Synthesis J. E. Camp et al. Feature

Dehydrative Cross-Coupling of 1-Phenylethanol Catalysed by Palladium Nanoparticles Formed in situ Under Acidic Conditions

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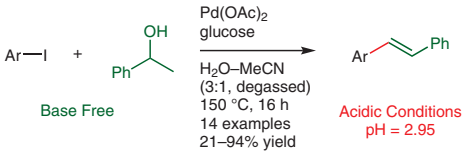

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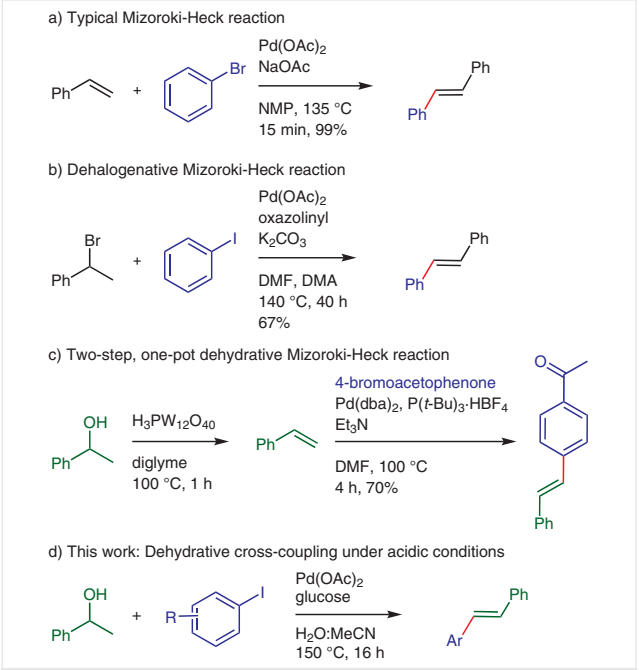
Abstract A dehydrative cross-coupling of 1-phenylethanol catalysed by sugar derived, in situ formed palladium(0) nanoparticles under acidic conditions is realised. The acidic conditions allow for use of alcohols as a feedstock in metal-mediated coupling reactions via their in situ dehydration and subsequent cross-coupling. Extensive analysis of the size and morphology of the palladium nanoparticles formed in situ showed that the zero-valent metal was surrounded by hydrophilic hydroxyl groups. EDX-TEM imaging studies using a prototype silicon drift detector provided insight into the problematic role of molecular oxygen in the system. This increased understanding of the catalyst deactivation allowed for the development of the cross-coupling methodology. A 250-12,000 fold increase in molar efficiency was observed when compared to related two-step protocols that use alternative feedstocks for the palladium-mediated synthesis of stilbenes. This work opens up a new research area in which the active catalyst is formed, stabilised and regenerated by a renewable sugar.

Key words glucose, nanoparticles, catalysis, dehydrative heck, palladium

Palladium-mediated cross-coupling reactions are some of the most powerful methods for the controlled formation of carbon–carbon bonds.[1] Of these, the Mizoroki–Heck reaction, is the method of choice for the formation of aryl–alkenyl bonds from the reaction of aryl halides and alkenes.[2] Since its initial development in the 1970s, the Mizoroki–Heck reaction has been optimised in terms of catalyst,[3] solvent[4] and reaction parameters[5] in order to address limitations of the methodology and expand its substrate scope (Scheme 1a).[6] Two factors that have remained relatively unexamined are the addition of an exogenous base[7] and the use of alkenes as the feedstock.[8] For related palladium-catalysed processes, the elimination of exogenous base has been shown to broaden their scope and increase overall sustainability.[9] In one of the rare instances of using an alternative feedstock in the Mizoroki–Heck reaction, Saiyed and Bedekar showed that benzylbromides, in the presence of excess base, could be used in a domino process to form stilbenes (Scheme 1b).[8a,10] Importantly, this work eliminated the need to preform and isolate the reactive alkene intermediate. In addition, Colbon et al. recently showed that aryl alcohols could be used in a two-step, one-pot process for the in situ generation and reaction of styrenes to form stilbenes (Scheme 1c).[11]



