Solvent-free chelation-assisted hydroacylation of olefin by rhodium(I) catalyst under microwave irradiation

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Received (in Cambridge, UK) 14th January 2002, Accepted 11th April 2002
First published as an Advance Article on the web 25th April 2002

A solvent-free protocol for the rhodium(I)-catalyzed intermolecular hydroacylation was achieved under microwave irradiation to furnish various ketones in high yields. The reactivity was improved by the addition of aniline as well as 2-amino-3-picoline and benzoic acid to induce a transimination, which facilitates the formation of intermediate aldimine. A comparison of the reactivity between the reaction performed under the conventional heating mode and the microwave irradiation using monomode reactor revealed an important specific microwave effect during the chelation-assisted hydroacylation. It is supposed that the observed specific microwave effect mainly originates from the formation of aldimine by condensation of aldehyde and amine, which leads to a development of charges in the transition state. This result confirms that the rate-determining step of the reaction is the initial condensation step rather than the subsequent hydroiminoacylation step.

Introduction

For the purpose of modernizing and improving classical synthetic procedures to be more economical, clean, safe and easy-to-perform, solvent-free organic synthesis is of great interest as one of the major tools for green chemistry.[1] The main interest lies in the fact that: a) it avoids the use of solvents which are very often toxic, expensive, and problematic to use and to remove, b) it allows operation at higher temperatures as there is no limitation of the boiling points of solvents, c) it enhances the reactivity by increasing the concentration.

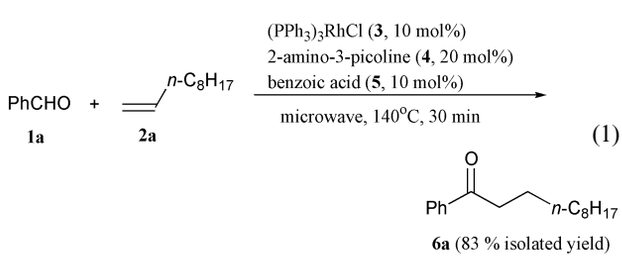
Solvent-free methods have been shown to be very efficient and advantageously coupled with microwave (MW) activation,[2] and many organic reactions have been carried out using "microwave-induced organic reaction enhancement" (MORE) technique delivering high yields in a short reaction time compared with the conventional heating mode performed in preheated thermostat oil bath.[3] Such an enhanced reactivity is supposed to arise mainly from rapid and homogeneous heating of the bulk reaction mixture by microwave irradiation. On the other hand, there are many examples implying that the intervention of a specific microwave effect, *i.e.* not purely thermal effects, also plays an important role depending on the medium and the mechanism of the reaction.[4]

Undoubtedly, it is quite desirable to develop microwave-promoted transition metal catalyzed reactions because of the versatile utilities of transition metals in organic synthesis. Recently, some valuable transition metal catalyzed reactions such as transfer hydrogenation,[5] phosphonation of aryl halides,[6] allylic alkylation,[7] Heck-type reaction,[8] Suzuki,[9] Stille,[9] and Sonogashira couplings[10] have been successfully accomplished using a microwave technique. Even though the examples are still rare, some cases have been described for MW-mediated palladium-catalyzed reactions without using any solvent.[11]

Intermolecular hydroacylation,[12,13] a synthetic method for ketones directly from aldehydes and olefins catalyzed by transition metal complexes, is a prominent way to obtain ketones in the light of atom economy.[14] We have recently developed a chelation-assisted hydroacylation using a catalyst system of Rh(I) complex and 2-amino-3-picoline† demonstrating its potential utility as a versatile protocol for the synthesis of ketones.[13] We were consequently encouraged to apply solvent-free microwave-assisted procedure to this reaction for the sake of enhanced reactivity, and hopefully for achieving green chemistry. Herein we wish to report a microwave-assisted intermolecular hydroacylation of olefin catalyzed by Rh(I) complex. A study on the effect of microwave activation was also undertaken.[15]

Results and discussion

In our experiment, in the absence of any additional solvent, benzaldehyde (**1a**) reacted with dec-1-ene (**2a**) in the presence of $(PPh_3)_3RhCl$ (Wilkinson's complex, **3**), 2-amino-3-picoline (**4**), and benzoic acid (**5**) under microwave irradiation for 30 min to afford 1-phenylundecan-1-one (**6a**) in a 83% yield (eqn. 1).



