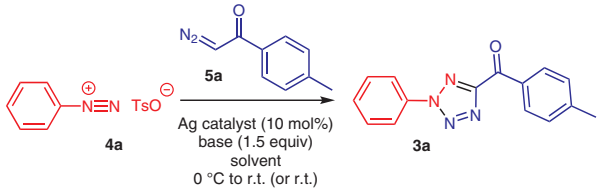
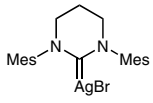
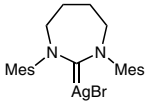
Table 2 Solvent, Base and Catalyst Screening for the Preparation of **3a**



Entry	Solvent	Base	Catalyst	Yield (%) of **3a**
1	THF	Cs_2CO_3	$AgNO_3$	54
2	1,4-dioxane (r.t.)	Cs_2CO_3	$AgNO_3$	56
3	MeOH	Cs_2CO_3	$AgNO_3$	21
4	MeCN	Cs_2CO_3	$AgNO_3$	56
5	DMF	Cs_2CO_3	$AgNO_3$	40
6	DMSO (r.t.)	Cs_2CO_3	$AgNO_3$	38
7	1,4-dioxane/DMF (r.t.)	Cs_2CO_3	$AgNO_3$	55
8	THF/DMF (r.t.)	Cs_2CO_3	$AgNO_3$	**65**
9	THF/DMF	KOH	$AgNO_3$	28
10	THF/DMF	K_2CO_3	$AgNO_3$	31
11	THF/DMF	MeONa	$AgNO_3$	32
12	THF/DMF	K_3PO_4	$AgNO_3$	18
13	THF/DMF	DIPEA	$AgNO_3$	59
14	THF/DMF	DABCO	$AgNO_3$	**61**
15	THF/DMF	DABCO	AgOAc	48
16	THF/DMF	DABCO	Ag_2CO_3	45
17	THF/DMF	DABCO	AgOTf	31
18	THF/DMF	DABCO	Ag_2O	51
19	THF/DMF	DABCO		5.5
20	THF/DMF	DABCO		5.1

All commercial reagents and solvents were used without further purification, unless otherwise noted. Diazocarbonyl compounds **5** were prepared according to the known methods. Analytical TLC was carried out on UV-254 silica gel plates using appropriate eluents. Compounds were visualized with short-wavelength UV light. NMR spectroscopic data were recorded with a 400 MHz spectrometer (400.13 MHz for ^1H and 100.61 MHz for ^{13}C) on solutions in $CDCl_3$ and in DMSO-d_6 and were referenced to residual solvent proton signals (δ_H = 7.26 and 2.50, respectively) and solvent carbon signals (δ_C = 77.0 and 39.5, respectively). All chemical shifts are reported in parts per million (ppm). Abbreviations used in the description of resonances are: s (singlet), d (doublet), t (triplet), q (quartet), br (broad), m (multiplet). Coupling constants (J) are quoted to the nearest 0.1 Hz. Melting points were determined in open capillary tubes with a Stuart SMP50 instrument. Mass spectra were recorded with a Bruker maXis HRMS-ESI-qTOF spectrometer (electrospray ionization mode).

Diazonium Tosylates 4a–k; General Procedure

To a stirred ice-cooled solution/suspension of the corresponding aniline (15.0 mmol) in THF (5 mL), a solution of *p*-toluenesulfonic acid monohydrate (3.043 mg, 16.0 mmol) in glacial acetic acid (15 mL) was added. The resulting suspension was stirred for 5 min and *t*-BuONO (2.44 mL, 22.5 mmol) was added in one portion. The mixture was stirred at 0 °C for 20 min, then the ice bath was removed and stirring was continued for 50 min at ambient temperature. The resulting solution was poured into Et_2O (150 mL) and the mixture was stirred for 30 min. The precipitate was collected by filtration, washed with Et_2O (2 × 50 mL) and dried under reduced pressure at 30 °C. The obtained arenediazonium tosylates were used without any further purification.

Benzenediazonium 4-Methylbenzenesulfonate (4a)

White solid; yield: 3.39 g (82%).

^1H NMR (400 MHz, DMSO-d_6): δ = 8.73–8.65 (m, 2 H), 8.30–8.21 (m, 1 H), 8.02–7.93 (m, 2 H), 7.50 (d, J = 8.1 Hz, 2 H), 7.13 (d, J = 7.8 Hz, 2 H), 2.30 (s, 3 H).

4-Fluorobenzenediazonium 4-Methylbenzenesulfonate (4b)

White solid; yield: 4.01 g (91%).

^1H NMR (400 MHz, DMSO-d_6): δ = 8.84 (dd, J = 9.4, 4.5 Hz, 2 H), 7.89 (dd, J = 9.3, 8.3 Hz, 2 H), 7.49 (d, J = 8.0 Hz, 2 H), 7.11 (d, J = 7.9 Hz, 2 H), 2.29 (s, 3 H).