Scheme 1 Comparison of feedstocks in the Mizoroki–Heck reaction

Biographical Sketches

Dr. Jason E. Camp is currently a Senior Lecturer in the Department of Chemical Sciences at the University of Huddersfield, working on the use of green solvents in organic synthesis as well as on sugar-powered catalysis protocols. Dr. Camp received his Bachelor of Science degree in Biochemistry from the University of California, Davis in June 2000. During his undergraduate studies he conducted research as an UCEAP Undergraduate Research Fellow supervised by Prof. Geoffrey T. Crisp (University of Adelaide, Australia) and completed an honours project with the support of Prof. Alan L Balch (UC Davis). Following graduate studies with Prof. Robert Williams at Colorado State University he completed his PhD in 2007 under the supervision of Prof. Steven M. Weinreb at The Pennsylvania State University before undertaking postdoctoral research with Prof. Donald Craig (2008-2009) at Imperial College London. Following his postdoctoral work, he was appointed as a lecturer at both the University of Nottingham (2009-2013) and Queen Mary University of London (2013-2014).

Thomas Bousfield is currently finishing his PhD at The University of Huddersfield, which has focused on the development of sugar-powered catalysis methods as well as the use of Cyrene as a green solvent. During his PhD, Thomas was awarded COST Short Term Scientific Mission funding to work with Prof. Wim Thielemans at the University of KU Leuven. He obtained a MChem degree from Loughborough University, during which time he worked with Dr Marc Kimber on the synthesis of *N*-allenyl amides, ureas, carbamates and sulfonamides.

Dr. Jay Dunsford is currently a chemist at the National Nuclear Laboratory, UK. He completed his BSc and PhD at Cardiff University. His doctoral research with Prof. Kingsley Cavell focused on the synthesis of expanded ring NHC carbene complexes and their use in catalytic processes. He then undertook post-doctoral research with Dr Jason Camp at the University of Nottingham followed by Dr Michael Ingelson at the University of Manchester.

James Adams is currently finishing his BBSRC funded PhD at The University of Manchester, which resulted in two publications and a prestigious SCI scholarship (2015). He obtained a First Class MSci degree in chemistry from The University of Nottingham. During his undergraduate studies he participated in numerous research projects, which resulted in three publications. James was the recipient of six different undergraduate awards, including the GSK Medal for Outstanding Work in Medicinal Chemistry (2013) and the BP Achievement Award (2012).

Dr. Joshua Britton earned his MSci at Nottingham University, UK and his PhD jointly at Flinders University and The University of California, Irvine under Colin L. Raston and Gregory A. Weiss, respectively, in the area of continuous-flow synthesis and biocatalysis. He then undertook post-doctoral studies at MIT with Prof. Tim Jamison, which focused on the advancing of multi-step continuous-flow synthesis of active pharmaceutical ingredients. After post-doctoral studies, he co-founded Synthase, a biotechnology company focused on the continuous-flow synthesis of pharmaceuticals and high-value chemicals using biocatalysis and organic synthesis.

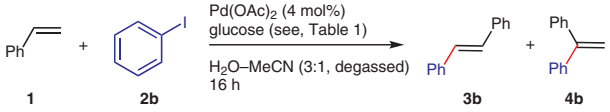
Dr. Michael Fay received his BSc degree from the University of Leicester in 1994 followed by an MSc from the University of Warwick in 1996 and a PhD from the University of Sheffield in 2001. He has been at the University of Nottingham since 2000, where he is currently a Senior Research Fellow responsible for the operation of transmission electron microscopes in the Nanoscale and Microscale Research Centre

Dr. Athanasios Angelis-Dimakis received his undergraduate diploma in Chemical Engineering from the National Technical University of Athens in Greece in 2005. He completed his PhD in Chemical Engineering in 2011 at the same university and then carried out an EU funded post-doctoral research on the life cycle assessment of innovative and eco-efficient technologies. In 2015, he joined the Centre for Environmental Policy at Imperial College London, to participate in a project, funded by Climate KIC and lead by Covestro AG, on enabling carbon dioxide reutilization between industries. In May 2016, he was appointed as a Lecturer in Chemical Engineering at the University of Huddersfield. His research interests include industrial symbiosis, urban mining, and assessment of the performance of novel green processes using various indicators; including the molar efficiency of chemical processes.