(1)

6a (83 % isolated yield)

To certify whether any specific microwave effect exists, a control experiment was conducted under the same reaction conditions but in the preheated oil bath with comparable profiles of temperature during the reaction (Fig. 1) to afford **6a** in only 50% yield. This result clarifies that there is a significant specific microwave effect, which gives rise to enhancement of reactivity, in addition to thermal effect, under microwave irradiation (see below).

† The IUPAC name for picoline is methylpyridine.

 DOI: 10.1039/b200442a

Table 1 The chelation-assisted hydroacylation of various olefins (**2**) with benzaldehyde (**1a**) under microwave irradiation [a]

Entry	Olefin (**2**)	*T* /°C	Time/min	Product (**6**)	isolated yield (%) [b]
1	Dec-1-ene (**2a**)	140	30	**6a**	83 (50)
2 [c]	(**2a**)	140	30	**6a**	12
3	Allylbenzene (**2b**)	140	10	**6b**	84 (30)
4	Hex-1-ene (**2c**)	60	60	**6c**	0
5	(**2c**)	100	60	**6c**	31
6 [d]	(**2c**)	–	10	**6c**	75
7 [d]	3,3-Dimethylbut-1-ene (**2d**)	–	10	**6d**	69
8 [d]	Oct-1-ene (**2e**)	–	10	**6e**	75

[a] The reactions were conducted at 140 °C under the continuous microwave irradiation (see Fig. 1), unless otherwise designated. [b] Yields in parenthesis were obtained from the reaction conducted under the same condition, but in preheated oil bath at 140 °C. [c] The reaction was conducted in the absence of benzoic acid **5**. [d] The reactions were conducted in closed vessels using a domestic microwave oven with 5 mol% of **3**.

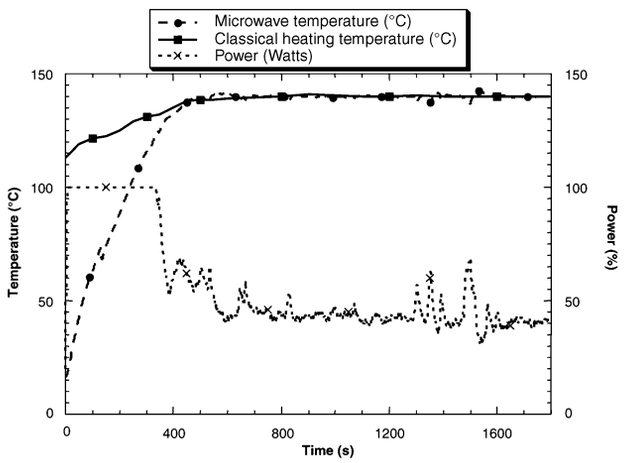
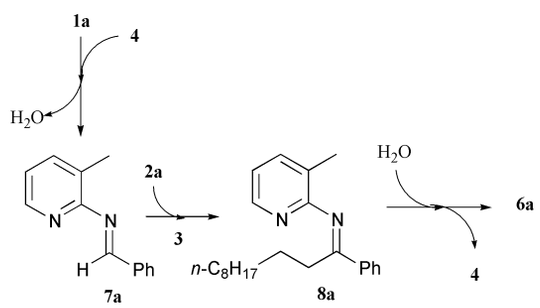


Fig. 1 Temperature and irradiation power profiles monitored during the reaction of **1a** and **2a** under microwave irradiation or conventional heating at 140 °C.

Various olefins were also examined and the main results are summarized in Table 1. The reactions were carried out either in a monomode microwave reactor (entry 1–5) or in a multimode domestic microwave oven (entry 6–8). A monomode reactor allows operation to be carried out with a homogeneous electric field due to focused wave irradiation. An accurate control and measurement of temperature by IR detection was made with monitoring at a constant value thanks to emitted microwave power modulation.[2a,16]

