Electronic Supplementary Information

Unravelling the Strain-Promoted [3+2] Cycloaddition Reactions of Phenyl Azide with Cycloalkynes within the Molecular Electron Density Theory Perspective

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*1. BET study of the 32CA reaction of phenyl azide **3** with cyclohexyne **C6***

The Bonding evolution theory[1] (BET) comes from the conjunction of ELF topological analysis[2,3] and Thom's Catastrophe theory[4]and has proven to be a very useful methodological tool to establish the nature of the electronic rearrangement associated along the reaction path.[5] Herein, the BETs of the 32CA reactions of phenyl azide **3** with cyclohexyne C**6** and with 2-butyne **13** are studied.

The 32CA reaction of phenyl azide **3** with **C6** takes place along eight different phases (see Table S1). *Phase I* starts at **S0-I**, d_{C4-N3} = 2.97 Å and d_{C5-N1} = 2.64 Å, which corresponds with the first structure of the IRC. ELF of **S0-I** is similar to that of the separated reagents (see section 3.1), except the formation of monosynaptic V(C4) integrating at 1.04 e, which mainly comes from the depopulation of the electron density of C4-C4' single bond adjacent to the alkyne framework. The disynaptic basin V(C4,C4') undergoes depopulation from 2.71 e in **1** to 1.90 e in **S0-I**.

The short phase *Phase II* starts at **S1-I**, d_{C4-N3} = 2.93 Å and d_{C5-N1} = 2.59 Å. The two V(N2,N3) and V'(N2,N3) disynaptic basins present at **S0-I** have merged into a new V(N2,N3) disynaptic basin, integrating 4.26 e. The short phase *Phase III* starts at **S2-I**, d_{C4-N3} = 2.80 Å and d_{C5-N1} = 2.49 Å. The disynaptic V(C4,C5) disynaptic basins present at **S1-I** has split into a two disynaptic basins V(C4,C5) and V'(C4,C5), respectively integrating at 2.24 e and 2.23 e.

Phase IV starts at **S3-I**, d_{C4-N3} = 2.71 Å and d_{C5-N1} = 2.43 Å, which is characterised by the creation of a new V(N2) monosynaptic basin, integrating 0.47 e, associated with the formation of a lone pair at the N2 nitrogen. The electron density of this lone pair mainly comes from the depopulation of the N1-N2 and N2-N3 bonding regions along *Phase III*. In this phase, **TS1** is found. These bonding changes demand an energy cost of 2.2 kcal·mol^{-1}.

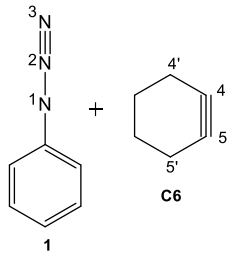
Phase V starts at **S4-I**, d_{C4-N3} = 2.20 Å and d_{C5-N1} = 1.98 Å, which is characterised by the creation of a new V(C5) monosynaptic basin, integrating 0.18 e, associated with the formation of a *pseudoradical* center at the C5 carbon. Together with this change, the V(C4,C5) disynaptic basin experiences a depopulation of 0.30 e along *Phase IV*.

Phase VI starts at **S5-I**, d_{C4-N3} = 2.13 Å and d_{C5-N1} = 1.91 Å. At the beginning of this phase the first more relevant change along the IRC takes place. At this structure, while the V(C5) monosynaptic basin present at **S4-I** is missing, a new V(N1,C5) disynaptic basin, integrating 1.39 e, is created. This topological changes indicate that the formation of the first

N1-C5 single bond has begun at a C–N distance of 1.91Å. Together with this change, the monosynaptic V(N1) basin experiences a depopulation of 1.10 e along *Phase V*.

Phase VII starts at **S6-I**, d_{C4-N3} = 1.95 Å and d_{C5-N1} = 1.73 Å. At this structure, the V(N3) monosynaptic basin present at **S5-I** splits in two V(N3) and V'(N3) monosynaptic basins, integrating 3.34 e and 0.40 e, respectively.