This was accomplished by first reacting the aryl alcohol with a catalytic amount of acid followed by the addition of excess base under Mizoroki–Heck reaction conditions. During the course of our study, Sinha and co-workers used an ionic liquid for the dehydrative-Heck cross-coupling of benzylic alcohols with aryl halides[12] to form potential anti-cancer compounds.[13] This methodology was further extended to include a double dehydrative-Heck process for the synthesis of lead compounds against Alzheimer's disease.[14] Aryl alcohol 1-phenylethanol (PE) is currently made on an industrial scale as the byproduct of the reaction of ethylbenzene hydroperoxide to form propylene oxide.[15] The majority of the alcohol is then dehydrated to form styrene.[16] Whilst styrene is a highly useful reagent, it is inherently unstable and precautions must be taken to prevent rapid exothermic polymerization.[17] Importantly, the International Agency for Research on Cancer recently classified styrene in Group 2A 'probably carcinogenic to humans'.[18] Therefore, there are key safety, economic and green drivers to develop cross-coupling methods that can eliminate the issues associated with bulk styrene. Previously, it was shown that the addition of reducing sugars, such as glucose, to palladium-mediated cross-coupling reactions leads to increased yields as well as facile catalyst recycling and increased metal remediation.[19–21] Herein, we report a dehydrative cross-coupling of 1-phenylethanol with aryl iodides catalysed by palladium nanoparticles formed in situ under base-free, acidic conditions in which the reducing sugars form, stabilise and regenerate the active catalyst (Scheme 1d).

The Mizoroki–Heck reaction between iodobenzene and styrene to form stilbene was used to assess the feasibility of the removal of base (Table 1). It was found that merely removing the base from the previously reported reaction conditions did not afford any of the desired products (Table 1, entries 1 vs. 2).[18] In order to eliminate the competing oxidation of palladium by molecular oxygen[22] (see below), the solvents were degassed with nitrogen.[23]

Table 1 Development of the Mizoroki–Heck Cross-Coupling under Acidic Conditions



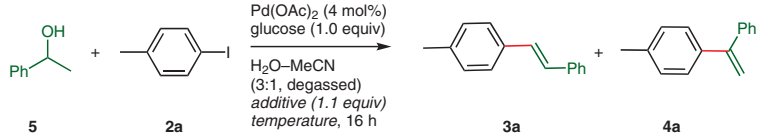
1 2b 3b 4b

Entry	Pd/sugar ratio	Temp. (°C)	Yield (%)[b]	Notes
1	1:2	100	97[a]	Ref.[18]
2	1:2	100	00	
3	1:2	150	05	
4	1:10	150	41	
5	1:25	150	97	pH 2.95
6	1:50	150	40	
7	1:100	150	33	

[a] Et_3N (1.5 equiv) was added
[b] **3b**/**4b** were isolated in a ratio of >90:10.

Heating a solution of styrene (**1**) and iodobenzene (**2b**) to 150 °C for 16 h, in the presence of $Pd(OAc)_2$ and glucose, gave alkenes **3b**/**4b** as a 94:6 mixture in excellent yield (Table 2, entry 5). The regiochemical distribution is in line with previously reported high-temperature Mizoroki–Heck cross-coupling reactions.[24,25] The final pH of this solution was determined to be 2.95. Additionally, it was found that the ratio of sugar to palladium had a substantial effect on the yield of the product, with a 1:25 ratio being optimal (Table 2, entries 3–7).