The important role of carboxylic acid **5** in the reaction [13d] was confirmed by the result obtained from the reaction performed in its absence, which afforded only 12% yield of **6a** (entry 2) instead of 83% in its presence (entry 1). Allylbenzene (**2b**) reacted with **1a** readily to afford a good yield (84%) of 1,4-diphenylbutan-1-one (**6b**) in a short reaction time of 10 min. In this reaction, a specific microwave effect was observed by comparison with the yield (only 30%) obtained from the reaction performed in the preheated oil bath at 140 °C (entry 3). Since it was impossible to carry out the reaction with hex-1-ene (**2c**) at high temperature due to its low boiling point (60–61 °C), at which temperature the reaction did not proceed at all (entry 4), the reaction was performed at moderate temperature, 100 °C, to afford only a 31% yield of 1-phenylheptan-1-one (**6c**) in a long reaction time (1 h, entry 5). We found it beneficial to use a domestic microwave oven with closed reaction vessels,‡ [17] although it is not easy to control the temperature and microwave power.§ [18] Therefore, the reactions with **2c** and other volatile olefins such as 3,3-dimethylbut-1-ene (**2d**) and oct-1-ene (**2e**) were carried out successfully using domestic microwave oven to give good yields of corresponding ketones with 5 mol% of **3** (entries 6–8).

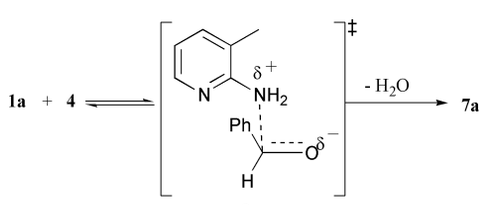
The mechanism of the reaction is depicted in Scheme 1.



Scheme 1

Initially, aldehyde **1a** and 2-amino-3-picoline **4** condense to form intermediate aldimine **7a** catalyzed by benzoic acid **5**. Then, **7a** and **2a** undergo hydroiminoacylation [19] under catalyst **3** to give ketimine **8a**, which is hydrolyzed by H_2O generated during the condensation to yield ketone **6a** as the final product.

It is quite reasonable to assume that the specific microwave effect might originate from the condensation of **1a** and **4**, since it leads to a development of charges in the transition state (**9**) inducing thus an important dipole–dipole interaction (Scheme 2).[4] In this circumstance, molecules are sensitive to the electric



Scheme 2

field, which results in an increased stabilization of the dipolar transition state compared with its less polar ground state under microwave irradiation.

To check the possible intervention of specific microwave effect during hydroiminoacylation of **2a** (*i.e.* the formation of **8a** from **7a** in Scheme 1), the reaction of **7a** and **2a** was undertaken under both the activation modes (eqn. 2, Table 2).

From these results, it is clear that the specific microwave effect observed during this reaction is highly dependent on the temperature level as the same effect appeared when the reaction was performed under reduced temperature and/or reaction

‡ A caution should be addressed since occasional explosions have been reported when using a domestic oven in sealed vessel (see ref. 17). Of course, we carried out the reactions on a small scale without any mishaps.

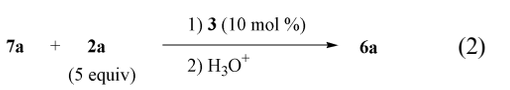
§ Since it is not easy to control the level of power, all the reactions were performed under this condition without any modification. The irradiation power of domestic microwave oven was determined as approximately 700 W, the full power the equipment can generate, according to the known procedure (see ref. 18).

Table 2 The hydroiminoacylation of dec-1-ene (**2a**) with aldimine **7a** under solvent-free conditions (eqn. 2)

Entry	*T*/°C	*t*/min	Isolated yield of **6a** (%) MW[a]	Δ[b]
1	100	5	40	22
2	120	5	74	52
3[c]	140	10	85	79

[a] MW = microwave irradiation. [b] Δ = conventional heating. [c] Identical results were observed with or without **5**.

time.¶ However, it is evident that the overall specific effect observed during the chelation-assisted hydroacylation (eqn. 1) derives from the initial condensation step for aldimine formation, and this is the rate-determining step as there is no specific microwave effect in the second step within 10 min at 140 °C (Table 2, entry 3) whereas it is very important in the total process (30 min at 140 °C, Table 1, entry 1). This is also reinforced by the fact that there is no enhancement of reactivity by the addition of **5** in the course of hydroiminoacylation.

