Coupling of Two Multistep Catalytic Cycles for the One-Pot Synthesis of Propargylamines from Alcohols and Primary Amines on a Nanoparticulated Gold Catalyst

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Abstract: A one-pot reaction was performed with a nanoparticulated gold catalyst. A secondary amine is formed through N-monoalkylation of a primary amine with an alcohol by a borrowing hydrogen methodology in a three-step reaction. The secondary amine formed enters into a second A^3 -coupling cycle to give propargylamines. The multistep reaction requires a gold species formed and stabilized on a ceria surface.

Introduction

Gold has recently attracted considerable attention in the area of homo- and heterogeneous catalysis.^[1-3] Analogously to other transition metals, Au-H hydride-type complexes have been synthesized^[3h] or postulated as intermediates in a number of gold-catalyzed reactions, such as hydrogenations,^[3b,c,4] hydrosilylations,^[5] dehydrogenative silvlation of alcohols,^[6] hydroboration,^[7] C-H activation,^[8] and aerobic oxidation of alcohols, among others.^[9,10] For oxidation of alcohols it has been proposed that these gold hydride species can react with oxygen and regenerate the Au catalytic sites with concomitant production of water.^[9b] Nonetheless, the replacement of O₂ by other hydrogen acceptor molecules may yield additional products of high added value. The strategy relates to the so-called borrowing hydrogen methodology, which combines hydrogen transfer reactions with additional transformations to obtain more complex structures.^[11]

It has recently been described that a diverse range of metals catalyze the N-monoalkylation of primary amines with alcohols under hydrogen-transfer conditions to afford secondary amines after three coupled reactions, dehydrogen-ation–condensation–hydrogenation.^[11] In this case, after dehydrogenation by a metal catalyst, the hydrogen-donor compound (the alcohol) gives a carbonyl compound that can condense with an amine to form an imine and a metal hydride. Finally, the imine is hydrogenated by the metal-hydride complex to afford a secondary amine and the metal

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active site is regenerated. It may be possible to integrate the above reaction for the formation of amines with an additional catalytic cycle to access more-complex structures, for example, propargylamines,^[12,13] preferably in the presence of the same catalyst.

Propargylamine or 2-propinylamine derivatives are molecules of pharmaceutical relevance and important building blocks in the preparation of nitrogen-containing compounds.^[12] Because these compounds can be obtained from secondary amines and terminal alkynes in the presence of gold nanoparticles supported on nanometric oxides such as CeO_2 ,^[13] we envisaged connecting the two catalytic cycles in a gold-catalyzed cascade (Scheme 1). In the first cycle (A, Scheme 1), N-monoalkylation of amines with alcohols will take place to afford secondary amines under hydrogentransfer conditions. In a consecutive cycle (B, Scheme 1), 2propinylamines will be formed through a multicomponent A³ transformation (Scheme 1).

This strategy might lead to the direct formation of diverse C-C and C-N bonds with a single catalyst in a straightforward fashion, through four successive transformations without interference. The result would be a more-intensive process with higher product yield and fewer waste products.



Scheme 1. Schematic representation of the one-pot synthesis of propargylamines. Cycle A: monoalkylation of a primary amine; cycle B: A³ coupling reaction.

Results and Discussion

Gold nanoparticles deposited on an oxide surface (e.g., CeO_2 , ZrO_2 , TiO_2) were used as the catalyst for the multi-

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step transformation described above and the characteristics of the catalyst are given in Table 1S (see the Supporting Information). First, we studied the one-pot N-monoalkylation of amines with alcohols to give secondary amines by a borrowing hydrogen methodology. Second, the amine generated in situ was reacted in a multicomponent catalytic A³ coupling to afford propargylamines (Scheme 1). Comprehensive studies for the catalytic A³ coupling on heterogeneous gold catalysts have shed light on the mechanism of the reaction,^[13a] therefore we initially focused on the gold-catalyzed synthesis of N-monoalkylated amines to discern how the reaction proceeds kinetically and mechanistically on the metal surface.^[11d] Finally, the optimum catalyst and experimental conditions were tuned to carry out the two cycles coupled as a single process.