Table 2 Optimization of the Dehydrative Cross-Coupling Reaction



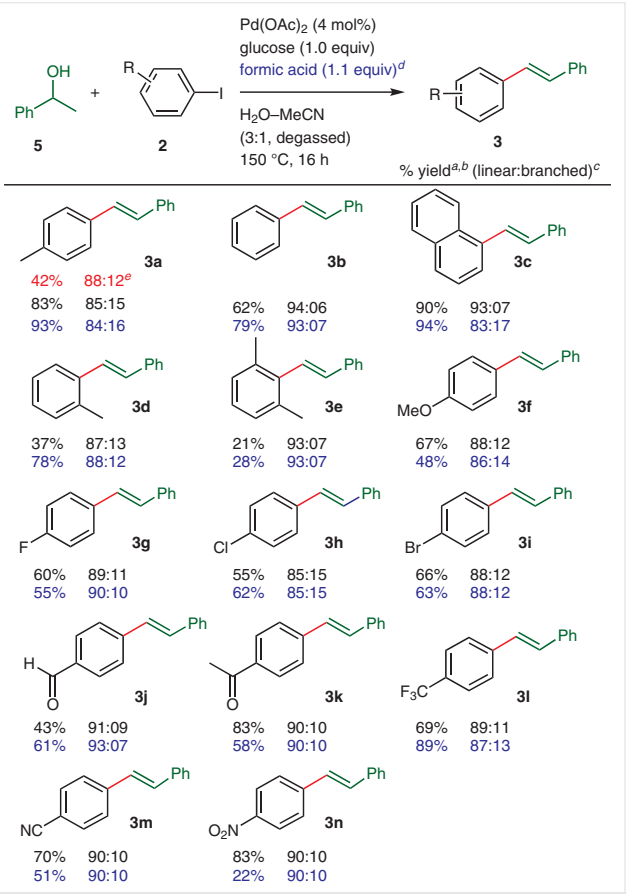
5 2a 3a 4a

Entry	Temp (°C)	Additive	Ratio **3**/**4**	Yield (%)
1	130	–	85:15	27
2	140	–	84:16	53
3	150	–	85:15	83
4	150	HCl	87:13	57[a]
5	150	H_2SO_4	87:13	16[a]
6	150	formic acid	83:17	22[b]
7	150	formic acid	84:16	93[a]

[a] 1.1 equiv of additive.
[b] 0.1 equiv formic acid used.

With a better understanding of the acidic cross-coupling reaction in hand, the dehydrative cross-coupling of 1-phenylethanol (**5**) with 4-iodotoluene (**2a**) was investigated (Table 2 and Table S3). It was found that the reaction gave the highest yield when 2 equivalents of alcohol **5** and 1 equivalent of glucose were used at 150 °C for 16 h (Table 2, entry 3). The product alkenes were isolated as a 85:15 mixture of linear **3a** to branched isomers **4a**. The equivalent of glucose is required to both reduce the palladium and stabilise the in situ formed nanoparticles (see below). To facilitate the dehydration of 1-phenylethanol (**5**), acidic additives were screened (Table 2, entries 5–8). The addition of strong acids led to a decreased yield of alkenes **3a**/**4a** (Table 2, entries 5 and 6). In contrast, the addition of 1.1 equivalents of formic acid resulted in an increase in yield of the desired product to 93%, but had no effect on the isomeric ratio. In contrast, the addition of 10 mol% of formic acid gave a deceased yield (Table 2, entry 7 vs. 6). Unfortunately, neither 4-bromotoluene nor 4-chlorotoluene afforded any of the desired cross-coupled products and only the starting materials were isolated. A comparison of the molar efficiency (Mol. E%)[26,27] of this protocol versus related two-step protocols that use alcohols or carboxylic acids for the palladium-mediated synthesis of stilbenes showed a 250–12,000 fold increase in efficiency.[23] Importantly, we have previously shown that palladium nanoparticles formed in situ can readily be recycled without significant loss of catalytic reactivity, which would mitigate the relatively high catalyst loading required in this protocol.[19]

To assess the generality of these conditions, the reaction of 1-phenylethanol (**5**) with a variety of aryl iodides **2** was investigated. As there was some ambiguity in the initial study with regard to the use of formic acid in the dehydrative cross-coupling process, the substrate scope investigation was conducted in both its presence and absence (Scheme 2). For comparison, base-free Mizoroki–Heck cross-coupling reactions were also conducted to gain further insights into the dehydrative process (Table S2). Whilst the products were isolated as a mixture of regioisomers **3**/**4**, the ratio of branched to linear was generally >85:15. The reactions of 4-iodotoluene and iodobenzene with 1-phenylethanol (**5**) in the presence of 4 mol% palladium acetate and 1 equivalent of glucose proceeded in good yields to form stilbenes **3a** and **3b**, respectively. For these substrates, a substantial increase in yield was observed upon the addition of formic acid. The products of the reaction of 1-iodonaphthalene, **3c**, were formed in good yield under the standard reaction conditions. The addition of formic acid to the reaction of 2-iodotoluene resulted in an increased yield of stilbene **3d**. In contrast, the addition of formic acid had little effect on the formation of the more sterically hindered adduct **3e**. Electron-rich substrate, 4-iodoanisole, was tolerated well under the reaction conditions. Iodobenzenes with electron-withdrawing groups afforded the desired cross-coupled adducts **3g**–**n** in good to excellent yields. In general, formic acid had either a beneficial or negligible effect on the dehydrative cross-coupling reaction, except in cases where additional reactions may have occurred.