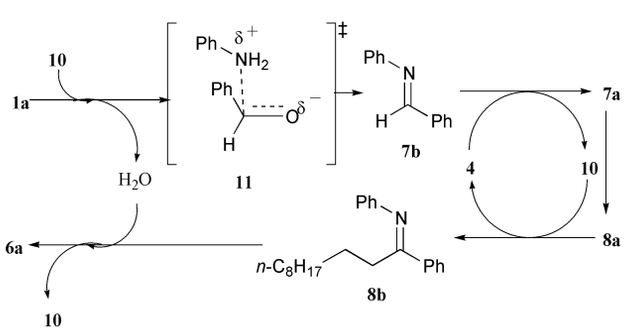


(2)

The existence of non-thermal effects in microwave-assisted chemical reaction still remains controversial.[20] It has been suggested that the rate increases in the reactions carried out under solvent-free conditions could be due to differential heating (temperature heterogeneity),[21] which could be minimized by using a monomode reactor (field homogeneity) and mechanical stirring as in the case of the reactions we carried out. Also it has been shown that reactions under homogeneous conditions[22] did not have as high a rate enhancement as a heterogeneous catalyst, which is probably due to the higher localized temperature at the active site of the catalyst.

Prompted by these results, other aldehydes were examined with solvent-free microwave-assisted hydroacylation. Disappointingly, the reaction of anisaldehyde (**1b**) and **2a** furnished only a low yield of 1-(4-methoxyphenyl)undecan-1-one (**6f**, 47%) under the same reaction conditions (Table 3, entry 1). A possible explanation could be the existence of the electron donating group in the *para* position that is unfavourable for the condensation step. The influence of temperature or reaction time was not so significant (Table 3, entry 2–4).

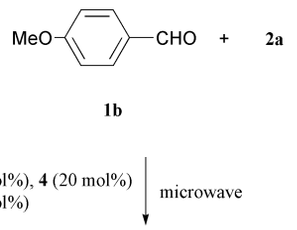
Already we found that the reactivity in hydroacylation was dramatically improved using a transimination protocol,[23] which facilitates the formation of intermediate aldimine (*e.g.* **7a**) through the initial facile formation of **7b**, followed by rapid transimination with **4** to form **7a** (Scheme 3).[13d,24]

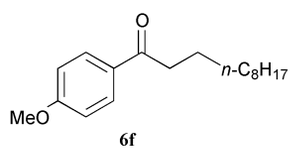


Scheme 3

¶ The origin of the specific microwave effect observed in the hydroiminoacylation step is not clear, but it is possible that a polar intermediate or transition state might be generated by complexation of rhodium with nitrogen atoms.

Table 3 The chelation-assisted hydroacylation of **2a** with anisaldehyde (**1b**) under microwave irradiation





Entry	Aniline(**10**)	*T*/°C	*t*/min	Isolated yield (%)[a]
1	–	140	30	47
2	–	160	30	40
3	–	160	120	52
4	–	180	30	37
5	100 mol%	160	30	84
6[b]	100 mol%	160	30	92 (95)
7[b]	100 mol%	100	30	90 (48)

[a] Yields in parenthesis were obtained from the reactions conducted in a preheated oil bath at the same temperature. [b] A 40 mol% of **4** was used.

Hence aniline (**10**) was added to the catalyst system in order to induce transimination, and an improved yield of 84% was obtained (entry 5). Increasing the amount of **4** up to 40 mol%, improved the yield to 92% (entry 6) and the yield was still high at lower temperature of 100 °C to give 90% after 30 min (entry 7).

When the reaction was carried out at high temperature, 160 °C, the yields are very similar regardless of the mode of activation, microwave irradiation or conventional heating, and gave yields of 92% and 95% **6f**, respectively (entry 6). However, at 100 °C, an important specific microwave effect was observed, as the yield obtained under conventional heating mode was only 48%, by far lower than that under microwave irradiation (90%, entry 7). The profile of temperatures for both modes of activation and microwave power is shown in Fig. 2.

The magnitude of specific microwave effects is known to be highly dependent on temperature. Similar observations have