Table S1. ELF valence basin populations, distances of the forming bonds, and relative[a] electronic energies of the gas phase IRC structures **S0-I** – **S7-I** defining the eight phases characterizing the molecular mechanism of the 32CA reaction between phenyl azide **3** with cyclohexyne C**6** yielding 1,2,3-triazole **8**. Distances are given in angstroms, Å, and relative energies in kcal·mol^{-1}.



Phases	*I*	*II*	*III*	*IV*	*V*	*VI*	*VII*	*VIII*	
Structures	**S0-I**	**S1-I**	**S2-I**	**S3-I**	**S4-I**	**S5-I**	**S6-I**	**S7-I**	**8**
d(C4–N3)	2.968	2.925	2.796	2.713	2.200	2.134	1.951	1.727	1.348
d(C5–N1)	2.635	2.594	2.493	2.431	1.979	1.912	1.727	1.551	1.351
ΔE	0.0	0.3	1.4	2.2	-3.9	-8.9	-29.2	-58.8	-115.0
V(N1)	3.30	3.29	3.27	3.26	3.30	2.20	2.00	1.83	1.18
V'(N2)				0.47	2.24	2.35	2.59	2.79	3.13
V(N1,N2)	2.48	2.47	2.40	2.33	1.75	1.72	1.67	1.65	1.74
V(N2,N3)	1.65	4.26	4.34	3.96	2.87	2.80	2.65	2.48	2.08
V'(N2,N3)	2.59								
V(N3)	3.66	3.65	3.64	3.63	3.64	3.66	3.34	3.10	2.88
V′(N3)							0.40		
V(C4,C5)	4.47	4.47	2.24	2.29	2.07	2.03	1.97	1.89	3.47
V'(C4,C5)			2.23	2.16	2.08	2.05	1.95	1.94	
V(C4,C4')	1.90	1.89	1.88	1.87	1.94	1.96	2.01	2.04	2.08
V(C5,C5')	2.41	2.40	2.39	2.38	2.26	2.19	2.11	2.08	2.11
V(C4)	1.04	1.06	1.10	1.13	1.16	1.15	1.05		
V(C5)					0.18				
V(N3,C4)								1.66	2.28
V(N1,C5)						1.39	1.77	2.03	2.41

Finally, the last *Phase VIII* starts at **S7-I**, d_{C4-N3} = 1.73 Å and d_{C5-N1} = 1.55Å., and ends at 1,2,3-triazole **6**, d_{C4-N3} = 1.35 Å and d_{C5-N1} = 1.35Å. At **S7-I** the second more relevant change along the IRC takes place. At this structure, while the V(C4) and V'(N3) monosynaptic basins are missing, a new V(N3,C4) disynaptic basin, integrating 1.66 e, is created. These relevant topological changes indicate that the formation of the second N3–C4 single bond has begun at a C–N distance of 1.73Å, through the C-to-N coupling of the electron density of the C4 *pseudoradical* carbon (integrating 1.05 e) and part of the non-bonding electron density of the N3 nitrogen. Along this last phase, the molecular electron density is relaxed to reach the structure of 1,2,3-triazole **8**, in which the population of the V(N3,C4) and V(N1,C5) disynaptic basins reach a population of 2.28 and 2.41 e, respectively.

*2. BET study of the 32CA reaction of phenyl azide **3** with 2-butyne* **13**

The 32CA reaction of phenyl azide **3** with 2-butyne **13** takes place along nine different phases (see Table S2). *Phase I* starts at **S0-II**, d_{C4-N3} = 3.02 Å and d_{C5-N1} = 2.91 Å, which corresponds with the first structure of the IRC. ELF of **S0-II** is similar to that of the separated reagents (see section 3.1).

The short phase *Phase II* starts at **S1-II**, d_{C4-N3} = 2.78 Å and d_{C5-N1} = 2.72 Å. At this structure the two V(N2,N3) and V'(N2,N3) disynaptic basins present at **S0-II** have merged into a V(N2,N3) disynaptic basin, integrating 4.21 e. This phase demands an energy cost of 3.8 kcal·mol^{-1}.