Gold-catalyzed N-monoalkylation of alcohols to give secondary amines by a borrowing hydrogen strategy: N-Monoalkylation of benzylamine with benzyl alcohol to afford dibenzylamine (\mathbf{P}_2) was chosen as a model reaction. No conversion was found in the absence of catalyst. The experimental results obtained for the one-pot synthesis of the secondary amine \mathbf{P}_2 at different temperatures and metal loadings are summarized in Table 1. The reactions were performed with

Table 1. Direct gold-catalyzed synthesis of P_2 from benzyl alcohol and benzylamine. $^{\rm [a]}$



[a] Reaction conditions: PhCH₂OH (1 mmol), PhCH₂NH₂ (1 mmol), TFT (1 mL), catalyst (0.9 mol%), dodecane (0.2 mmol), 180 °C, N₂. [b] Conversion (amount of benzyl alcohol transformed) determined by GC. [c] Turnover number = (mmol benzyl alcohol converted)/[mmol catalyst (total Au content)]. [d] Turnover frequency = [mmol benzyl alcohol converted)/mmol catalyst (total Au content] × h. [e] No solvent used. [f] Au (0.3 mol%). [g] Unreduced Au/CeO₂–NH sample was used as the catalyst (see the Experimental Section for catalyst preparation). [h] Reaction carried out at 140 °C. [i] Au (0.24 mol%). [j] Au (0.14 mol%). [k] Au (0.24 mol%).

trifluorotoluene (TFT) as the solvent, as well as under solvent-free conditions.

In general, the results collected in Table 1 show that gold supported on cerium oxide gives the highest conversions and yields of the secondary amine \mathbf{P}_2 , when compared with gold supported on other carriers, regardless of the metal loading. The evolution of reactants and products over time with an Au/CeO₂ catalyst are shown in Figure 1.



Figure 1. Plots showing the yields of benzyl alcohol (\mathbf{v}) , \mathbf{P}_1 (\mathbf{n}) , \mathbf{P}_2 (\mathbf{o}) , and \mathbf{P}_3 (\mathbf{A}) versus time in the N-alkylation of benzylamine with benzyl alcohol catalyzed by Au/CeO₂ (1.7% wt; Table 1, entry 1).

Interestingly, secondary products (such as benzene and toluene), typically formed when working from similar onepot reactions with other metals,^[11a,b] were not detected. Nonetheless, in some cases, minor amounts of the dialkylated product, tribenzylamine (\mathbf{P}_3), were formed (Table 1), which indicated that the N-alkylation proceeds in a stepwise manner.

The yield of monoalkylated amine did not improve either with an excess of alcohol or in the presence of H_2 (5 bar), which indicates that H_2 does not dissociate under these experimental conditions or hydrogenation by hydrogen transfer is not the rate-determining step.

Finally, it should be noted that the conversion and yield of the secondary amine \mathbf{P}_2 are also very high in the presence of Au/CeO₂ under solvent-free conditions (Table 1, entries 1, 4–7). This fact is especially relevant when seeking compatibility for catalysts involved in sequential transformations because, in an ideal situation, the residual products (solvent, additives, and even the catalyst) from preceding steps should not interfere with the catalyst involved in the next catalytic cycle (Scheme 1). In a practical sense, the fact that solvent is not required will eliminate potential limitations when multiple catalytic cycles are combined.

Rate-determining step for the gold-catalyzed N-monoalkylation of amines with alcohols: Similar monoalkylations of amines with alcohols have been carried out with solid palladium-based bifunctional catalysts. Kinetic studies have

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shown that the rate-determining step for the reaction is the hydrogen transfer from the surface hydride moieties to the olefin.^[11a,b] In the case of gold catalysts, we first performed a kinetic study to determine the rate-determining step for the N-monoalkylation of amines by alcohols, not only for gaining further insight into the reaction mechanism, but also to determine what catalyst parameters should be changed to improve the reaction rate.

The three elementary steps for the N-monoalkylation of benzylamine with benzyl alcohol-that is, alcohol dehydrogenation, condensation between the aldehyde and the primary amine to form the imine, and finally hydrogenation of the imine-have been formulated in Equations 1-3 (Scheme 2):

$$PhCH_2OH + 2 Au^0 \xrightarrow{k_a} PhCHO + 2 Au-H$$
(1)

$$PhCHO + PhCH_2NH_2 \xrightarrow{\kappa_b} PhHC \longrightarrow NCH_2Ph + H_2O$$
(2)

hHC
$$\longrightarrow$$
 NCH₂Ph + 2 Au-H $\xrightarrow{\kappa_c}$ PhH₂C \longrightarrow NHCH₂Ph + 2 Au⁰ (3)

Scheme 2. The three reaction steps and their kinetic constants, $k_{\rm a}$, $k_{\rm b}$, and k_c .