4-Methoxybenzenediazonium 4-Methylbenzenesulfonate (4c)

Pale purple solid; yield: 4.15 g (86%).

^1H NMR (400 MHz, DMSO-d_6): δ = 8.64 (d, J = 9.4 Hz, 2 H), 7.52–7.44 (m, 4 H), 7.11 (d, J = 7.8 Hz, 2 H), 4.04 (s, 3 H), 2.29 (s, 3 H).

4-Nitrobenzenediazonium 4-Methylbenzenesulfonate (4d)

White solid; yield: 4.15 g (86%).

^1H NMR (400 MHz, DMSO-d_6): δ = 8.96 (d, J = 9.2 Hz, 2 H), 8.70 (d, J = 9.1 Hz, 2 H), 7.47 (d, J = 7.9 Hz, 2 H), 7.11 (d, J = 7.7 Hz, 2 H), 2.29 (s, 3 H).

4-(Methoxycarbonyl)benzenediazonium 4-Methylbenzenesulfonate (4e)

White solid; yield: 4.81 g (96%).

^1H NMR (400 MHz, DMSO-d_6): δ = 8.82 (d, J = 9.0 Hz, 2 H), 8.42 (d, J = 9.0 Hz, 2 H), 7.48 (d, J = 8.0 Hz, 2 H), 7.11 (d, J = 7.9 Hz, 2 H), 3.96 (s, 3 H), 2.29 (s, 3 H).

2-Methoxybenzenediazonium 4-Methylbenzenesulfonate (4f)

Pale beige solid; yield: 3.86 g (84%).

^1H NMR (400 MHz, DMSO-d_6): δ = 8.55 (dd, J = 8.4, 1.6 Hz, 1 H), 8.22 (ddd, J = 9.0, 7.5, 1.7 Hz, 1 H), 7.69 (d, J = 8.8 Hz, 1 H), 7.48 (d, J = 7.9 Hz, 2 H), 7.44 (ddd, J = 8.3, 7.4, 0.7 Hz, 1 H), 7.12 (d, J = 7.8 Hz, 2 H), 4.18 (s, 3 H), 2.29 (s, 3 H).

4-(Trifluoromethyl)benzenediazonium 4-Methylbenzenesulfonate (4g)

White solid; yield: 4.9 g (95%).

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^{1}H NMR (400 MHz, DMSO-d_6): δ = 8.93 (d, *J* = 8.6 Hz, 2 H), 8.41 (d, *J* = 8.8 Hz, 2 H), 7.48 (d, *J* = 8.0 Hz, 2 H), 7.11 (d, *J* = 7.9 Hz, 2 H), 2.29 (s, 3 H).

4-(Trifluoromethoxy)benzenediazonium 4-Methylbenzenesulfonate (4h)

White solid; yield: 4.91 g (91%).

^{1}H NMR (400 MHz, DMSO-d_6): δ = 8.86 (d, *J* = 9.3 Hz, 2 H), 7.98 (d, *J* = 8.7 Hz, 2 H), 7.47 (d, *J* = 8.0 Hz, 2 H), 7.10 (d, *J* = 7.8 Hz, 2 H), 2.28 (s, 3 H).

2,3-Dihydrobenzo[*b*][1,4]dioxine-6-diazonium 4-Methylbenzenesulfonate (4i)

Light brown solid; yield: 4.23 g (91%).

^{1}H NMR (400 MHz, DMSO-d_6): δ = 8.25–8.00 (m, 2 H), 7.48 (d, *J* = 8.1 Hz, 2 H), 7.43–7.40 (m, 1 H), 7.12 (d, *J* = 7.9 Hz, 2 H), 4.59–4.54 (m, 2 H), 4.46–4.41 (m, 2 H), 2.29 (s, 3 H).

4-(Piperidin-1-ylcarbonyl)benzenediazonium 4-Methylbenzenesulfonate (4j)

White solid; yield: 5.12 g (88%).

^{1}H NMR (400 MHz, DMSO-d_6): δ = 8.75 (d, *J* = 8.8 Hz, 2 H), 7.96 (d, *J* = 8.9 Hz, 2 H), 7.48 (d, *J* = 8.0 Hz, 2 H), 7.11 (d, *J* = 7.9 Hz, 2 H), 3.67–3.54 (m, 2 H), 3.20–3.08 (m, 2 H), 2.29 (s, 3 H), 1.66–1.55 (m, 4 H), 1.50–1.42 (m, 2 H).

4-((3*R*,5*R*,7*R*)-Adamantan-1-yl)benzenediazonium 4-Methylbenzenesulfonate (4k)

White solid; yield: 5.42 g (88%).

