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Gold and diazo reagents: A fruitful couple as a tool to develop molecular complexity

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Since the discovery in 2005 of the potential of soluble Au complexes to catalyse the transfer of carbene groups from diazo compound to organic substrates, an increasing number of transformations have been reported. In this contribution the advances in the field are presented as the foundations for further developments in the incoming years.

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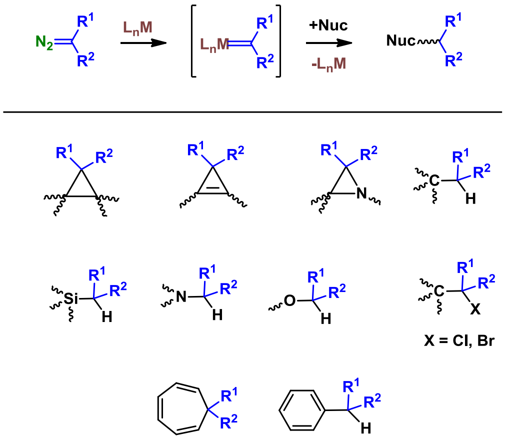
Introduction

It is difficult to find a field in current chemistry that has developed with such a high rate as that of the use of gold in homogeneous catalysis.[1] Interestingly, the first examples were described in the 90's of the last century when Utimoto[2] and Teles[3] described the use of gold complexes for the reaction of alkynes and water in a catalytic manner. This is in contrast with the expansion of the homogeneous catalysis field in the last half century, where very most of the transition- and post-transition metals were employed for catalytic purposes.[4] This "golden-gap" has been associated with the idea of a certain inertness of this metal and their complexes. However, chemistry with gold has been known for decades. As an example, back in 1972, one of the reference books[5] in Inorganic Chemistry already contained a section describing Au(I)-, Au(III)- and organogold complexes, including acetylides. Thus, the foundations for the development of gold-based catalytic systems were available at least 20 years before the aforementioned seminal reports on gold catalysis. Better late than never, since then a nearly exponential growth in the number of contributions on this issue has occurred, most of them based on the capabilities of Au(I) complexes to activate unsaturated, alkyne carbon-carbon bonds.

The metal-catalysed carbene transfer reaction from a diazo compound to an organic substrate has also experienced a substantial increase in the last decade.[6,7] This is due to the fact that the incorporation of the carbene group provides a certain increase in the molecular complexity, a strategy that also allows exerting control in regio-, diastereo- and/or enantio selectivity. Scheme 1 shows some representative transformations reported with this methodology in an intermolecular fashion, the intramolecular versions have also been described in all cases. The reaction is triggered by the formation of a transient metallocarbene intermediate that, acting as the electrophile, reacts with a series of nucleophiles. Thus, unsaturated double bonds of olefins, alkynes or imines can be converted into three member rings upon carbene addition. Saturated E-H bonds, where E = C, N, O, Si, Cl, Br, have also been functionalized in this manner, the products deriving from the insertion of the carbene group into the E-H bond. For C-H bonds, examples of both $C_{sp}{}^3$-H and $C_{sp}{}^2$-H functionalization have been described.[7a] Carbon-halogen bonds have also been analogously modified.[8]



Scheme 1 The metal-catalysed carbene transfer reaction from diazo compounds and representative examples of products. In 2005, gold yet remained as undescribed for any of the above transformations.

For decades, this area has been dominated by dirhodium tetraacetate and copper-based catalysts, although examples with other mid- and late transition metals were gradually appearing in the literature.[6,7] In 2005 those examples covered 11 out of the 12 metals of Groups 8-11, with gold being the unique non-reported element for any of the transformations shown in Scheme 1. Following our research projects on the use

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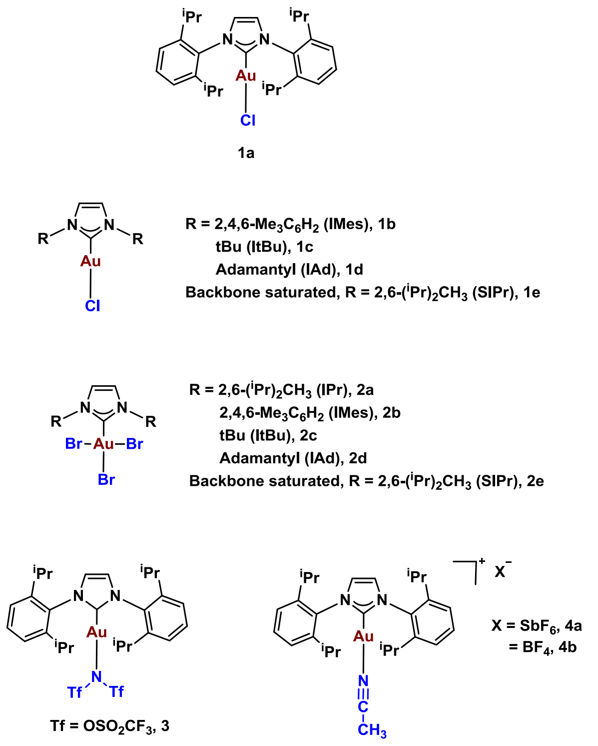
of copper- and silver-based catalysts for carbene transfer reactions from ethyl diazoacetate, a collaboration between our and Nolan's group provided the first example of the use of a Au(I) complex as catalyst in this context (*vide infra*).[9] Since then, a rapid development of Au-based catalysts for diazo compound decomposition and subsequent carbene transfer has occurred. In this contribution, we provide an account of such development with the aim of showing the general features, the accomplished achievements and possible future objectives yet to be reached. [10]