From these equations, three kinetic rate expressions were derived by assuming that each step [dehydrogenation of benzyl alcohol to give benzaldehyde and metal hydride [Eq. (1)], the condensation reaction [Eq. (2)], or the hydrogenation [Eq. (3)] in turn was the overall rate-determining step, with the other two steps in equilibrium (Table 2).

Table 2. Kinetic rate expressions obtained for each potential rate-determining step.

Entry	Rate- determining step	Rate equation ^[a,b]
1	Eq. (1)	$r_0 = k_a [PhCH_2OH]$
2	Eq. (2)	$r_0 = k_b [PhCHO] [PhCH_2NH_2]$
3	Eq. (3)	$r_0 = k_c[P_1][Au-H] = k_c K_b K_a[PhCH_2NH_2][PhCH_2OH]$

[a] $k_{\rm a}$, $k_{\rm b}$, and $k_{\rm c}$ are the kinetic constants for steps 1–3, respectively. [b] $K_{\rm a}$ and $K_{\rm b}$ are the steady-state constants for the dehydrogenation and condensation steps, respectively.

To discriminate among the three kinetic expressions, the initial concentration of the alcohol was kept constant (1 mmol) and the initial concentration of the amine was varied. The initial reaction rates were measured with Au/ CeO_2 as the catalyst. The same procedure was applied with the initial concentration of amine constant (1 mmol) and variation of the initial concentration of the alcohol. Interestingly, and contrarily to what was observed with palladium,^[11a,b] the initial reaction rate (r_0) was first order with respect to the alcohol ([PhCH2OH]) but did not depend on the concentration of the amine ([PhCH₂NH₂]) (Figure 2).

According to the rate equations shown in Table 2, only Equation (1) depends only on the concentration of the alcohol. The results from Figure 2 indicate that the dehydrogenation reaction should be the slowest step in the gold-cata-



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Figure 2. a) Initial reaction rate (r_0) versus PhCH₂NH₂/PhCH₂OH (1 mmol); b) r₀ versus PhCH₂OH/PhCH₂NH₂ (1 mmol).

lyzed N-monoalkylation. If so, a positive effect on the rate of alcohol dehydrogenation when the crystallite size of the gold nanoparticles is decreased could be expected.^[9d] We prepared a series of Au/CeO2 catalysts with different metal crystal size^[9d] and, taking into account the particle-size distribution, TOF values were calculated by dividing the initial reaction rate for dehydrogenation of benzyl alcohol by the number of surface metal atoms. The results were plotted versus the average particle size for the different catalysts (Figure 3).^[XXX]

As can be observed, the TOF for dehydrogenation of benzyl alcohol increases as the gold crystal size decreases, which indicates that dehydrogenation of the alcohol occurs preferentially on gold atoms with lower coordination, that is, those located at crystal edges and corners.

Mechanism of hydrogen-transfer reduction; alcohol-aldehyde equilibrium on Au/CeO₂: To shed light on the mechanism of gold-mediated hydrogen transfer to imines, we considered the alcohol-aldehyde equilibrium established at an initial stage of the reaction and the possible intermediates involved in this process. Our aim was to determine how the hydrogen transfer occurs and, if possible, the nature of the gold catalytic species involved.

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Figure 3. Initial reaction rate (r_0) per surface atom as a function of metal particle size for dehydrogenation of benzyl alcohol to afford benzaldehyde (**n**), condensation to give P₁ (**•**), and hydrogenation to afford **P**₂ (**•**).

Thus, theoretical DFT calculations have shown that the selective oxidation of ethanol to ethanal can proceed through two elementary steps: 1) homolytic activation of the OH group on Au⁰; 2) homolytic breaking of the C–H positioned α to the OH group with formation of ethanal and Au–H species on the metal surface.^[9d] According to these calculations, the gold-catalyzed dehydrogenation of PhCD₂OH should afford PhCDO and Au–H and Au–D intermediate species on the catalyst surface. Then, in the equilibrium, Au–H and Au–D would hydrogenate the aldehyde (or in general a multiple bond, for example, the imine **P**₁) and a mixture of deuterated alcohols should be obtained at the end of the reaction, if the pathway presented in Figure 4 is followed.^[11a]

The hydrogen transfer in this pathway would take place through H/D scrambling, which should be easily recognized by NMR spectroscopy. Isotopically enriched alcohol PhCD₂OH was reacted with freshly reduced Au/CeO₂ at 180 °C and the ¹³C NMR spectrum was recorded after the reaction reached equilibrium. In this case, three different signals were detected in the ¹³C NMR spectrum, which were assigned to CD₂, CDH, and CH₂.