^{1}H NMR (400 MHz, DMSO-d_6): δ = 8.62 (d, *J* = 9.0 Hz, 2 H), 7.99 (d, *J* = 9.0 Hz, 2 H), 7.49 (d, *J* = 8.0 Hz, 2 H), 7.11 (d, *J* = 7.8 Hz, 2 H), 2.29 (s, 3 H), 2.10 (br s, 3 H), 1.93–1.90 (m, 6 H), 1.84–1.63 (m, 6 H).

Tetrazoles 3a–y; General Procedure

A dry test tube with a screw cap and a magnetic stir bar was charged with $AgNO_3$ (5.3 mg, 0.03 mmol, 0.1 equiv) and DABCO (50 mg, 0.45 mmol, 1.5 equiv). A mixture of anhydrous DMF (0.2 mL) and anhydrous THF (2 mL) was added, followed by addition of the corresponding diazo compound **5** (0.3 mmol, 1.0 equiv). The resulting suspension was stirred at 0 °C for 5 min before the corresponding diazonium tosylate **4** (0.33 mmol, 1.1 equiv) was added. The reaction mixture was stirred for 16 h at ambient temperature. The resulting suspension was poured onto a Celite plug and washed with EtOAc (2 × 15 mL). The resulting filtrate was washed with water (10 mL) and brine (10 mL), and dried over Na_2SO_4. After filtration, the solution was concentrated under reduced pressure, and the residue was purified by column chromatography on silica gel to afford the corresponding tetrazole.

(2-Phenyl-2*H*-tetrazol-5-yl)(*p*-tolyl)methanone (3a)

Prepared from 2-diazo-1-(*p*-tolyl)ethan-1-one (**5a**)[14] and benzenediazonium tosylate (**4a**).

Pale yellow solid; yield: 48 mg (61%); mp 98.4–100.7 °C.

^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.39–8.32 (m, 2 H), 8.31–8.23 (m, 2 H), 7.67–7.56 (m, 3 H), 7.39 (d, *J* = 8.0 Hz, 2 H), 2.49 (s, 3 H).

^{13}C NMR (101 MHz, $CDCl_3$): δ = 182.0, 162.6, 145.6, 136.5, 133.0, 130.9, 130.5, 129.8, 129.4, 120.4, 21.9.

HRMS-ESI: *m*/*z* calcd for $C_{15}H_{12}N_4ONa$ [M + Na]: 287.0903; found: 287.0906.

(2-(4-Fluorophenyl)-2*H*-tetrazol-5-yl)(*p*-tolyl)methanone (3b)

Prepared from 2-diazo-1-(*p*-tolyl)ethan-1-one (**5a**)[14] and 4-fluorobenzenediazonium tosylate (**4b**).

Yellow solid; yield: 49 mg (58%); mp 122.7–123.9 °C.

^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.38–8.30 (m, 2 H), 8.30–8.21 (m, 2 H), 7.38 (d, *J* = 8.0 Hz, 2 H), 7.35–7.27 (m, 2 H), 2.49 (s, 3 H).

^{13}C NMR (101 MHz, $CDCl_3$): δ = 181.8, 164.8, 162.7, 162.3, 145.6, 133.0, 132.7, 130.9, 129.4, 122.5, 122.4, 117.1, 116.8, 21.9.

HRMS-ESI: *m*/*z* calcd for $C_{15}H_{11}FN_4ONa$ [M + Na]: 305.0809; found: 305.0814.

(2-(4-Methoxyphenyl)-2*H*-tetrazol-5-yl)(*p*-tolyl)methanone (3c)

Prepared from 2-diazo-1-(*p*-tolyl)ethan-1-one (**5a**)[14] and 4-methoxybenzenediazonium tosylate (**4c**).

Orange solid; yield: 53 mg (60%); mp 107.0–109.0 °C.

^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.38–8.32 (m, 2 H), 8.16 (d, *J* = 9.1 Hz, 2 H), 7.38 (d, *J* = 8.0 Hz, 2 H), 7.09 (d, *J* = 9.1 Hz, 2 H), 3.92 (s, 3 H), 2.49 (s, 3 H).

^{13}C NMR (101 MHz, $CDCl_3$): δ = 182.0, 162.5, 161.2, 145.4, 133.1, 130.9, 129.9, 129.4, 121.9, 114.8, 55.7, 21.9.

HRMS-ESI: *m*/*z* calcd for $C_{16}H_{14}N_4O_2Na$ [M + Na]: 317.1009; found: 317.1014.

(2-(4-Nitrophenyl)-2*H*-tetrazol-5-yl)(*p*-tolyl)methanone (3d)

Prepared from 2-diazo-1-(*p*-tolyl)ethan-1-one (**5a**)[14] and 4-nitrobenzenediazonium tosylate (**4d**).