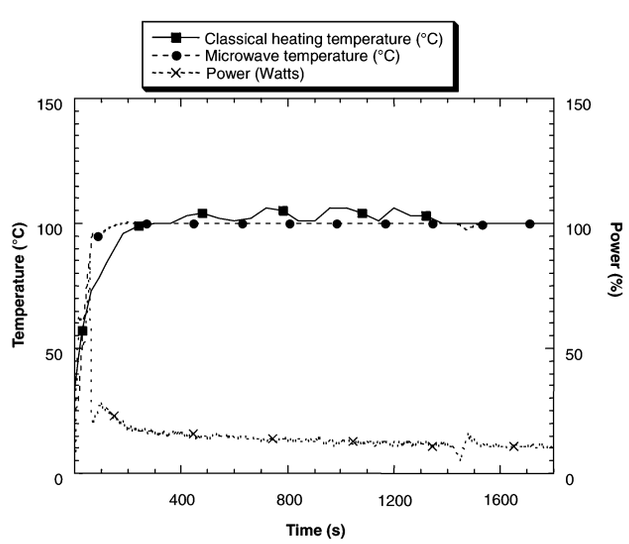
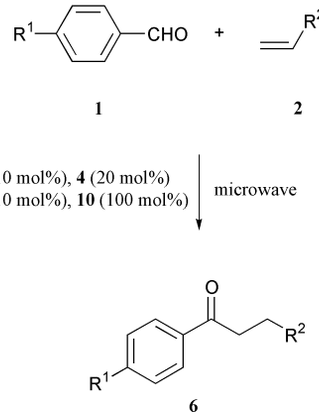


Fig. 2 Temperature and irradiation power profiles monitored during the reaction of **1b** and **2a** under microwave irradiation and conventional heating at 100 °C (Table 3, entry 7).

Table 4 The microwave-assisted hydroacylation of olefins (**2**) with various aldehydes (**1**) using transimination



Entry	R^1 (**1**)	R^2 (**2**)	Method[a] T/°C	t/min	Product (**6**)	Isolated yield (%) MW	Isolated yield (%) Δ[b]
1	H (**1a**)	n-C_8H_{17}(**2a**)	A/100	30	**6a**	48	30
2		**2a**	B	10	**6a**	95	–
3		$PhCH_2$(**2c**)	A/100	60	**6c**	74	14
4		**2c**	B	10	**6c**	84	–
5		Bu^t (**2d**)	B	10	**6d**	91	–
6	MeO (**1b**)	**2a**	A/100	10	**6f**	90	48
7		**2a**	B	10	**6f**	93	–
8		**2b**	A/140	10	**6g**	92	48
9[c]	Me_2N (**1c**)	**2a**	A/160	60	**6h**	12	–
10		**2a**	A/120	30	**6h**	85	36
11		**2a**	B	10	**6h**	60	–
12		**2b**	A/160	60	**6i**	83	57
13[c]	CF_3 (**1d**)	**2a**	A/140	30	**6j**	21	–
14		**2a**	A/160	10	**6j**	91	52
15		**2b**	A/140	60	**6k**	86	33

[a] The reaction was carried out either in open vessel using monomode microwave reactor with 10 mol% of **3** (Method A) or in closed vessel using domestic microwave oven with 5 mol% of **3** (Method B). [b] The reaction was conducted under same condition (either method A or B), but in preheated oil bath. [c] The reaction was carried out in the absence of **10**. A 20 mol% of **4** was used.

been made in some studies where specific microwave effects appeared at relatively low temperatures (here 100 °C) whereas they are masked at higher temperatures where yields of conventionally heated reactions are also elevated.[25]

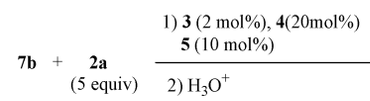
Other aldehydes were applied to the microwave-assisted hydroacylation using the transimination technique and the results are summarized in Table 4.

As for **1a**, the involvement of transimination permitted enhanced reactivity to give corresponding ketones in good yields (85–95%) under short reaction times (entries 1–5). It is noteworthy that **2c** also gave a fairly good yield (74%) of **6c** in the presence of **10** (entry 3) compared with in its absence (Table 1, entry 5, 31%), even though it was carried out in the open vessel instead of the closed vessel. Aldehydes bearing either electron donating groups or electron withdrawing groups also reacted with olefins to give good yields of the corresponding ketones in the presence of **10**. Compared with the reaction performed in the absence of aniline, the intervention of transimination was quite significant for a large enhancement of reactivity.‖ Both microwave equipments, domestic oven and monomode reactor, allowed high reactivity.[26]

‖ The hydroacylation did not occur in the absence of 2-amino-3-picoline **4**, which bears a coordination site and facilitates the C–H bond activation, a key step of hydroacylation, by forming aldimine intermediate **7a**. The role of aniline (**10**), which has no coordination site, is to facilitate the formation of aldimine intermediate **7a**. Actually, when the reaction of **1a** and **2d** was carried out under the same conditions described in Table 4 (entry 5) but in the absence of **4**, no hydroacylation product was obtained. A chelation-assisted hydroacylation and the essential role of 2-amino-3-picoline have been well documented (see ref. 13).