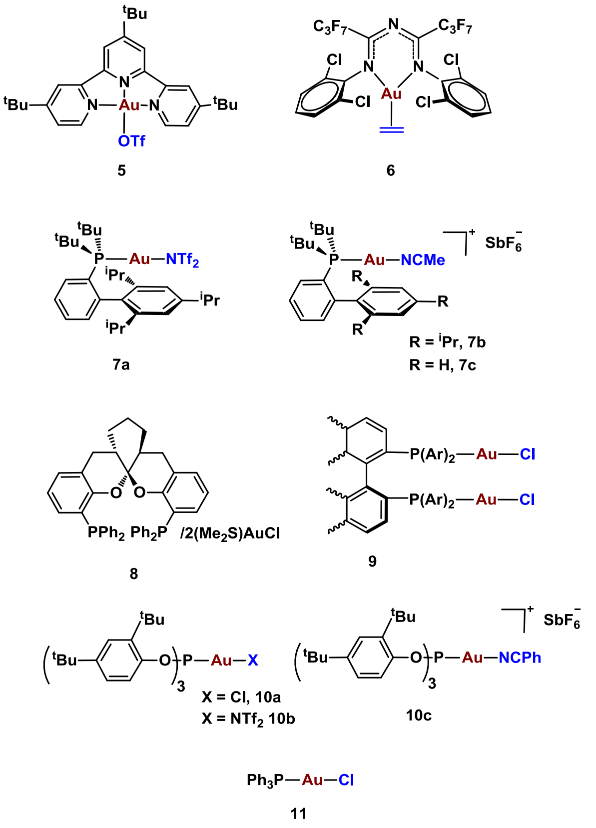
The Catalysts

The gold-based catalysts described for the carbene transfer reaction from diazo compounds do not display much diversity. In addition to simple salts or bulk/nanoparticulate material, most of them correspond to the general formula LAuX, where L is a N-heterocyclic carbene (NHC) or a phosphane ligand and X is a halide or a weak coordinating ligand. Scheme 2 shows the gold complexes bearing NHC ligands that have been described to promote some reactions involving carbene transfer from diazo compounds. Neutral Au(I) (**1a-e**) or Au(III) (**2a-e**) derivatives contain halides as coligands as well as aryl or bulky alkyl substituents attached to the imidazolydene nitrogen atoms.[11,12] The backbone of the NHC ligand is usually unsaturated, albeit some catalytic examples have been described with the saturated ligand SIPr (Scheme 2, **1e** and **2e**). A neutral, halide-free complex with a NTf$_2$ ligand (**3**) has also been employed as catalyst,[13] on the basis of the weak donating capabilities of this N-based donor.



Scheme 2 Gold complexes bearing N-heterocyclic carbene ligands described as catalysts in carbene transfer reactions from diazo compounds.

Well-defined cationic gold complexes have also been reported as catalysts in this area. The NHC-derivatives have been prepared on the basis of halide removal with a silver salt in the presence of a nitrile,[14] leading to the formation of compounds **4a,b**. The isolation of these complexes contrasts with the *in situ* generation of cationic species in solution upon mixing stoichiometric amounts of a neutral gold complex of general composition LAuX and a halide scavenger. Albeit this strategy has proven successful in many cases, the nature of the actual catalytic species might be influenced by this previous step. On one side, it has been claimed by several authors the existence of the so-called "silver effect":[15] the presence of silver seems to enhance the capabilities of the gold-based catalyst in some transformations in which there is none or low activity of the silver salt by itself. The possible formation of dinuclear species with Au-Au and Au-Ag species has been recently invoked to explain such effect in the gold-catalysed hydroalkoxylation of alkynes. In other interesting work, the relative amount of halide scavenger employed was crucial to avoid the formation of non-active halide bridged dinuclear species.[16]



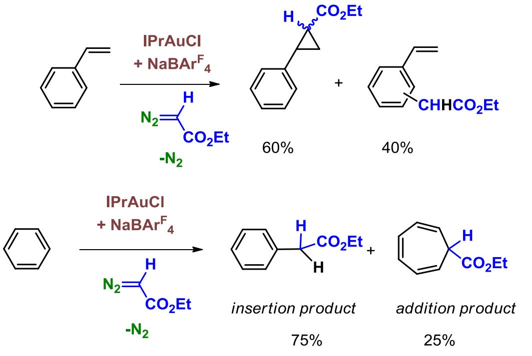
Scheme 3 Gold complexes bearing P- or N-donor ligands described as catalysts in carbene transfer reactions from diazo compounds.

Gold complexes containing a P-donor constitute a second group of catalysts developed for this strategy. Scheme 3 displays the series of compounds that will be commented along this contribution on the basis of their catalytic capabilities. With a general formula of R_3P-Au-X, the neutral complexes can be employed either alone (when bearing the NTf_2 ligand) or with the addition of the corresponding X-scavenger. The aforementioned "silver effect" also applies in this case. Well-defined cationic complexes have been described as the catalysts, ensuring the nature of the catalyst precursor. With this family of complexes, chiral ligands have been employed, affording enantioselective catalytic processes. Scheme 3 also shows two examples of N-donor ligands for Au(I) centers, bi- and tridentate, that have also been described in some transformations.

The seminal IPrAuCl-based system

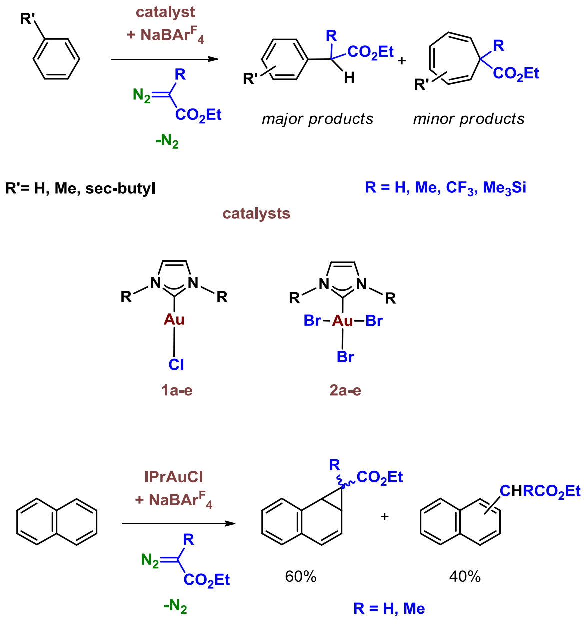
The arene C_{sp}^2-H bond functionalization.