Phase III starts at **S2-II**, d_{C4-N3} = 2.53 Å and d_{C5-N1} = 2.55 Å, which is characterised by the creation of a new V(N2) monosynaptic basin, integrating 0.58 e, associated with the formation of a lone pair at the N2 nitrogen. The electron density of this lone pair mainly comes from the depopulation of the N1–N2 and N2-N3 bonding regions, which experience depopulation of 0.15 e and 0.41 e along *Phase II*. These bonding changes demand an energy cost of 10.9 kcal·mol^{-1}.

The short phase *Phase IV* starts at **S3-II**, d_{C4-N3} = 2.32 Å and d_{C5-N1} = 2.41 Å. At **S3-II** the V(C4,C5) disynaptic basin is split in two new disynaptic basin, V(C4,C5) and V'(C4,C5), integrating 2.79 and 2.62 e, respectively. These bonding changes demand an energy cost of 18.7 kcal·mol^{-1}.

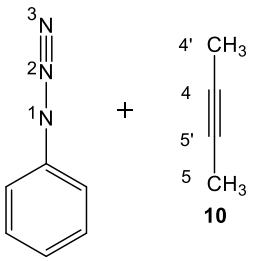
Phase V starts at **S4-II**, d_{C4-N3} = 2.00 Å and d_{C5-N1} = 2.20 Å, which is characterised for the creation of a new V(C4) monosynaptic basin, integrating 0.30 e, associated with the formation of a *pseudoradical* center at the C4 carbon. Together with this change, the V(C4,C5) disynaptic basin undergoes a depopulation of 0.45 e along *Phase IV*. These bonding changes demand an energy cost of 24.2 kcal·mol^{-1}.

Phase VI starts at **S5-II**, d_{C4-N3} = 1.82 Å and d_{C5-N1} = 2.08 Å. At this structure, the V(N3) monosynaptic basin presents at **S4-II** is split in two V(N3) and V'(N3) monosynaptic basins, integrating 3.46 and 0.39 e, respectively.

Phase VII starts at **S6-II**, d_{C4-N3} = 1.74 Å and d_{C5-N1} = 2.02 Å, which is characterised for the creation of a new V(C5) monosynaptic basin, integrating 0.13 e, associated with the formation of a *pseudoradical* center at the C5 carbon. Together with this change, the V(C4,C5) disynaptic basin undergoes a depopulation of 0.22 e along *Phase VI*. These bonding changes demand an energy cost of 12.4 kcal·mol^{-1}.

Phase VIII starts at **S7-II**, d_{C4-N3} = 1.70 Å and d_{C5-N1} = 1.99 Å. At the beginning of this phase the first more relevant change along the IRC takes place. At this structure, while the V(C4) and V'(N3) monosynaptic basins are missing, a new V(N3,C4) disynaptic basin, integrating 1.33 e, is created. These topological changes indicate that the formation of the first N3–C4 single bond has begun at a C–C distance of 1.70Å, through the C-to-N coupling of the two C4 and N3 *pseudoradicals*.

Table S2. ELF valence basin populations, distances of the forming bonds, and relative[a] electronic energies of the gas phase IRC structures **S0-I** – **S8-I** defining the nine phases characterizing the molecular mechanism of the 32CA reaction between phenyl azide **3** with 2-butyne **13** yielding 1,2,3-triazole **14.** Distances are given in angstroms, Å, and relative energies in kcal·mol^{-1}.