The appearance of CDH and CH_2 signals (Figure 5) confirmed the existence of H/D scrambling and indicated that homolytic activation of OH on metallic gold (Figure 4) is operative under our reaction conditions.

X-Ray photoelectron spectroscopy (XPS) data of the freshly reduced Au/CeO₂ catalyst confirmed that the gold is almost exclusively in the form of Au^0 species (binding



Figure 5. ¹³C NMR, spectra recorded in CDCl₃, of PhCD₂OH treated with Au/CeO₂ at the equilibrium. CDH (\blacktriangle), CD (\blacksquare), CH₂ (\blacklozenge).

energy Au $4f_{7/2}=83.7 \text{ eV}$; 100%). The persistence of the CD₂ signal may simply be ascribed to the existence of unreacted PCD₂OH provided that no other gold species are detected by XPS. These experimental facts evidence that, at least with the reduced Au/CeO₂ catalyst, hydrogen transfer by the pathway shown in Figure 4 takes place through H/D scrambling mediated by metallic gold species, as suggested by previous theoretical studies.

Scope of the reaction: The scope of the reaction has been studied with different amines and alcohols in the presence of Au/CeO₂ (Table 3). In general, the selectivity of the reaction and conversion into P_2 were higher with benzyl alcohol (Table 3, entries 1–6) than with simple aliphatic alcohols (Table 3, entries 7 and 12). The catalytic results were much worse when both substrates where aliphatic (Table 3, entry 12).

The presence of halogen substituents at the *para* position of the aromatic alcohol slowed the reaction, but the conversion and selectivity values towards P_2 were still excellent (Table 3, entry 8). Electron-donating substituents at the *para* position did not improve the selectivity of the reaction towards P_2 (Table 3, entries 9 and 10).

When sterically hindered secondary alcohol 1-phenylethanol was used the conversion values were only slightly lower, but the yield of P_2 fell to 5% and imine P_1 was the major product (Table 3, entry 11).

Domino gold-catalyzed N-monoalkylation of amines and A^3 coupling reaction: The successful N-monoalkylation of primary amines to secondary amines by a borrowing hydrogen methodology offers the possibility to increase the complexity of the reaction by coupling the secondary amine formed in situ to an aldehyde and an alkyne to afford 2-propinyl-

amine derivatives in one-pot (Scheme 3; Table 4).

It has been shown that gold can catalyze the second catalytic cycle, therefore, we first carried out the N-monoalkylation^[13a,15] at 160 °C until reac-



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Figure 4. Dehydrogenation-hydrogenation reaction of PhCD₂OH on supported Au⁰ nanoparticles.

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Table 3.	Monoalkylation	of	amines	with	alcohols	catalyzed	by	Au/CeO ₂	(2.5%)	wt). ^[a]
			TET							

		N ₂ atmosphere	-1~~R ² +		- 1	$A \sim R^2$		$R^1 \sim N^2$	
		180° C	R	N Ŧ	R'	Ъ Н	+		
		(2.5%wt)	I	P1		P2		P3	
Entry	Alcohol	Amine	Conv. [%] ^[b]	<i>t</i> [h]	Yie P ₁	ld [% P ₂	6] P3	TON ^[c]	TOF ^[d]
	CH₂OH	NH ₂							
1	\bigcirc	\bigcirc	100	5	6	90	4	152	64
2 ^[e]	CH ₂ OH	NH ₂	88	6.5	3	85	-	231	52
3	CH ₂ OH	CH ₂ NH ₂	100	6	15	84	1	112	81
4	CH ₂ OH	CH ₂ CH ₂ NH ₂	100	7.5	17	71	10	133	48
5	CH ₂ OH	NH ₂	94	18	11	70	13	90	93
6	CH ₂ OH	MH ₂	96	7	22	72	2	138	76
7	∕он	CH ₂ NH ₂	71	6	8	50	13	108	13
8	CH ₂ OH	NH ₂	100	9	14	85	1	176	39
9	CH ₂ OH	CH ₂ NH ₂	100	3	34	65	1	100	79
10	CH ₂ OH	NH ₂	95	30	19	76	<1	184	19
11	HO	NH ₂	90	21	65	5	20	120	268
12	c	NH2	51	8	31	8	12	53	35





Scheme 3. One-pot synthesis of propargylamines.

tion completion and then temperature was reduced to 85°C for the second cycle.