As mentioned above, in 2005 gold remained as the unique metal in groups 8-11 to induce the catalytic transfer of a carbene moiety from a diazo compound to an organic substrate. Aimed to cover this gap, we studied the catalytic capabilities of the complex IPrAuCl (**1a**) toward that end, in the common probe reaction of styrene cyclopropanation, and with ethyl diazoacetate (N_2CHCO_2Et, EDA) as the carbene source and $NaBAr^F_4$ as the halide scavenger. This system induced the complete consumption of EDA as the result of the formation of two styrene-derived products (Scheme 4):[9] in addition to the expected cyclopropanes, another series of compounds derived from the incorporation of the $CHCO_2Et$ moiety into the arene ring were identified, the vinylic double bond remaining unreacted in the latter. This observation was rather surprising, giving the high propensity of the styrene carbon-carbon double bond to add a carbene group forming a cyclopropane ring. When benzene was employed as the substrate, again two products were formed, now the *insertion product* derived from *formal insertion* of the carbene group into the C_{sp}^2-H bond of benzene being the major one. A second compound was observed derived from the so-called Buchner reaction, that is the cyclopropanation of the benzene C=C bond and subsequent ring expansion toward the cycloheptatriene ring (named as the *addition* product). It is worth mentioning that the terms *insertion/addition* are employed exclusively on the basis of the nature of the final products and do not necessarily imply any mechanistic explanation.



Scheme 4 The first example of a gold-catalysed carbene transfer from a diazocompound.

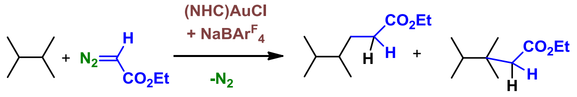
Expansion of the initial studies with substituted arenes,[12] different diazo compounds and a family of NHC-containing Au(I) and Au(III) complexes as the catalysts (Scheme 5) revealed the following features: (i) the insertion product was the major ones in all cases; (ii) when C_{sp}^3-H bonds were available in the substituted benzenes, the reaction was completely selective toward the arene C_{sp}^2-H bond; (iii) the *o:m:p* ratio was only slightly affected by the nature of the catalyst. When naphthalene was used, the selectivity was reversed and the addition product, *i. e.*, the cyclopropanation derivative, was obtained in higher yields than the two possible insertion products (Scheme 5).[17]



Scheme 5 Gold-catalysed functionalization of alkyl-aromatics (top) and naphthalene (bottom) with several diazo reagents

The alkane C_{sp}^3-H bond functionalization.

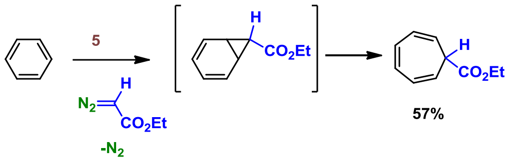
After the discovery of the catalytic potential of **1a** for carbene transfer reactions with aromatic substrates, the less reactive alkanes C_nH_{2n+2} were also tested,[11] following previous work



NHC	%	%
IPr	83	17
IAd	60	40
I^{t}Bu	53	47
IMes	32	68

Scheme 6 The effect of the ancillary ligand in the gold-catalysed C_{sp}^3-H bond functionalization with ethyl diazoacetate

from our group with copper- and silver-based catalysts. A series of linear or branched alkanes were functionalized with **1a-d** as catalysts. In all cases, mixtures of products derived from the insertion in all available C-H bonds were obtained. Albeit with low selectivity, this system proven the access to the high energetic primary C-H bonds of pentane or hexane (Scheme 6). Also, and at variance with the arene system, the selectivity of the system was influenced by the nature of the catalyst employed, as inferred from the data obtained with 2,3-dimethylbutane as the alkane and complexes **1a-d** as the catalysts (Scheme 6). The NHC ligand induced a certain effect in both the activity and the selectivity, a feature that was related to the steric pressure onto the metal centre.

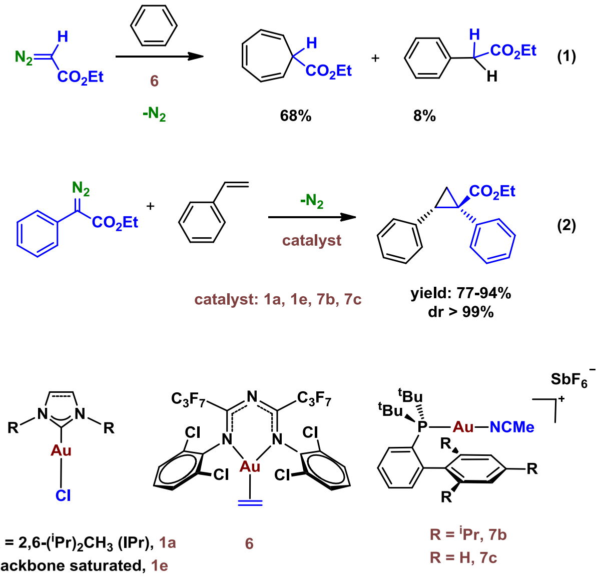


Scheme 7 Benzene conversion into cycloheptatriene carboxylate described by He.

Addition reactions to multiple carbon-carbon bonds

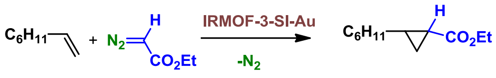
Olefin cyclopropanation

As mentioned above, the C=C cyclopropanation reaction often serves as the probe reaction to evaluate the catalytic potential of a given metal complex to transfer a carbene ligand formed from a diazo reagent. In this sense, after the seminal work described in the previous section, several reports on the use of gold-based catalyst for this transformation appeared. In 2006 He and co-workers[18] described the use of catalyst **5** (Scheme 7) for the addition of $CHCO_2Et$ units from EDA to benzene, leading to the corresponding cycloheptatriene though the cyclopropanated (norcaradiene) intermediate.