Scheme 2 Substrate scope and role of formic acid in the dehydrative cross-coupling reaction. [a] Isolated yield. [b] Reaction conditions: aryliodide (1.0 equiv), 1-phenylethanol (2.0 equiv), $Pd(OAc)_2$ (4 mol %), glucose (1.0 equiv), H_2O/MeCN (3:1, degassed), 150 °C, 16 h. [c] Linear/branched selectivity was determined by ^1H NMR spectroscopy. [d] Reaction conditions: aryliodide (1.0 equiv), 1-phenylethanol (2.0 equiv), $Pd(OAc)_2$ (4 mol %), glucose (1.0 equiv), formic acid (1.1 equiv) H_2O/MeCN (3:1, degassed), 150 °C, 16 h. [e] Styrene (1.0 equiv) was used in place of 1-phenylethanol.

For example, the nitro group of (*E*)-4-nitro-*trans*-stilbene **3n** could have been reduced under the reaction conditions,[28] whereas the nitrile moiety of **3m** could have been hydrolysed in the presence of formic acid. Iodoarenes that contained basic nitrogen centres, such as 4-iodoaniline and 3-iodopyridine, did not give any of the desired cross-coupled products **3**/**4** under the optimised conditions. This result is in contrast to the related work by Liotta and coworkers,[7a] who found that basic-nitrogen-containing substrates were required for exogenous base-free Suzuki–Miyaura reactions and furthermore highlights the importance of the acidic conditions in our dehydrative cross-coupling protocol.

Transmission electron microscopy (TEM) analysis indicated that nanoparticles were formed when the palladium(II) pre-catalyst was subjected to the standard reaction conditions. The less dense amorphous matter at the periphery of the nanoparticles most likely contains the sugar residues (Figure 1a).[23] Analysis of the sugar-derived nanoparticles suspended in water at room temperature showed that the nanoparticles aggregate into larger clusters of around 100 nm (Figure 1b).[23] XPS analysis revealed that the palladium was present only in the zero oxidation state (Figure 1c).[23] A prototype EDX-TEM silicon drift detector was used to determine the amount of carbon and oxygen on the surface of the nanoparticles that were formed in both the absence and presence of oxygen (Figure 1d and Figure 1e, respectively).[23] It was found that there was a statistically significant decrease in the amount of carbon and oxygen on the surface of the nanoparticles that were formed in the presence of oxygen, 5%, versus those that were formed in the absence of oxygen, 37% (Figure 1f).[23] This difference in surface coverage is significant because if too little carbon and oxygen are present on the surface of the metal then the catalyst is unreactive (cf. Table 1). To our knowledge, this is the first time that a EDX-TEM silicon drift detector has been used to probe the difference in reactivity between in situ formed catalysts.

Our mechanistic hypothesis for the dehydrative cross-coupling reaction is predicated on the accepted mechanism for the classical Mizoroki–Heck process[2,29] as well as on the wealth of information on both the formation of metal nanoparticles[20,30] from reducing sugars and the synthesis of gluconic acid from glucose (Scheme 3).[31] Initially, the palladium(II) precatalyst is reduced by glucose to generate palladium(0) nanoparticles (Pd^0NP) with concomitant formation of gluconic acid.[19–21] The formation of gluconic acid was confirmed by analysis of a truncated reaction by mass spectrometry. After this initial oxidation, the gluconic acid can undergo a series of further palladium(II) mediated oxidations to eventually afford carbon dioxide and water, whilst simultaneously releasing additional reducing equivalents.[32] It is the sequential oxidation of the glucose in combination with the generation of one equivalent of hydrogen iodide