The rate enhancements in the reactions shown in Table 4 (entry 3, 6, 8, 10, 12, 14, and 15) suggest the participation of an effect other than the thermal microwave effect. Considering the mechanism of the reaction (Scheme 3), the specific microwave effect might derive from the condensation step of aldehydes and aniline **10**, which develops a dipolar transition state **11**.

To check whether the other steps of the reaction, *i.e.* transimination of **7b** with **4**, and subsequent hydroiminoacylation, are also responsible for the observed specific microwave effect, the microwave-assisted alkylation of **7b** with olefins[24] was conducted. As shown in Table 5, aldimine **7b** underwent Rh(I)-catalyzed alkylation smoothly under microwave irradiation to give corresponding ketones after hydrolysis. However, no significant specific microwave effect was observed within 20 min at 140 °C, as similar yields were obtained from the control experiments performed using monomode microwave reactor or preheated oil bath (eqn. 3, Table 6, entry 1).



(3)

On the other hand, as previously shown in the case of the hydroiminoacylation using aldimine **7a** (Table 2), a specific microwave effect could be observed by decreasing temperature and/or reaction time (Table 6, entry 2 and 3).

This result certifies that the specific microwave effect originates from the condensation of aldehyde and **10**, and it is the rate-determining step of the reaction.

Table 5 Microwave-assisted alkylation of aldimine **7b** with olefins **2** through transimination[a]

Entry	Olefin (**2**)	Product (**6**)	Isolated yield (%)
1	**2a**	**6a**	76
2	**2b**	**6b**	93
3	**2c**	**6c**	97
4	**2d**	**6d**	94
5	**2e**	**6e**	83

[a] The reactions were conducted in closed vessels using a domestic microwave oven in the presence of 2 mol% of **3**, 20 mol% of **4**, and 10 mol% of **5** for 10 min.

Table 6 The hydroiminoacylation of dec-1-ene with aldimine **7b** under solvent-free conditions (eqn. 3)

			Isolated yield of **6a**(%)	
Entry	*T* /°C	*t*/min	MW[a]	Δ[b]
1	140	20	91	85
2	140	10	81	50
3	120	10	45	31

[a] MW = microwave irradiation. [b] Δ = conventional heating.

Conclusion

As a promising way to prepare ketones from aldehydes, a chelation-assisted hydroacylation of olefins was achieved under microwave irradiation in a solvent-free protocol. The reactivity of this reaction was largely improved with introducing a transimination by means of adding aniline as well as 2-amino-3-picoline. Various aldehydes and olefins were applied to this protocol to afford corresponding ketones. Both domestic microwave oven and monomode reactor effected the transformation of aldehydes into ketones successfully. An important specific microwave effect was observed during the reaction within 10–30 min at 140 °C from comparison of the reactivity between the conventional heating mode and the microwave activation mode performed using monomode reactor, which permitted the accurate control of microwave power and temperature. The existence of specific microwave effect under these conditions certifies that the rate-determining step of the overall reaction is the initial condensation of amine and aldehyde, rather than the subsequent transimination or hydroiminoacylation, where the significant specific microwave effect could be observed only under mild conditions.

Experimental

Aldehydes and olefins used in the experiments were purchased from commercial sources and purified by standard procedures.[27] Aldimine such as benzylidene(3-methylpyridin-2-yl)amine (**7a**) and benzylidene(phenyl)amine (**7b**) were prepared under microwave activation by reacting benzaldehyde with 2-amino-3-picoline or aniline using K10 clay as a catalyst in dry conditions within 3 min (yields 95%) according to Varma's procedure.[28] $(PPh_3)_3RhCl$ (Wilkinson's complex, **3**) was prepared as described in the literature.[29] Either a multimode domestic microwave oven (Samsung, RE-431H, 700 W) or a monomode microwave reactor (Synthewave™ 402 from Prolabo) was used for microwave irradiation. In the case of the latter equipment, the microwave power can be modulated between 15 and 300 W (2450 MHz), and an accurate control of temperature at constant value can be achieved, while it is impossible with the former due to non-homogeneous electromagnetic field owing to reflex of microwave on the oven walls. ^{1}H NMR spectra were recorded at 250 or 200 MHz. The chemical shifts (δ) are reported in ppm relative to the internal standard. *J* values are given in Hz. ^{13}C NMR spectra were recorded at 62.5 or 50 MHz. Infrared spectra were recorded with a Nicolet Impact 400 spectrometer. GC analyses were conducted using Donam DS 2000 Gas Chromatography. Mass spectra were obtained using G1800A GCD System.