Dias, Lovely and co-workers reported[19] on the styrene and benzene cyclopropanation reactions with the 1,3,5-triazapentadienyl gold complex **6**. Moderate yields of the corresponding cyclopropanated products were obtained, with a relatively small amount (<10%) of the insertion products accompanying the reaction outcome (eq 1).

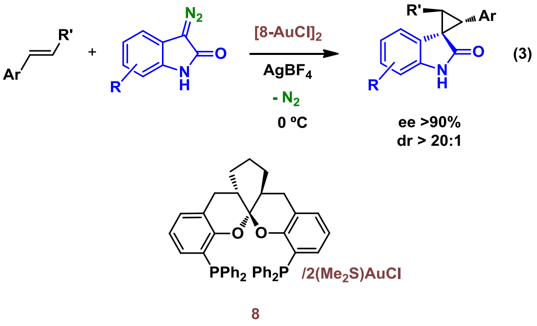
A study involving different NHC (**1a**, **1e**), phosphine (**7b**) and phosphite (**7c**) ligands in gold complexes was developed by our group in collaboration with the group of Echavarren (eqn 2),[20] using 2-phenyldiazoacetate as the carbene source. Cyclopropanes were obtained in a nearly exclusive manner with complete diastereoselectivity toward the *trans*- isomer. A comparative with the related copper and silver derivatives was also carried out, showing the effectiveness of the gold system for such process.



Cycle	cis:trans%	selectivity to cyclopropanes
1	43:57	85
2	43:57	88
3	43:57	85
4	42:58	88

Scheme 8 Recyclable MOF-Au-based catalytic system for 1-octene cyclopropanation.

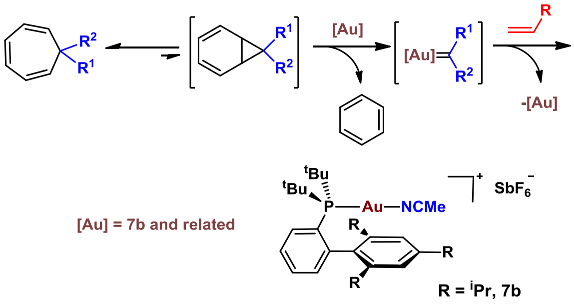
A series of studies involving Au(0) as catalyst for the olefin cyclopropanation reaction have also been described. Corma and co-workers demonstrated that Au(I) or Au(II) simple salts such as $NaAuCl_4$ or $KAu(CN)_2$ readily transfer the carbene $CHCO_2Et$ group (from EDA) to olefins.[21] However, they noticed the formation of nanoparticulated material both in organic solvents and in ionic liquids, the latter medium providing a certain stability to the agglomerated material allowing catalyst recycling. Angelici, Woo and co-workers employed bulk Au metal for several transformations involving carbene transfer, including that of olefin cyclopropanation with EDA: moderate yields were obtained with a certain amount of the olefins derived from the carbene coupling side reaction. The size of the gold particles influenced the reaction outcome.[22]



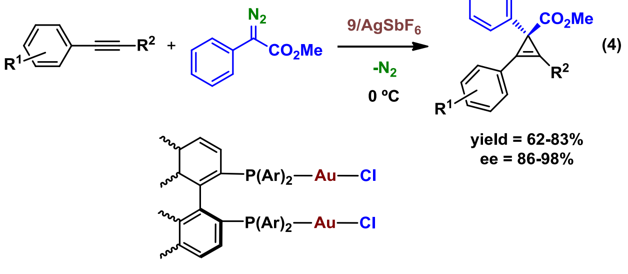
Corma and co-workers have also demonstrated that gold-containing metal-organic frameworks (MOF) can also catalyse the olefin cyclopropanation reaction.[23] This system was effective for a number of olefins and, more interestingly, could be recycled up to four times with the same degrees of conversion, chemo- and diastereoselectivity (Scheme 8).

A chiral digold complex bearing a spiroketal bisphosphine (**8**) has been described by Zhou and co-workers for the highly selective, both in diastereo- and enantioselective manner, olefin cyclopropanation reaction (eqn 3).[24] Diazooxindoles were employed as the carbene source. The system employs aryl-substituted olefins and high yields into cyclopropanes were observed, along with high dr (>20:1) and ee (>90%).

Despite the aim of this contribution, focused to the chemistry involving diazo compounds and gold catalysts for the corresponding carbene transfer reaction, it is worth briefly mentioning that other sources of the carbene moiety have been described.[25] The most frequently employed substrate is 3,3-diphenylcyclopropene, that upon coordination to gold undergoes ring-opening and subsequent formation of metal-carbene intermediates. A second system has been described by Echavarren and co-workers,[26] in which gold catalysts of type **7b** induce the *decarbenation* of cyclotropylium derivatives, i. e., a carbene group is abstracted from the seven member ring (Scheme 9). The resulting gold-carbene species attacks the nucleophiles available in the reaction medium, added styrene inducing the expected cyclopropanation reaction.



Scheme 9 The gold-catalysed cycloheptatriene decarbenation (Echavarren) reaction



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Alkyne cyclopropenation

The conversion of alkynes into cyclopropenes by carbene addition from diazo reagents has been developed with several transition metal-based catalysts including the asymmetric version. [6c,27] One of the main drawbacks of this methodology is its use with internal alkynes in an asymmetric manner. Davies and co-worker have developed[28] a gold-based catalytic system that operates with disubstituted alkynes and provides high yields with very good enantioselectivities (eqn 4). Catalyst is a digold complex bearing a BINAP-modified ligand.