Orange solid; yield: 36 mg (39%); mp 147.4–148.2 °C (dec).

^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.51 (s, 4 H), 8.35–8.28 (m, 2 H), 7.40 (d, *J* = 8.0 Hz, 2 H), 2.50 (s, 3 H).

^{13}C NMR (101 MHz, $CDCl_3$): δ = 181.4, 163.1, 148.5, 146.0, 140.1, 132.7, 130.9, 129.6, 125.6, 121.0, 21.9.

HRMS-ESI: *m*/*z* calcd for $C_{15}H_{11}N_5O_3Na$ [M + Na]: 332.0754; found: 332.0755.

Methyl 4-(5-(4-Methylbenzoyl)-2*H*-tetrazol-2-yl)benzoate (3e)

Prepared from 2-diazo-1-(*p*-tolyl)ethan-1-one (**5a**)[14] and 4-(methoxycarbonyl)benzenediazonium tosylate (**4e**).

Pale yellow solid; yield: 49 mg (51%); mp 160.8–161.6 °C (dec).

^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.46–8.28 (m, 6 H), 7.40 (d, *J* = 8.1 Hz, 2 H), 4.01 (s, 3 H), 2.50 (s, 3 H).

^{13}C NMR (101 MHz, $CDCl_3$): δ = 181.7, 165.6, 162.8, 145.8, 139.2, 132.9, 132.0, 131.4, 130.9, 129.5, 120.1, 52.6, 21.9.

HRMS-ESI: *m*/*z* calcd for $C_{17}H_{14}N_4O_3Na$ [M + Na]: 345.0958; found: 345.0957.

(2-(2-Methoxyphenyl)-2*H*-tetrazol-5-yl)(*p*-tolyl)methanone (3f)

Prepared from 2-diazo-1-(*p*-tolyl)ethan-1-one (**5a**)[14] and 2-methoxybenzenediazonium tosylate (**4f**).

Light yellow solid; yield: 64 mg (73%); mp 97.6–98.9 °C.

^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.35 (d, *J* = 8.3 Hz, 2 H), 7.66–7.51 (m, 2 H), 7.36 (d, *J* = 8.1 Hz, 2 H), 7.21–7.08 (m, 2 H), 3.89 (s, 3 H), 2.46 (s, 3 H).

^{13}C NMR (101 MHz, $CDCl_3$): δ = 182.0, 162.4, 153.6, 145.4, 133.1, 132.6, 130.9, 129.4, 127.0, 125.9, 120.7, 112.8, 56.3, 21.8.

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HRMS-ESI: *m*/*z* calcd for $C_{16}H_{14}N_4O_2Na$ [M + Na]: 317.1009; found: 317.1013.

(*p*-Tolyl(2-(4-(trifluoromethyl)phenyl)-2*H*-tetrazol-5-yl)methanone (3g)

Prepared from 2-diazo-1-(*p*-tolyl)ethan-1-one (**5a**)[14] and 4-(trifluoromethyl)benzenediazonium tosylate (**4g**).

Pale beige solid; yield: 81 mg (81%); mp 130.9–133.3 °C (dec).

^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.43 (d, *J* = 8.5 Hz, 2 H), 8.34 (d, *J* = 8.0 Hz, 2 H), 7.91 (d, *J* = 8.5 Hz, 2 H), 7.40 (d, *J* = 8.0 Hz, 2 H), 2.50 (s, 3 H).

^{13}C NMR (101 MHz, $CDCl_3$): δ = 181.6, 162.9, 145.9, 138.7, 132.9, 132.5 (q, *J* = 33.3 Hz), 130.9, 129.5, 127.2 (q, *J* = 3.7 Hz), 123.3 (q, *J* = 272.5 Hz), 120.6, 21.9.

HRMS-ESI: *m*/*z* calcd for $C_{16}H_{11}F_3N_4ONa$ [M + Na]: 355.0777; found: 355.0786.

(4-Methoxyphenyl)(2-phenyl-2*H*-tetrazol-5-yl)methanone (3h)

Prepared from 2-diazo-1-(4-methoxyphenyl)ethan-1-one (**5b**)[16] and benzenediazonium tosylate (**4a**).

Beige solid; yield: 66 mg (78%); mp 94.6–97.2 °C.

^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.51–8.42 (m, 2 H), 8.28–8.18 (m, 2 H), 7.64–7.50 (m, 3 H), 7.03 (d, *J* = 9.0 Hz, 2 H), 3.91 (s, 3 H).

^{13}C NMR (101 MHz, $CDCl_3$): δ = 180.6, 164.7, 162.7, 136.4, 133.3, 130.5, 129.8, 128.5, 120.3, 114.0, 55.6.