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In this case, the best results for the global onepot experiments were achieved with an Au/CeO₂ sample (2.5 wt%) treated at 250 °C with a H₂ flow (see the Experimental Section); the kinetic profile of the global reaction (cycles A+B, Scheme 1) in the presence of Au/CeO₂ is given in Figure 6.

To prove the generality of the method, we systematically varied the reactants (amine, aldehyde, alkyne) for the two catalytic cycles but maintained the aromatic nature of the hydrogen donor (Table 4).

As expected, the conversion and selectivity for \mathbf{P}_4 were higher when aryl alcohols and aryl amines were used as substrates (Table 4), which were also the best substrates for synthesis of the N-monoalkylated product \mathbf{P}_2 (Table 3). The nature of the aldehyde (R³CHO) and alkyne (R⁴C=CH) also had a critical influence on the global reaction. The best combination was to use a benzyl alcohol and benzylamine for steps a–c, then a cyclic aliphatic aldehyde and an aromatic terminal alkyne for step d.

The strong association experienced by different gold species on the ceria lattice is thought to be the key factor that stabilizes the gold nanoparticles during the one-pot reaction.

Conclusion

Gold on CeO_2 (Au/CeO₂) is able to sequentially activate reactants in two catalytic cycles for production of propargylamines or 2-propinylamines in one-pot. In this catalytic system, gold atoms at the crystal corners promote the N-monoalkylation of amines with alcohols to give secondary amines in moderate to good yields.

Because cationic gold works better for the A^3 consecutive reaction, the experimental conditions (temperature, metal loading, preparation of catalyst) were optimized to avoid a sharp decrease of these oxidized gold active species, as well as their sinterization.

The strong interaction between different gold species on ceria accounts for the observed high activity and stability of the catalytic species during the overall cascade reaction.

Experimental Section

Reagents and solvents were supplied by Aldrich and they were used as received. CeO₂ (specific surface area, Brunauer–Emmett–Teller (BET) $\geq 252~m^2g^{-1}$) was supplied by Rhodia. MgO (surface area=670 m^2g^{-1}) was purchased from NanoScale Materials. Carbon (surface area=1400 m^2g^{-1}) was purchased from Norit. ZrO₂ (surface area $\geq 100~m^2g^{-1}$) was purchased from Sigma–Aldrich. TiO₂ (Aeroxide-P25, surface area=35–65 m^2g^{-1}) was purchased from Evonik. Au/Fe₂O₃ (4.4 % wt) was supplied

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Table 4. Synthesis of 2-propinylamine derivatives P_4 by N-monoalkylation coupled to a multicomponent catalytic A^3 coupling with an Au/CeO₂ catalyst.^[a]

	R⁴ <i>-</i> ==-H							
		R ³ −C⊦						
R^{1} -CH ₂ OH + R^{2} -NH ₂ $$ TFT N ₂ , 160°C step a		$R^1 \stackrel{A^2}{H} R^2$	TFT air, 85°C step d	$ \begin{array}{c} $				
Entry	Product	Conv. [%] ^[b] step a	Conv. [%] ^[c] step d	Yield P ₄ [%] ^[d]				
1		100	100	80				
2		100	65	60				
3		100	100	50				
4	(CH ₂) ₇ CH ₃	100	50	48				
5		94	35	31				
6		100	75	40				
7		90	79	60				

[a] Reaction conditions: steps a)–c) R^1CH_2OH (1 mmol), R^2NH_2 (1 mmol), Au/CeO₂ (2.5% wt, 1 mol%), 160°C, N₂, TFT (1 mL); step d) R^3CHO (1.5 mmol), $R^4-C=CH$ (1.5 mmol), 85°C, under air. [b] The amount of R^1CH_2OH transformed was calculated by GC. [c] The amount of R^3CHO transformed was calculated by GC. [d] Isolated yield.

by World Gold Council. Au/ZnO (1% wt) was supplied by Mintek. Au/ MgO and Au/C were prepared by literature procedures.^[11a]

Preparation of Au/CeO₂ (x % wt): The appropriate amount of HAuCl₄·3H₂O was dissolved in deionized water (100 mL). The solution was adjusted to pH 10 with NaOH (0.2 M) and a suspension of CeO₂ (1.5 g) in deionized H₂O (50 mL) was added. The resulting mixture was readjusted to pH 10 with NaOH (0.2 M) and stirred for 18 h at RT. The agitation was stopped and the slurry was aged for 2 h. The mixture was filtered and the solid washed with deionized H₂O, to completely eliminate chlorides, then washed with acetone (100 mL). The residue was dried overnight (18 h) in an oven (100 °C) then treated with a H₂ flow (80 mLmin⁻¹) at 250 °C for 2 h.