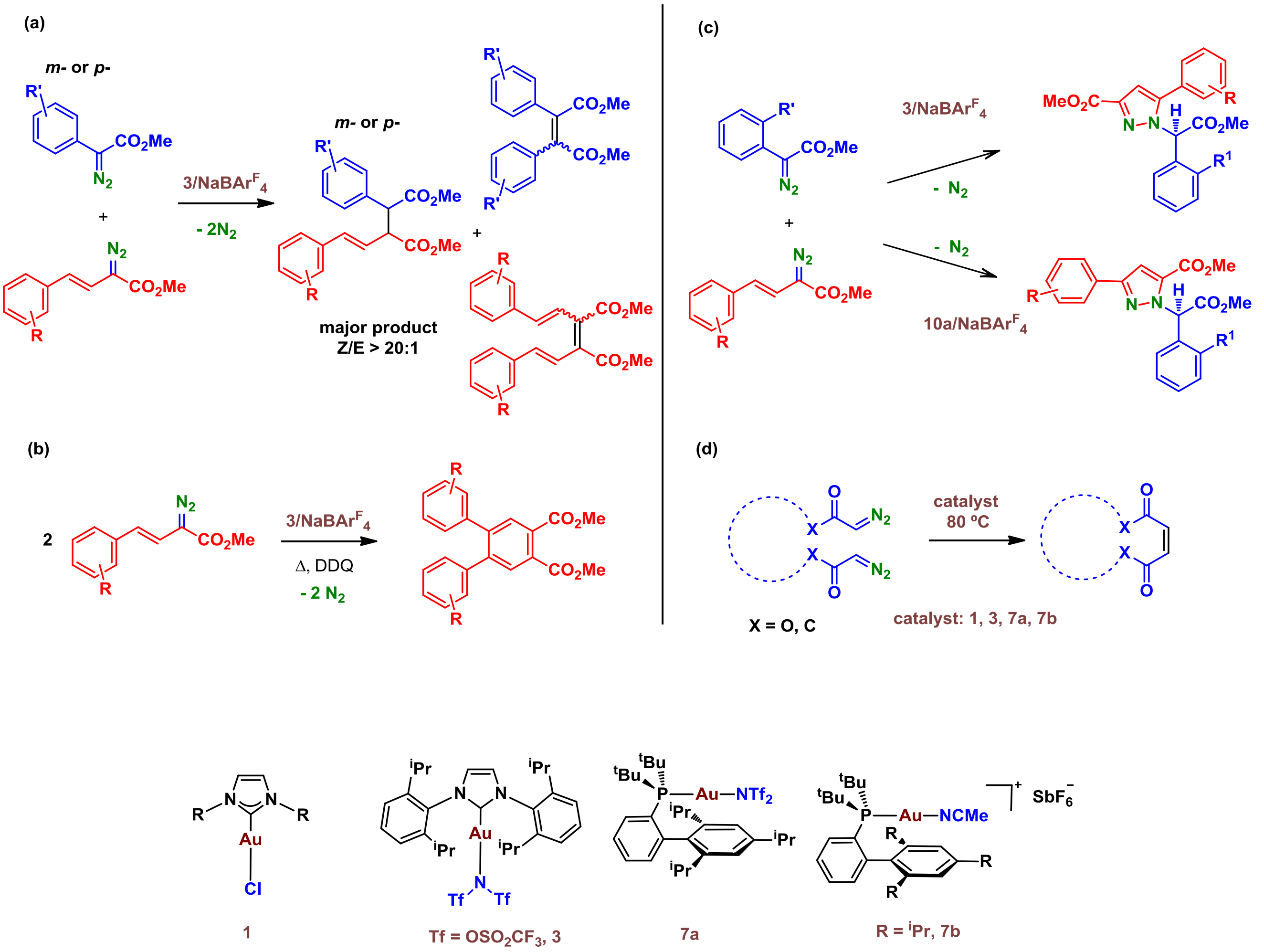
Olefin formation from diazo cross coupling reactions

Many of the metal-catalysed carbene transfer reactions using diazo compounds as the carbene source suffer from a side reaction in which two carbene moieties couple to give an olefin. For many years, this was an undesired reaction that lacked of selectivity. However, in the last decade a number of catalytic systems have been developed with the aim of coupling two carbene units from two different diazocompounds, i. e., a diazo cross-coupling reaction,[29,30] with a certain degree of selectivity.

The use of gold for the diazo cross-coupling reaction has been developed by Sun and co-workers.[31] They discovered that IPrAuNTf$_2$ (**3**) along with NaBAr$^F_4$ promoted the selective coupling of the carbene groups from two different diazo compounds (Scheme 10a). The homocoupling products were formed in ca. 15% whereas the cross-coupling product was by far the main component of the reaction mixture. In addition, a Z/E > 20:1 selectivity was also induced by this gold catalyst. Interestingly, when the vinyldiazoacetate was employed as the sole reactant, a benzene ring could be formed upon carbene coupling followed by heating and oxidation (Scheme 10b).

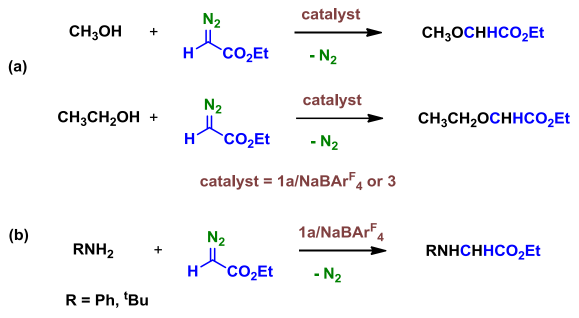
The reaction shown in Scheme 10a proceeded with *m*- or *p*-substituted aryldiazoacetates. However, Sun and co-workers found[32] an interesting and novel transformation with the *o*-substituted derivatives. In this case, a pyrazole was obtained as the result of a denitrogenation and cyclization steps. The election of the gold catalyst became crucial, since the use of either IPrAuNTf$_2$ or [(2,4-tBu$_2$C$_6$H$_3$O)$_3$AuCl], in addition to NaBAr$^F_4$ directed the reaction to a different isomer (Scheme 10c). Finally, this same group has applied this strategy to the intramolecular coupling of two carbene units leading to 8 to 24 membered rings and with a certain control of the Z/E ratio that varied from 20:1 to 1:20 (Scheme 10d).[33]

Insertion reactions in O-H and N-H bonds



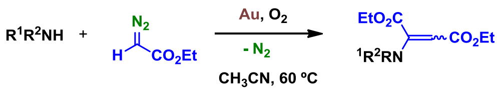
Scheme 10 Diazo cross coupling reactions described with gold-based catalysts.