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Phases	*I*	*II*	*III*	*IV*	*V*	*VI*	*VII*	*VIII*	*IX*	
Structures	**S0-II**	**S1-II**	**S2-II**	**S3-II**	**S4-II**	**S5-II**	**S6-II**	**S7-II**	**S8-II**	**14**
d(C4–N3)	3.017	2.780	2.534	2.317	2.002	1.823	1.743	1.697	1.623	1.350
d(C5–N1)	2.909	2.724	2.545	2.405	2.203	2.081	2.023	1.986	1.922	1.354
ΔE	0.0	3.8	10.9	18.7	24.2	18.1	12.4	8.2	0.1	-71.2
V(N1)	3.30	3.27	3.25	3.27	3.31	3.32	3.31	3.31	1.98	1.16
V'(N2)			0.58	1.54	2.21	2.44	2.53	2.57	2.64	3.13
V(N1,N2)	2.52	2.49	2.34	2.09	1.81	1.78	1.79	1.78	1.79	1.75
V(N2,N3)	1.70	4.21	3.80	3.12	2.77	2.60	2.54	2.50	2.44	2.07
V'(N2,N3)	2.47									
V(N3)	3.72	3.71	3.69	3.67	3.75	3.46	3.32	3.27	3.19	2.88
V′(N3)						0.39	0.59			
V(C4,C5)	1.70	5.21	5.48	2.79	2.46	2.29	2.24	2.20	2.12	3.51
V'(C4,C5)	1.82	0.30		2.62	2.50	2.38	2.21	2.17	2.13	--
V"(C4,C5)	1.91									
V"(C4,C5)	0.10									
V(C4,C4')	2.16	2.17	2.18	2.20	2.24	2.20	2.16	2.15	2.13	2.06
V(C5,C5')	2.15	2.16	2.17	2.18	2.13	2.07	2.06	2.06	2.05	2.08
V(C4)					0.30	0.55	0.62			
V(C5)							0.13	0.16		
V(C4,N3)								1.33	1.51	2.28
V(C5,N1)									1.54	2.41

Finally, the last *Phase IX* starts at **S8-II**, d_{C4-N3} = 1.62 Å and d_{C5-N1} = 1.92 Å., and ends at 1,2,3-triazole **14**, d_{C4-N3} = 1.35 Å and d_{C5-N1} = 1.35Å. At **S8-II** the second more relevant change along the IRC takes place. At this structure, while the V(C5) monosynaptic basin is missing, a new V(N1,C5) disynaptic basin, integrating 1.54 e, is created. These relevant topological changes indicate that the formation of the second C5–N1 single bond has begun, through the C-to-N coupling of the electron density of the C5 *pseudoradical* carbon (integrating 0.16 e) and part of the non-bonding electron density of the N1 nitrogen. Along this last phase, the molecular electron density is relaxed to reach the structure of 1,2,3-triazole **14**, in which the population of the V(N3,C4) and V(N1,C5) disynaptic basins reach a population of 2.28 and 2.41 e, respectively.

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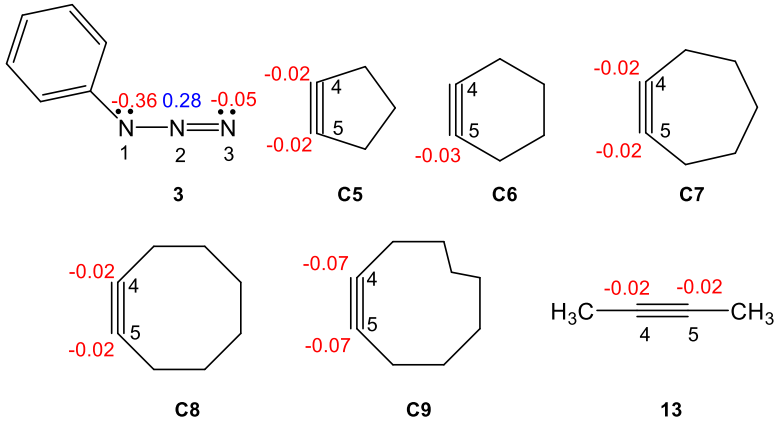

Figure S1. MPWB1K/6-311G(d) calculated gas phase natural atomic charges, in average number of electrons e,of phenyl azide **3**, cycloalkynes series **C5 - C9** and 2-butyne **13**. Negative charges are coloured in red, and positive charges in blue.

Table S3. MPWB1K/6-311G(d,p) calculated gas phase electronic chemical potential μ, chemical hardness η, global electrophilicity ω and global nucleophilicity N, in eV, of phenyl azide **3**, cycloalkyne series **C5 - C9** and 2-butyne **13**.