Typical procedure for the catalytic reaction using monomode microwave reactor (method A)

Preparation of 1-phenylundecan-1-one (6a, eqn. 1). In a 10 cm^3 Pyrex tube, were introduced successively benzaldehyde (**1a**, 160 mg, 1.4 mmol), 2-amino-3-picoline (**4**, 30 mg, 0.28 mmol), dec-1-ene (**2a**, 980 mg, 7 mmol), $(PPh_3)_3RhCl$ (**3**, 130 mg, 0.14 mmol) and benzoic acid (**5**, 34 mg, 0.14 mmol). The reaction, which was followed by TLC, was carried out with external mechanical stirring for 30 min to ensure homogeneous conditions at 140 °C under microwave irradiation using monomode reactor. After cooling, the reaction mixture was diluted with 10 cm^3 of chloroform and washed with 2 × 10 cm^3 of a 10% sodium bisulfite solution. The organic layer was separated and concentrated. The crude product was purified by flash column chromatography (SiO_2, *n*-pentane–ethyl acetate = 8 : 1) to afford 1-phenylundecan-1-one **6a** (327 mg, 95%), which was identified by ^{1}NMR and GC-MS.[30] Mp 28–30 °C δ_H (250 MHz, $CDCl_3$, Me_4Si): 7.95 (2H, d, *J* 7.3), 7.5 (3H, m), 2.96 (2H, t, *J* 7.4), 1.73 (2H, m), 1.3–1.2 (14H, m) and 0.88 (3H, t, *J* 6.5); *m*/*z* (EI) 246 (M^+, 3%), 133 (11), 120 (100), 105 (95) and 77 (47).

Reactions under conventional heating were carried out with exactly the same vessels and under similar conditions of time and temperature (see Fig. 1 and Fig. 2) but inside a preheated oil bath.

Typical procedure for the catalytic reaction using multimode domestic microwave oven (method B)

Preparation of 1-phenylheptan-1-one (6c, Table 1, entry 6). In a 1 cm^3 screw capped pressure vial, were charged **1a** (21.2 mg, 0.200 mmol), **4** (8.6 mg, 0.080 mmol), hex-1-ene (**2c**, 84.2 mg, 1.00 mmol), **3** (9.2 mg, 0.010 mmol) and **5** (2.4 mg, 0.020 mmol). The reaction mixture was placed in a microwave oven and heated for 10 min without stirring. The reaction mixture was kept homogeneous throughout the reaction. After cooling, the crude product was purified by column chromatography (SiO_2, *n*-hexane–ethyl acetate = 5 : 1) to give 1-phenylheptan-1-one **6c** (28.0 mg, 75%), which was identified by comparison with authentic specimen commercially available.

Among the other products, ketones **6b**,[31] **6d**,[32] **6e**,[33] and **6g**[13d] are already known. All of the new compounds are characterized below.

1-(4-Methoxyphenyl)undecan-1-one 6f. Mp 51–52 °C δ_H (200 MHz, $CDCl_3$, Me_4Si): 7.9 (2H, d, *J* 9.0 Hz), 6.9 (2H, d, *J* 8.9), 4.1 (3H, s), 2.8 (2H, t, *J* 7.4 Hz), 1.7 (2H, m), 1.3–1.2 (14H, m) and 0.8 (3H, t, *J* 6.3);δ_C (50 MHz, $CDCl_3$, Me_4Si): 198.42, 163.07, 129.99, 113.38, 55.03, 38.98, 31.76, 29.33, 24.37, 22.53 and 13.82; ν_{max}(neat)/cm^{-1}: 3089, 2917, 1679, 1603, 839 and 731; *m*/*z* (EI) 276.2065 ($M^+\cdot C_{18}H_{28}O_2$ requires 276.2089).