The incorporation of a carbene moiety from a diazo compound into a saturated E-H bonds (E = C, N, O, Si, halide) with the intermediacy of metal-based catalysts has been known for decades.[6c] In our seminal work with **1a** as the catalyst precursor, we reported[9] such reaction using alcohols and aryl and alkyl amines as the reactants as examples of O-H and N-H functionalization, respectively. Gagosz also described[13] the same methanol and ethanol modification with **3** as the catalyst (Scheme 11).



Scheme 11 Functionalization of O-H and N-H bonds.

A transformation involving N-H functionalization/oxidation has been described by Angelici, Woo and co-workers,[34] with gold powder as the catalyst. As shown in eqn 5, amines react with ethyl diazoacetate at 60 °C in the presence of Au(0) to give enamines.



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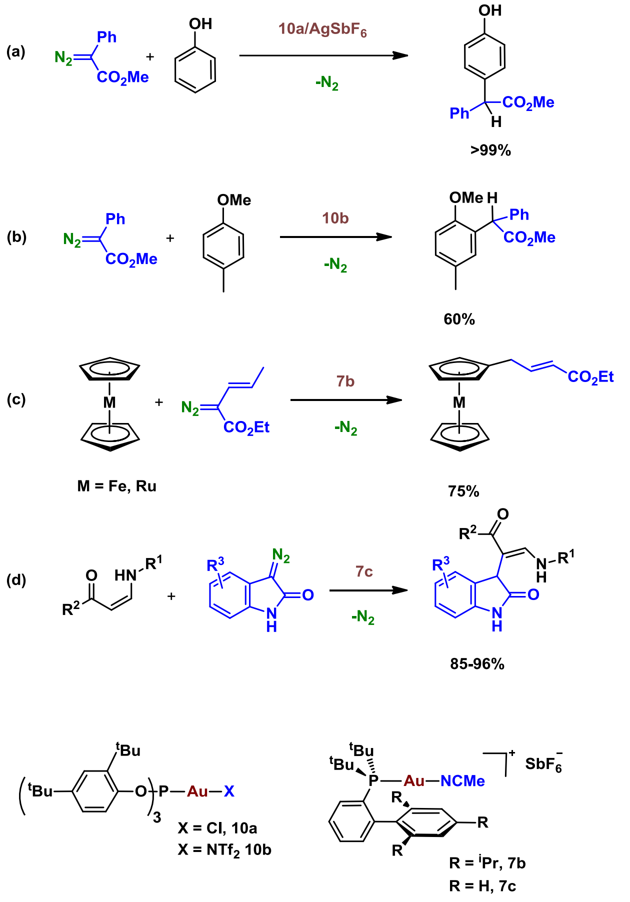
Insertion reactions into C-H bonds

Saturated carbon-hydrogen bonds have also been modified with this strategy. It has already been mentioned the capabilities of the system IPrAuCl/NaBAr$^F_4$ for the incorporation of CHCO$_2$Et groups (from EDA) into the C$_{sp}$^{3}-H bonds of linear or branched alkanes C$_n$H$_{2n+2}$ (see Scheme 6).[11]

This is, to date, the only example reported with a gold-based with such substrates.

Regarding the C_{sp^2}-H, and in addition to the initial reports from our group (see Schemes 4 and 5),[9,12,17] some other examples have been described. Zhang and co-workers have developed[35] a very selective gold-based system for the functionalization of phenols by insertion of carbene units in the arene C-H bonds. This is of interest since previous work with phenols followed the aforementioned O-H derivatization. At variance with that, the group of Zhang found that catalyst **10a**/AgSbF$_6$ induced the exclusive insertion into the C_{sp^2}-H bond (Scheme 12a). The mechanism of this transformation has been elucidated on the basis of a complete experimental and theoretical study.

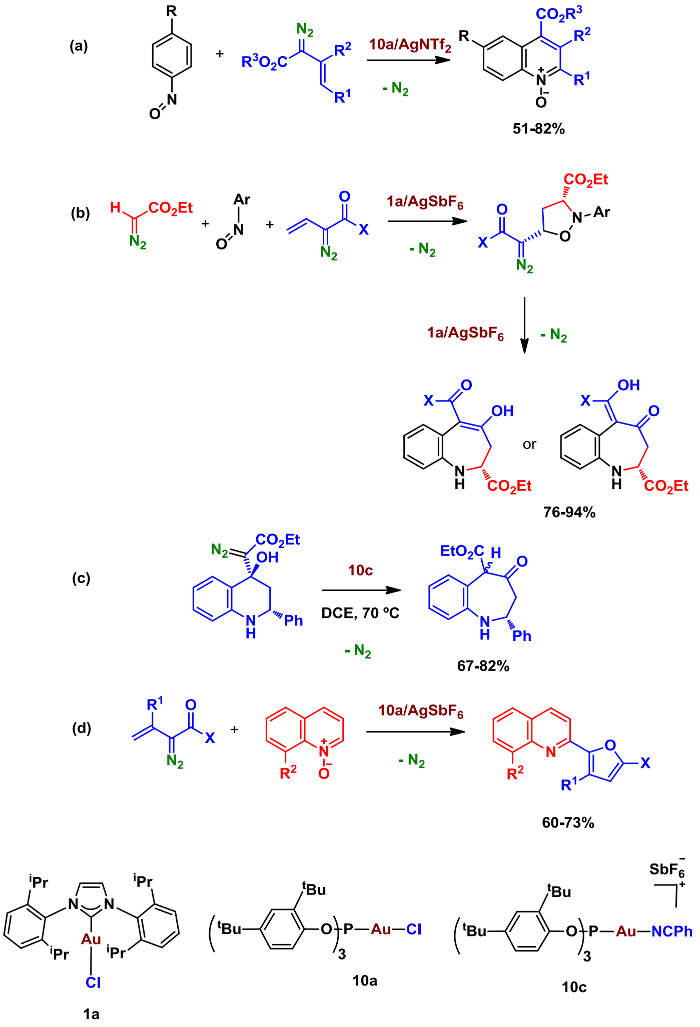


Scheme 12 Functionalization of C_{sp^2}-H bonds (see also Schemes 4 and 5)

Almost simultaneous to the previous work, Shi and co-workers described[36] the use of the catalyst **10b** for the selective, toward the C_{sp^2}-H bond of a series of substituted arenes, fused aromatics and heterocycles. For example, phenol was converted into the corresponding *p*-disubstituted product in high yield whereas p-methylanisol inserted the carbene unit only at moderate yield (Scheme 12b). It is worth mentioning that this work also reported on the use of 1,3-diketones as carbon electrophiles promoting the functionalization of the C_{sp^3}-H located in between both carbonyl groups.