HRMS-ESI: *m*/*z* calcd for $C_{15}H_{12}N_4O_2Na$ [M + Na]: 303.0852; found: 303.0858.

(4-Fluorophenyl)(2-phenyl-2*H*-tetrazol-5-yl)methanone (3i)

Prepared from 2-diazo-1-(4-fluorophenyl)ethan-1-one (**5c**)[17] and benzenediazonium tosylate (**4a**).

Light yellow solid; yield: 59 mg (74%); mp 101.9–103.2 °C.

^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.65–8.44 (m, 2 H), 8.34–8.20 (m, 2 H), 7.70–7.56 (m, 3 H), 7.35–7.22 (m, 2 H).

^{13}C NMR (101 MHz, $CDCl_3$): δ = 180.6, 166.6 (d, *J* = 257.7 Hz), 162.4, 136.4, 133.6 (d, *J* = 9.6 Hz), 131.9 (d, *J* = 3.0 Hz), 130.7, 129.9, 120.4, 116.0 (d, *J* = 22.0 Hz).

HRMS-ESI: *m*/*z* calcd for $C_{14}H_9FN_4ONa$ [M + Na]: 291.0653; found: 291.0644.

(4-Chlorophenyl)(2-phenyl-2*H*-tetrazol-5-yl)methanone (3j)

Prepared from 1-(4-chlorophenyl)-2-diazoethan-1-one (**5e**)[16] and benzenediazonium tosylate (**4a**).

Yellow solid; yield: 60 mg (71%); mp 86.9–87.8 °C.

^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.48–8.37 (m, 2 H), 8.31–8.20 (m, 2 H), 7.70–7.51 (m, 5 H).

^{13}C NMR (101 MHz, $CDCl_3$): δ = 181.0, 162.3, 141.1, 136.4, 133.8, 132.1, 130.7, 129.9, 129.1, 120.4.

HRMS-ESI: *m*/*z* calcd for $C_{14}H_{10}ClN_4O$ [M + H]: 285.0538; found: 285.0539.

(2-Chlorophenyl)(2-phenyl-2*H*-tetrazol-5-yl)methanone (3k)

Prepared from 1-(2-chlorophenyl)-2-diazoethan-1-one (**5d**)[18] and benzenediazonium tosylate (**4a**).

Light yellow solid; yield: 49 mg (57%); mp 104.3–105.8 °C.

^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.26–8.16 (m, 2 H), 7.76–7.72 (m, 1 H), 7.67–7.52 (m, 5 H), 7.46 (ddd, *J* = 7.7, 6.5, 2.2 Hz, 1 H).

^{13}C NMR (101 MHz, $CDCl_3$): δ = 183.8, 162.5, 136.39, 136.38, 133.0, 132.7, 130.70, 130.69, 130.67, 129.9, 126.9, 120.4.

HRMS-ESI: *m*/*z* calcd for $C_{14}H_9ClN_4ONa$ [M + Na]: 307.0357; found: 307.0371.

(3,4-Dimethoxyphenyl)(2-phenyl-2*H*-tetrazol-5-yl)methanone (3l)

Prepared from 2-diazo-1-(3,4-dimethoxyphenyl)ethan-1-one (**5f**)[18] and benzenediazonium tosylate (**4a**).

Pale yellow solid; yield: 65 mg (70%); mp 122.7–123.9 °C (dec).

^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.26 (dd, *J* = 8.1, 2.2 Hz, 3 H), 7.96 (d, *J* = 2.0 Hz, 1 H), 7.67–7.55 (m, 3 H), 7.02 (d, *J* = 8.5 Hz, 1 H), 4.02 (s, 6 H).

^{13}C NMR (101 MHz, $CDCl_3$): δ = 180.6, 162.8, 154.7, 149.2, 136.5, 130.5, 129.8, 128.6, 126.8, 120.3, 112.1, 110.2, 56.2, 56.1.

HRMS-ESI: *m*/*z* calcd for $C_{16}H_{14}N_4O_3Na$ [M + Na]: 333.0958; found: 333.0961.

(3,4-Difluorophenyl)(2-phenyl-2*H*-tetrazol-5-yl)methanone (3m)

Prepared from commerically available 2-diazo-1-(3,4-difluorophenyl)ethan-1-one (**5g**) and benzenediazonium tosylate (**4a**).

Beige solid; yield: 53 mg (62%); mp 106.0–107.5 °C.

^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.45–8.33 (m, 2 H), 8.32–8.19 (m, 2 H), 7.70–7.56 (m, 3 H), 7.45–7.33 (m, 1 H).