Figure 6. Plot showing the evolution of products $P_2(\bullet)$ and $P_4(\blacktriangle)$ in the one-pot reaction (cycle A+B) between benzyl alcohol (\blacksquare), benzyl amine, cyclohexylcarboxaldehyde, and phenylacetylene in the presence of Au/ CeO₂ (2.5% wt; Table 4, entry 1). Cyclohexylcarboxaldehyde and phenylacetylene were incorporated when almost all of the imine P_1 , formed in the condensation step, was hydrogenated to the amine P_2 .

Preparation of Au/CeO₂–NH (1.6 % wt): HAuCl₄·3H₂O (120 mg) was dissolved in deionized H₂O (150 mL) and adjusted to pH 10 with NaOH (0.2 M). A suspension of CeO₂ (3.0 g) in deionized H₂O (150 mL) was added. The mixture was readjusted to pH 10 with NaOH (0.2 M) and stirred for 18 h at RT. The agitation was stopped and the slurry was aged for 2 h. The mixture was filtered with deionized H₂O to completely eliminate chlorides, then washed with acetone (100 mL). The residue was dried overnight (18 h) in an oven (100 °C).

Preparation of Au/ZrO₂: ZrO₂ (1.5 g) was calcined (25–400 °C; 5 °C min⁻¹; 7 h) then diluted in deionized water. HAuCl₄·3H₂O (50 mg) in H₂O (50 mL) was incorporated by pump infusion (0.83 mLmin⁻¹). The mixture was adjusted to pH \approx 7.6 by addition of NaOH (0.2 m) and stirred overnight.

The mixture was readjusted to pH = 7.6 with NaOH (0.2 M), aged for about 10 h, filtered, and washed with deionized H_2O (2 L) and acetone (100 mL). The solid was dried in an oven (100 °C) for 24 h, then calcined under air (20–250 °C; 5 °C min⁻¹; 2 h).

Preparation of Au/TiO₂: HAuCl₄·3H₂O (77.8 mg) in deionized water (150 mL) was mixed with TiO₂ (2 g). The mixture was heated to 70 °C and adjusted to pH 9 with NaOH (2 M). The mixture was stirred overnight. The solid was filtered and washed with deionized water (2 L) and acetone (100 mL), dried in an oven (100 °C) for 24 h, then calcined under air (20–400 °C; 5 °C min⁻¹; 4 h).

Catalyzed N-alkylation of amines with alcohols: Alcohol (1 mmol), amine (1 mmol), catalyst (0.0075 mmol), trifluorotoluene (1 mL), and *n*-dodecane (20 μ L) as an internal standard were placed into an autoclave. The mixture was vigorously stirred at 180 °C under nitrogen. The reaction was monitored by GC.

Catalyzed A³ coupling of aldehydes, alkynes, and secondary amines generated in situ: A mixture of alcohol (1 mmol), amine (1 mmol), catalyst (0.0075 mmol), trifluorotoluene (1 mL), and *n*-dodecane (20 μ L) as an internal standard were placed into an autoclave. The mixture was vigorously stirred at 180 °C under nitrogen, and monitored by GC. After the alcohol was transformed into secondary amine, the temperature was lowered to 80 °C and alkyne (1 mmol) and aldehyde (1 mmol) were incorporated into the reactor. The reaction was monitored by GC at 85 °C under air.

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Gold Catalysis -

Coupling of Two Multistep Catalytic Cycles for the One-Pot Synthesis of Propargylamines from Alcohols and Primary Amines on a Nanoparticulated Gold Catalyst



All in one: A one-pot reaction was performed with a nanoparticulated gold catalyst. A secondary amine was formed through N-monoalkylation of a primary amine with an alcohol by a

borrowing hydrogen methodology. The secondary amine entered into a second coupling cycle to give propargylamines (see scheme).