Barluenga and co-workers have reported[37] the modification of C_{sp^2}-H bonds of alkenes or arenes using vinyl diazocompounds in the presence of catalytic amounts of **3**. As a follow-up of this work, López and co-workers applied the same strategy to ferrocene/ruthenocene as the substrates, with **7b** as the catalyst (Scheme 12c). [38] The reactions have been proposed occurring through the intermediacy of a gold-carbene species containing an allyl moiety that attacks such ring in an electrophilic manner.

Li and co-workers have employed[39] catalyst **7c** for the selective functionalization of C_{sp^2}-H bonds of enaminones, where the N-H bond remains unreacted (Scheme 12d). The products thus obtained could be further converted into more complex molecules upon acid catalysis.

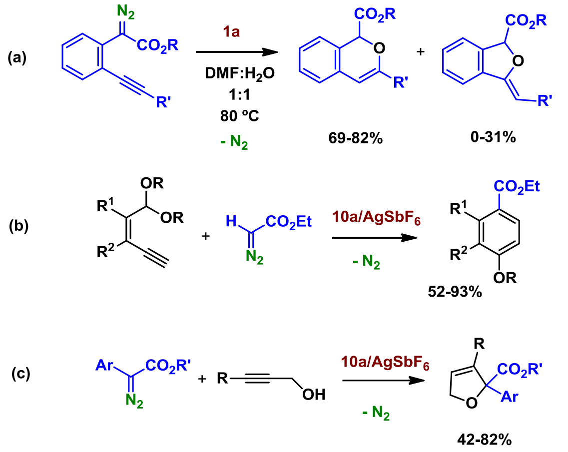


Scheme 13 Cycloaddition reactions involving nitrosoarenes

Cycloaddition reactions

The previous paragraphs have shown the development of gold-based catalysts for the carbene transfer reaction in transformations where one or two bonds are formed corresponding to either addition or insertion of the carbene entity. A second general type of reactions involve the formation of cycles that is accompanied, in many cases, by concomitant rearrangement of a given group. In this section the use of gold catalysts for such reactions is presented.

Liu and co-workers have described a number of reactions in which nitroarenes are involved (Scheme 13) leading to a series of bicyclic compounds. Thus, when a nitrosoarene was reacted with a vinyldiazoacetate in the presence of **10a**/AgNTf$_2$, quinolone oxides were obtained in moderate to high yield (Scheme 13a), in a formal [3+3] addition reaction.[40]



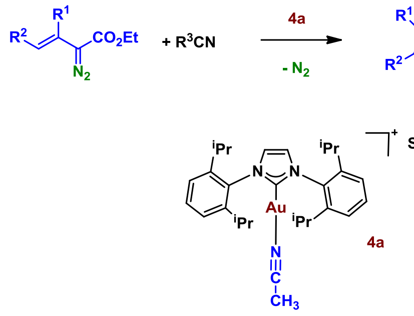
Scheme 14 Alkyne substrates employed in gold-catalysed cycloaddition reactions.

In a second interesting transformation, catalyst **1a**/AgSbF$_6$ catalysed a three component reaction involving a nitrosoarene and two different diazo reagents that first provided a diazo compound bearing a five membered ring derived from a [3+2] cycloaddition.[41] A subsequent, also gold-catalysed cycloaddition afforded benzoazepines (Scheme 13b) in 76-94% yield. Actually, this second step corresponds to a 1,2-H shift/[3,3] rearrangement. These benzoazepines had been previously prepared also by means of gold-catalysis with **10c** as the catalyst and a diazo-cycloadduct precursor (prepared by acid catalysis from an alkenyldiazo reagent and imine) in similar yields (Scheme 13c).[42]

Quinoline oxides have also been reacted with alkenyldiazoacetates[43] in a transformation that involves formal C$_{sp}{}^2$-H functionalization and furan ring formation (Scheme 13d).

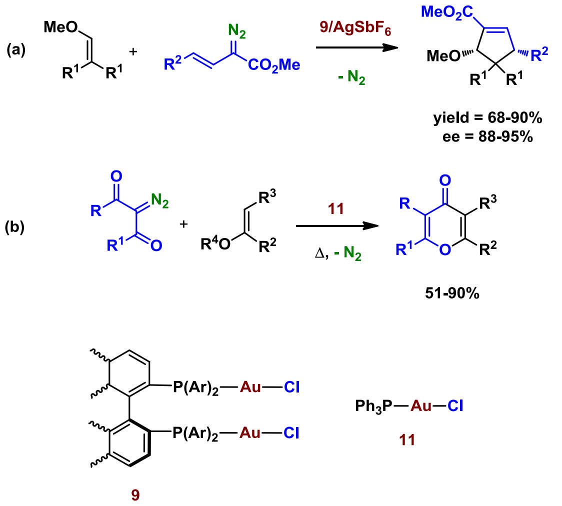
A second group of cycloaddition reactions involve alkyne functionalities (Scheme 14). Wang and co-workers employed **1a** as the catalyst to induce the conversion of *o*-acetylenyl plenyldiazoacetates into 1*H*-isochromenes with water as the second reactant.[44] The product resulting from 5-*exo-dig* cyclization was detected as the minor component of the final reaction mixture (Scheme 14a). Liu and co-workers employed[45] ethyl diazoacetate and alkyne-containing acetals in the presence of **10a**/AgSbF$_6$ to deliver arene rings (Scheme 14b). Wang and Zhang employed the same catalyst precursors for the reaction of aryldiazoacetates with propargyl alcohols that provided 2,5-dihydrofurans in moderate to high yields (Scheme 14c).[46]

López and co-worker found[47] that alkenyldiazo compounds can be reacted with nitriles yielding pyrroles with **4a** as the catalyst (eqn 6). The transformation, that implies a formal [3+2] cycloaddition, took place in a completely regioselective manner.