^{13}C NMR (101 MHz, $CDCl_3$): δ = 179.5, 162.0, 154.6 (dd, *J* = 259.7, 12.9 Hz), 150.4 (dd, *J* = 251.1, 13.0 Hz), 136.3, 132.3 (dd, *J* = 5.0, 3.6 Hz), 130.8, 130.0, 128.2 (dd, *J* = 7.7, 3.6 Hz), 120.4, 120.1 (dd, *J* = 18.9, 1.9 Hz), 117.8 (d, *J* = 17.9 Hz).

HRMS-ESI: *m*/*z* calcd for $C_{14}H_8F_2N_4ONa$ [M + Na]: 309.0558; found: 309.0558.

2,2-Dimethyl-1-(2-phenyl-2*H*-tetrazol-5-yl)propan-1-one (3n)

Prepared from 1-diazo-3,3-dimethylbutan-2-one (**5h**)[19] and benzenediazonium tosylate (**4a**).

Yellow solid; yield: 30 mg (43%); mp 117.0–118.2 °C (dec).

^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.22 (d, *J* = 7.8 Hz, 2 H), 7.72–7.53 (m, 3 H), 1.52 (s, 9 H).

^{13}C NMR (101 MHz, $CDCl_3$): δ = 196.5, 161.3, 136.5, 130.5, 129.8, 120.3, 44.7, 26.5.

HRMS-ESI: *m*/*z* calcd for $C_{12}H_{14}N_4ONa$ [M + Na]: 253.1060; found: 253.1065.

(2-Phenyl-2*H*-tetrazol-5-yl)(pyridin-3-yl)methanone (3o)

Prepared from 2-diazo-1-(pyridin-3-yl)ethan-1-one (**5i**)[20] and benzenediazonium tosylate (**4a**).

Pale orange solid; yield: 48 mg (64%); mp 74.6–77.6 °C.

^{1}H NMR (400 MHz, $CDCl_3$): δ = 9.66 (d, *J* = 2.2 Hz, 1 H), 8.90 (dd, *J* = 4.9, 1.7 Hz, 1 H), 8.72 (dt, *J* = 8.0, 2.0 Hz, 1 H), 8.32–8.16 (m, 2 H), 7.70–7.47 (m, 4 H).

^{13}C NMR (101 MHz, $CDCl_3$): δ = 181.0, 161.9, 154.3, 151.8, 137.8, 136.3, 131.2, 130.8, 129.9, 123.6, 120.4.

HRMS-ESI: *m*/*z* calcd for $C_{13}H_{10}N_5O$ [M + H]: 252.0880; found: 252.0886.

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(2-Phenyl-2*H*-tetrazol-5-yl)(thiophen-2-yl)methanone (3p)

Prepared from 2-diazo-1-(thiophen-2-yl)ethan-1-one (**5j**)[18] and benzenediazonium tosylate (**4a**).

Beige solid; yield: 54 mg (70%); mp 109.5–110.8 °C.

^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.68 (dd, *J* = 3.9, 1.1 Hz, 1 H), 8.32–8.24 (m, 2 H), 7.89 (dd, *J* = 4.9, 1.2 Hz, 1 H), 7.68–7.56 (m, 3 H), 7.30 (dd, *J* = 5.0, 3.9 Hz, 1 H).

^{13}C NMR (101 MHz, $CDCl_3$): δ = 173.7, 162.1, 141.8, 137.1, 136.7, 136.4, 130.7, 129.9, 128.8, 120.4.

HRMS-ESI: *m*/*z* calcd for $C_{12}H_8N_4OSNa$ [M + Na]: 279.0311; found: 279.0319.

(1-Methyl-1*H*-pyrrol-2-yl)(2-phenyl-2*H*-tetrazol-5-yl)methanone (3q)

Prepared from 2-diazo-1-(1-methyl-1*H*-pyrrol-2-yl)ethan-1-one (**5k**)[21] and benzenediazonium tosylate (**4a**).

Beige solid; yield: 53 mg (70%); mp 82.0–83.3 °C (dec).

^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.24 (dt, *J* = 6.4, 1.3 Hz, 2 H), 7.82 (dd, *J* = 4.3, 1.7 Hz, 1 H), 7.66–7.51 (m, 3 H), 7.05 (t, *J* = 2.1 Hz, 1 H), 6.29 (dd, *J* = 4.3, 2.4 Hz, 1 H), 4.12 (s, 3 H).

^{13}C NMR (101 MHz, $CDCl_3$): δ = 170.9, 163.5, 136.6, 133.8, 130.3, 129.8, 129.6, 124.9, 120.2, 109.5, 38.1.

HRMS-ESI: *m*/*z* calcd for $C_{13}H_{11}N_5ONa$ [M + Na]: 276.0856; found: 276.0861.