	μ	η	ω	N
3	-3.62	7.18	0.91	3.18
C5	-4.66	6.11	1.78	2.68
C6	-3.82	7.59	0.96	2.78
C7	-3.27	8.65	0.62	2.80
C8	-2.94	9.63	0.45	2.64
C9	-2.91	9.80	0.43	2.58
13	-2.78	10.23	0.38	2.50

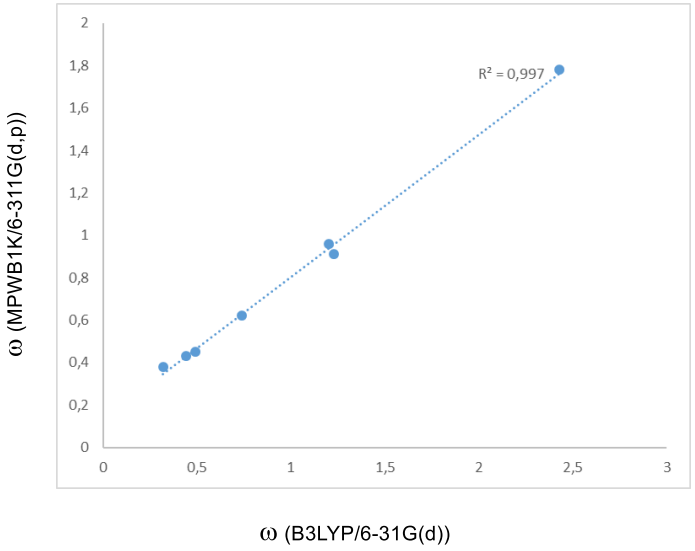

Figure S2. Plot of the MPWB1K/6-311G(d,p) gas phase electrophilicity ω indices *vs* the B3LYP/6-31G(d) ones of phenyl azide **3**, cycloalkyne series **C5 - C9** and 2-butyne **13**.

Table S4. MPWB1K/6-311G(d,p) calculated electronic energies, E in a.u., enthalpies, H in a.u., and Gibbs free energies, G in a.u., computed at 298 K in gas phase, of the stationary points involved in the 32CA reactions of phenyl azide **3** with cycloalkyne series **C5** - **C9** and 2-butyne **13**.

	E	H	G
3	-395.726968	-395.612629	-395.652220
C5	-193.895898	-193.797192	193.829793
C6	-233.253251	-233.122345	-233.157246
C7	-272.580026	-272.417963	-272.455134
C8	-311.894748	-311.701556	-311.741219
C9	-351.201515	-350.977942	-351.019508
13	-155.919626	-155.826896	-155.863417
TS1	-589.631925	-589.417555	-589.473779
8	-589.843793	-589.622840	-589.671029
TS2	-628.974200	-628.728121	-628.783426
9	-629.163459	-628.911488	-628.961484
TS3	-668.292664	-668.016731	-668.071962
10	-668.460498	-668.178074	-668.230810
TS4	-707.598896	-707.291223	-707.351616
11	-707.751148	-707.437731	-707.492988
TS5	-746.900217	-746.562602	-746.621276
12	-747.047856	-746.704090	-746.761249
TS6	-551.607718	-551.400112	-551.452673
14	-551.760068	-551.546929	-551.596012

Table S5. MPWB1K/6-311G(d,p) calculated electronic energies, E in a.u., enthalpies, H in a.u., and Gibbs free energies, G in a.u., computed at 298 K in acetonitrile, of the stationary points involved in the 32CA reactions of phenyl azide **3** with cycloalkyne series **C5 - C9** and 2-butyne **13**.

	E	H	G
3	-395.735105	-395.621680	-395.661304
C5	-193.899214	-193.800683	-193.833386
C6	-233.258460	-233.128128	-233.163170
C7	-272.584897	-272.423436	-272.460637
C8	-311.899348	-311.706804	-311.746457
C9	-351.205865	-350.982974	-351.024528
13	-155.922991	-155.831421	-155.863661
TS1	-589.643586	-589.429140	-589.485085
8	-589.854209	-589.633309	-589.681491
TS2	-628.984832	-628.739937	-628.794909
9	-629.179176	-628.928436	-628.978679
TS3	-668.303597	-668.027900	-668.084768
10	-668.476697	-668.195283	-668.247856
TS4	-707.608430	-707.302116	-707.362018
11	-707.767717	-707.455634	-707.511066
TS5	-746.910277	-746.572932	-746.633552
12	-747.063787	-746.721110	-746.778426
TS6	-551.616071	-551.409372	-551.461748
14	-551.775026	-551.563334	-551.613718