1-(4-Dimethylaminophenyl)undecan-1-one 6h. Mp 72–73 °C, δ_H (200 MHz, $CDCl_3$, Me_4Si): 7.9 (2H, d, *J* 9.2), 6.6 (2H, d, *J* 9.1), 3.0 (6H, s), 2.8 (2H, t, *J* 7.2), 1.7 (2H, m), 1.3–1.2 (14H, m) and 0.8 (3H, t, *J* 6.4); δ_C(50 MHz, $CDCl_3$, Me_4Si): 198.5, 152.96, 129.98, 124.93, 110.36, 39.71, 37.68, 31.71, 29.26, 24.86, 22.49 and 13.93; ν_{max}(neat)/cm^{-1}: 2917, 1659, 1611, 820 and 795; *m*/*z* (EI) 289.2436 ($M^+\cdot C_{19}H_{31}NO$ requires 289.2406).

1-(4-Dimethylaminophenyl)-4-phenylbutan-1-one 6i. Mp 100–101 °C δ_H (200 MHz, $CDCl_3$, Me_4Si): 7.9 (2H, d, *J* 9.0), 7.3 (5H, m), 6.6 (2H, d, *J* 9.1), 3.0 (6H, s), 2.9 (2H, t, *J* 7.3), 2.7 (2H, t, *J* 7.6) and 2.1 (2H, m); δ_C(50 MHz, $CDCl_3$, Me_4Si): 198.02, 153.25, 142.07, 130.19, 128.45, 125.85, 124.94, 110.62, 39.85,

36.98, 35.44 and 26.43; ν_{max}(neat)/cm^{-1}: 3024, 2930, 1659, 1603 and 814. *m/z* (EI) 277.1661 ($M^+\cdot C_{18}H_{21}NO$ requires 267.1623).

1-(4-Trifluoromethylphenyl)undecan-1-one 6j. Mp 46–47 °C δ_H (200 MHz, $CDCl_3$, Me_4Si): 8.1 (2H, d, *J* 8.2), 7.7 (2H, d, *J* 8.2), 3.0 (2H, t, *J* 7.3), 1.7 (2H, m), 1.3–1.2 (14H, m) and 0.9 (3H, t, *J* 6.5); δ_C(50 MHz, $CDCl_3$, Me_4Si): 198.85, 139.23, 133.46, 128.24, 125.50, 120.00, 37.74, 31.82, 29.36, 24.00, 22.59 and 13.93; ν_{max}(neat)/cm^{-1}: 2917, 1686, 1580, 863, and 833; *m/z* (EI) 314.1894 ($M^+\cdot C_{18}H_{25}F_3O$ requires 314.1858).

1-(4-Trifluoromethylphenyl)-4-phenylbutan-1-one 6k. Mp 74–75 °C δ_H (200 MHz, $CDCl_3$, Me_4Si): 8.0 (2H, d, *J* 8.2), 7.7 (2H, d, *J* 8.2), 7.3 (5H, m), 3.0 (2H, t, *J* 7.2), 2.8 (2H, t, *J* 7.5) and 2.1 (2H, m); δ_C(50 MHz, $CDCl_3$, Me_4Si): 198.68, 141.32, 138.46, 133.46, 128.24, 125.91, 125.42, 120.39, 37.70, 34.88 and 25.28; ν_{max}(neat)/cm^{-1}: 3028, 2952, 1688, 1603, 870, and 826; *m/z* (EI) 292.1078 ($M^+\cdot C_{17}H_{15}F_3O$ requires 292.1075).

Typical procedure for the alkylation of 7b using multimode domestic microwave oven (Table 5, entry 3)

In a 1 cm^3 screw capped pressure vial, were charged **7b** (36.2 mg, 0.200 mmol), **4** (4.8 mg, 0.040 mmol), **2c** (84.2 mg, 1.00 mmol), **3** (3.7 mg, 0.0040 mmol) and **5** (2.4 mg, 0.020 mmol). The reaction mixture was placed in a microwave oven and heated for 15 min without stirring. After the reaction, the reaction mixture was treated with 1 M HCl at rt for 6 h, then the mixture was extracted with 10 cm^3 of Et_2O. The organic layer was dried over $MgSO_4$, and concentrated. The crude product was purified by column chromatography (SiO_2, *n*-hexane–ethyl acetate = 5 : 1) to give **6c** (37.0 mg, 97%).

Acknowledgements

This work was supported by the National Research Laboratory (Organotransition Metal Catalysis Lab. 2000-N-NL-01-C-271) Program administrated by the Ministry of Science and Technology, and by Korean Science and Engineering Foundation (20004010). Authors also acknowledge Brain Korea 21 project.

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