Morpholino(2-(4-(trifluoromethoxy)phenyl)-2*H*-tetrazol-5-yl)methanone (3r)

Prepared from 2-diazo-1-morpholinoethan-1-one (**5l**)[22] and 4-(trifluoromethoxy)benzenediazonium tosylate (**4h**).

Yellowish amorphous solid; yield: 44 mg (43%).

^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.33–8.22 (m, 2 H), 7.46 (d, *J* = 8.7 Hz, 2 H), 3.96–3.89 (m, 4 H), 3.88–3.83 (m, 2 H), 3.83–3.76 (m, 2 H).

^{13}C NMR (101 MHz, $CDCl_3$): δ = 160.1, 157.2, 150.3 (q, *J* = 1.8 Hz), 134.5, 122.2, 121.8, 120.3 (q, *J* = 255.2 Hz), 66.9, 66.7, 47.6, 43.1.

HRMS-ESI: *m*/*z* calcd for $C_{13}H_{12}F_3N_5O_3Na$ [M + Na]: 366.0784; found: 366.0804.

2-(4-(Adamantan-1-yl)phenyl)-*N*,*N*-diethyl-2*H*-tetrazole-5-carboxamide (3s)

Prepared from 2-diazo-*N*,*N*-diethylacetamide (**5m**)[23] and 4-((3*R*,5*R*,7*R*)-adamantan-1-yl)benzenediazonium tosylate (**4k**).

Pale yellow, amorphous solid; yield: 20 mg (18%).

^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.17–8.06 (m, 2 H), 7.63–7.51 (m, 2 H), 3.63 (dq, *J* = 21.1, 7.1 Hz, 4 H), 2.21–2.10 (m, 3 H), 2.03–1.92 (m, 6 H), 1.89–1.75 (m, 6 H), 1.32 (td, *J* = 7.1, 2.0 Hz, 6 H).

^{13}C NMR (101 MHz, $CDCl_3$): δ = 160.5, 158.6, 153.9, 134.1, 126.3, 119.8, 43.4, 43.0, 40.9, 36.6, 36.5, 28.8, 14.6, 12.7.

HRMS-ESI: *m*/*z* calcd for $C_{22}H_{29}N_5ONa$ [M + Na]: 402.2264; found: 402.2272.

(4-Bromophenyl)(2-(4-(trifluoromethoxy)phenyl)-2*H*-tetrazol-5-yl)methanone (3t)

Prepared from 1-(4-bromophenyl)-2-diazoethan-1-one (**5n**)[18] and 4-(trifluoromethoxy)benzenediazonium tosylate (**4h**).

Pale yellow solid; yield: 95 mg (77%); mp 113.6–116.3 °C.

^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.38–8.29 (m, 4 H), 7.80–7.71 (m, 2 H), 7.56–7.45 (m, 2 H).

^{13}C NMR (101 MHz, $CDCl_3$): δ = 181.0, 162.4, 150.5 (q, *J* = 1.9 Hz), 134.5, 134.1, 132.2, 130.2, 122.2 (q, *J* = 1.2 Hz), 122.0, 120.3 (q, *J* = 259.0 Hz).

HRMS-ESI: *m*/*z* calcd for $C_{15}H_8BrF_3N_4O_2Na$ [M + Na]: 434.9675; found: 434.9692.

Naphthalen-1-yl(2-(4-(trifluoromethyl)phenyl)-2*H*-tetrazol-5-yl)methanone (3u)

Prepared from 2-diazo-1-(naphthalen-1-yl)ethan-1-one (**5o**)[18] and 4-(trifluoromethyl)benzenediazonium tosylate (**4g**).

Beige solid; yield: 91 mg (82%); mp 144.8–146.6 °C (dec).

^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.75 (d, *J* = 8.5 Hz, 1 H), 8.41 (d, *J* = 8.5 Hz, 2 H), 8.28–8.12 (m, 2 H), 7.98 (dd, *J* = 8.1, 1.5 Hz, 1 H), 7.90 (d, *J* = 8.5 Hz, 2 H), 7.70 (ddd, *J* = 8.5, 6.8, 1.5 Hz, 1 H), 7.66–7.59 (m, 2 H).

^{13}C NMR (101 MHz, $CDCl_3$): δ = 184.3, 163.9, 138.7, 134.7, 133.9, 132.7, 132.5 (q, *J* = 33.2 Hz), 132.4, 131.0, 128.8, 128.7, 127.2 (q, *J* = 3.7 Hz), 126.9, 125.4, 124.7, 124.2, 123.3 (q, *J* = 272.6 Hz), 120.6.

HRMS-ESI: *m*/*z* calcd for $C_{19}H_{11}F_3N_4ONa$ [M + Na]: 391.0777; found: 391.0795.