(6)

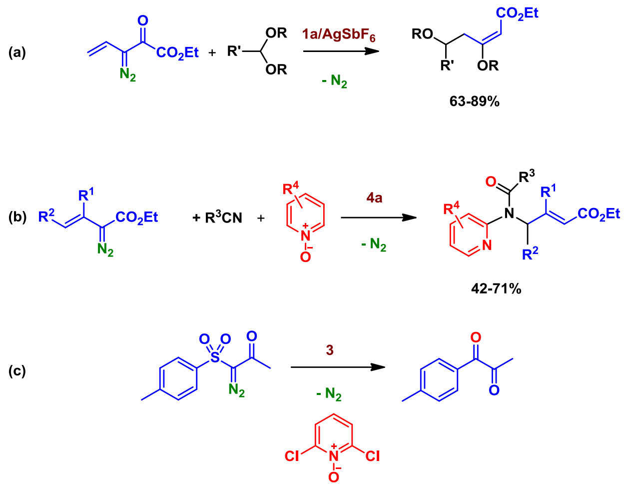
Enol ethers have also been modified with diazo compounds under gold catalysis. Davies and coworkers described[48] the vinylogous [3+2] reaction between these two reactants with a chiral gold catalyst (**9**/AgSbF$_6$), leading to cyclopentenes with high yields and very high ee values (Scheme 16a). Lee and co-workers have developed the synthesis of pyrenes from vivnyl ethers and diazocarbonyl reagents.[49] Albeit the catalyst precursor employed was PPh$_3$AuCl (**11**), the authors demonstrated the formation of nanoparticulated material that could be responsible for this transformation (Scheme 16b).



Scheme 16 Gold-catalysed reactions of diazo compounds and enol ethers

Miscellaneous reactions

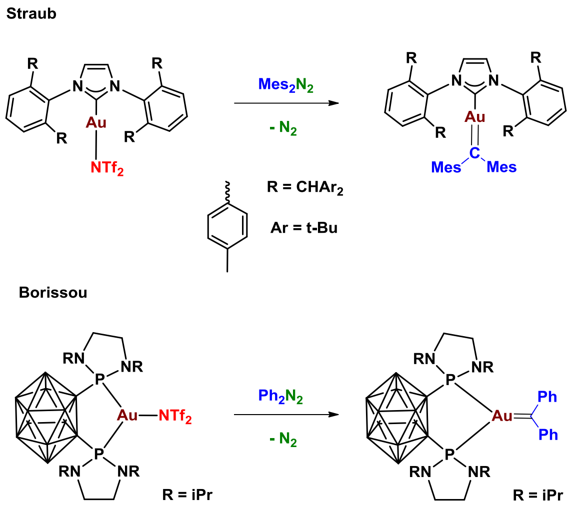
Three more examples that escape from the previous classifications deserve some comments. Liu and co-workers described[50] the catalytic potential of **1a**/$AgSbF_6$ for the coupling of alkenyl diazoacetates with organic acetals, that were converted into pent-2-enoates in a stereseolective manner (Scheme 17a). The same group reported[51] the gold-catalysed oxoarylations of nitriles in an intramolecular fashion, with **4a** as the catalyst. The reaction employed an N-oxide reagent, similarly to the reactions shown in Scheme 13. However in this case no cycloaddition reaction occurred since the nitrile induced a distinct reaction outcome (Scheme 17b). A third reaction constitutes a desulfonylative process of a diazo reagent (Scheme 17c): Zhang and co-worker demonstrated[52] that complex **3** catalysed the conversion of a α-sulfonyl-α-diazoacetone into the corresponding diketone.



Scheme 17 Gold-catalysed miscellaneous reactions with diazo compounds using NHC-Au-based catalysts (see Scheme 2).

Gold carbenes as intermediates

Many, but not all the transformations described in the previous sections have been proposed occurring through gold-carbene intermediates.[53] This class of compounds have been prepared by several strategies, albeit their synthesis from the direct interaction of a Au source and a diazo reagent is yet scarce. Two examples have been described independently by Straub[54] and Borissou.[55] As shown in Scheme 18, a $NHCAuNTf_2$ complex bearing the bulky IPr** ligand reacts with dimesityldiazomethane to give the gold-carbene complex, that was not only isolated but also structurally characterized by X-ray studies, showing a certain degree of backbonding from the Au centre to the carbene ligand. The second example employed a bisphosphine ligand with a carborane linker and a similar strategy: the NTf_2 derivative was reacted with diphenyldiazomethane affording the carbene complex. Structural studies showed that backbonding in this case was lower, or nearly inexistent.



Scheme 18 The examples of isolated gold-carbene complexes from diazo compounds

Summary and Outlook

After a decade since the first report on a gold-catalysed carbene transfer reaction from a diazo reagent, a number of interesting transformations with impact from a synthetic point of view have been reported. However, this area of gold catalysis is yet in its infancy and many development are yet to be done. One of them consists of the design of diverse catalysts: this contribution has shown that most of the work has been done with a relatively small number of catalysts, the same ones being employed in many cases. In spite of their success, a rational design might lead to significant improvement. This could help, for instance, in a better control of the selectivity for the C_{sp^2}-H or C_{sp^3}-H reactions described herein, a goal to be targeted. Enantioselective catalysis has been briefly reported, and further work should bring outstanding results on the basis of the known systems. Also, the silver effect, yet controversial, should be eliminated upon design of strategies for the synthesis of well-define, isolable gold complexes that could be employed without any additive. These and other features make the near future very attractive not only for the groups currently working in this area but also for those approaching to it.

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