Benzo[*d*][1,3]dioxol-5-yl(2-(2,3-dihydrobenzo[*b*][1,4]dioxin-6-yl)-2*H*-tetrazol-5-yl)methanone (3v)

Prepared from 1-(benzo[*d*][1,3]dioxol-5-yl)-2-diazoethan-1-one (**5p**)[18] and 2,3-dihydrobenzo[*b*][1,4]dioxine-6-diazonium tosylate (**4i**).

Light orange solid; yield: 79 mg (75%); mp 151.2–151.9 °C (dec).

^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.19 (dd, *J* = 8.3, 1.8 Hz, 1 H), 7.88 (d, *J* = 1.8 Hz, 1 H), 7.77 (d, *J* = 2.6 Hz, 1 H), 7.72 (dd, *J* = 8.8, 2.6 Hz, 1 H), 7.05 (d, *J* = 8.8 Hz, 1 H), 6.96 (d, *J* = 8.3 Hz, 1 H), 6.12 (s, 2 H), 4.36 (s, 4 H).

^{13}C NMR (101 MHz, $CDCl_3$): δ = 180.3, 162.4, 153.1, 148.3, 145.5, 144.2, 130.2, 130.1, 128.3, 118.2, 113.6, 110.0, 109.9, 108.2, 102.1, 64.5, 64.4.

HRMS-ESI: *m*/*z* calcd for $C_{17}H_{12}N_4O_5Na$ [M + Na]: 375.0700; found: 375.0728.

(4-(5-(3-Nitrobenzoyl)-2*H*-tetrazol-2-yl)phenyl)(piperidin-1-yl)methanone (3w)

Prepared from 2-diazo-1-(3-nitrophenyl)ethan-1-one (**5q**)[18] and 4-(piperidin-1-ylcarbonyl)benzenediazonium tosylate (**4j**).

Yellow solid; yield: 82 mg (67%); mp 132.1–134.3 °C (dec).

^{1}H NMR (400 MHz, $CDCl_3$): δ = 9.36 (t, *J* = 2.0 Hz, 1 H), 8.81 (dt, *J* = 7.8, 1.4 Hz, 1 H), 8.57 (ddd, *J* = 8.3, 2.3, 1.1 Hz, 1 H), 8.39–8.27 (m, 2 H), 7.83 (t, *J* = 8.0 Hz, 1 H), 7.73–7.65 (m, 2 H), 3.76 (br s, 2 H), 3.40 (br s, 2 H), 1.91–1.49 (m, 6 H).

^{13}C NMR (101 MHz, $CDCl_3$): δ = 179.9, 168.3, 161.8, 148.5, 139.2, 136.6, 136.5, 136.1, 130.1, 128.7, 128.5, 125.7, 120.5, 48.8, 43.3, 26.6, 25.6, 24.5.

HRMS-ESI: *m*/*z* calcd for $C_{20}H_{19}N_6O_4$ [M + H]: 407.1462; found: 407.1481.

Morpholino(2-phenyl-2*H*-tetrazol-5-yl)methanone (3x)

Prepared from 2-diazo-1-morpholinoethan-1-one (**5l**)[22] and benzenediazonium tosylate (**4a**).

Beige solid; yield: 32 mg (41%); mp 88.5–89.6 °C.

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^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.22–8.11 (m, 2 H), 7.64–7.50 (m, 3 H), 3.97–3.86 (m, 4 H), 3.83 (dd, *J* = 5.9, 4.0 Hz, 2 H), 3.78 (dd, *J* = 5.6, 4.0 Hz, 2 H).

^{13}C NMR (101 MHz, $CDCl_3$): δ = 159.8, 157.4, 136.4, 130.4, 129.8, 120.2, 66.9, 66.7, 47.5, 43.0.

HRMS-ESI: *m*/*z* calcd for $C_{12}H_{13}N_5O_2Na$ [M + Na]: 282.0961; found: 282.0967.

***N*,*N*-Diethyl-2-phenyl-2*H*-tetrazole-5-carboxamide (3y)**

Prepared from 2-diazo-*N*,*N*-diethylacetamide (**5m**)[23] and benzenediazonium tosylate (**4a**).

Yellow oil; yield: 22 mg (30%).

^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.23–8.16 (m, 2 H), 7.65–7.51 (m, 3 H), 3.65 (q, *J* = 7.1 Hz, 2 H), 3.60 (q, *J* = 7.1 Hz, 2 H), 1.33 (t, *J* = 7.1 Hz, 6 H).

^{13}C NMR (101 MHz, $CDCl_3$): δ = 160.6, 158.5, 136.5, 130.2, 129.8, 120.1, 43.4, 40.9, 14.6, 12.7.

HRMS-ESI: *m*/*z* calcd for $C_{12}H_{15}N_5ONa$ [M + Na]: 268.1169; found: 268.1182.

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