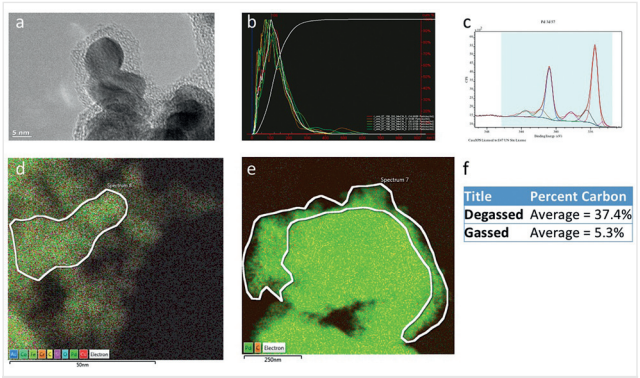
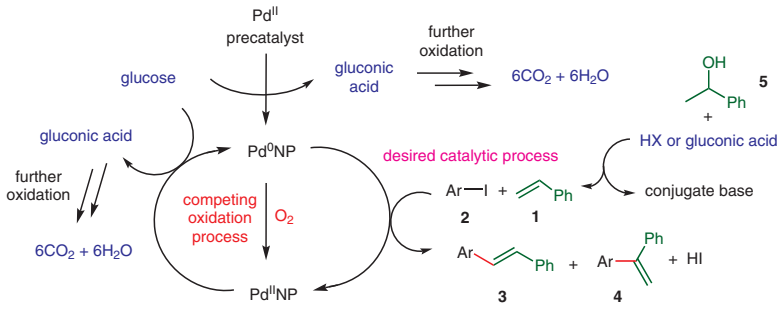


Figure 1 (a) TEM analysis (b) Nanosight analysis (c) XPS analysis (d) EDX-TEM analysis of palladium-nanoparticles formed in the absence of molecular oxygen (e) EDX-TEM analysis of palladium-nanoparticles formed in the presence of molecular oxygen (f) Percentage of carbon on the surface of palladium-nanoparticles formed in both the absence and presence of oxygen.

per catalytic cycle that makes the aqueous solution acidic, with a final pH 2.95. The acids generated in situ promote the dehydration of 1-phenylethanol (**5**) to styrene (**2**). Under the thermal conditions the in situ formed Pd^0NPs may be attacked by the arylating agent **1** to form a soluble anionic complex.[33] This species completes the desired Mizoroki–Heck reaction to form cross-coupled products **3**/**4**, with concomitant generation of a palladium(II) species. The active palladium(0) catalyst can be regenerated via reduction of the palladium(II) species by glucose or an oxidized derivative of glucose. A competing oxidation process involving molecular oxygen can short-circuit the catalytic cycle by converting the Pd^0NPs into a non-catalytically active palladium(II) species, which would then have to be reduced to re-enter the catalytic cycle. In aerated solvents we believe that the molecular oxygen outcompetes the iodobenzene for the Pd^0NP catalyst, leading to recovery of the starting material. It is believed that an increased temperature of 150 °C is needed to promote the requisite ring-opened conformation of glucose.[34]

In conclusion, a novel palladium-catalysed dehydrative cross-coupling protocol for the conversion of 1-phenylethanol into disubstituted alkenes was developed. The ability to



Scheme 3 Proposed mechanism for the dehydrative cross-coupling reaction

run the process under acidic conditions and use a secondary aryl alcohol as starting material significantly expands the scope and synthetic utility of the Mizoroki–Heck reaction. The high yields of cross-coupled products were achieved in an aqueous system, without the need to preform and isolate the catalyst, through the simple addition of a renewable reducing sugar. Mol.E% calculations showed that the direct dehydrative cross-coupling of 1-phenylethanol was significantly more efficient than previously reported two-step protocols. This work opens up exciting opportunities for the use of reducing sugars to power catalytic reactions, sugar-powered catalysis.

Unless otherwise indicated, all commercially available reagents and solvents were used directly from the supplier without further purification. Acetonitrile and water were degassed by bubbling nitrogen through the solvent at reflux for 1 h. Solvents used for column chromatography were of technical grade. For purification procedures using column chromatography, silica gel (60–120) mesh was used. Thin-layer chromatography was carried out using Merck Kieselgel silica gel 60 F254 plates (0.2 mm) and visualisation was achieved using UV light followed by dipping in a potassium permanganate solution and heating. All reactions were performed in a Biotage 5 mL microwave vial with Teflon coated cap.

^{1}H NMR and ^{13}C NMR were recorded with a Bruker AV400 (400 MHz) spectrometer, Bruker AV(III)400 (400 MHz) spectrometer, Bruker DPX400 (400 MHz) spectrometer or JOEL EX270 (270 MHz) spectrometer at ambient temperature using $CDCl_3$ (7.26 ppm), DMSO-d_6 (2.50 ppm), $(CD_3)_2CO$ (2.05 ppm) or CD_3OD (3.31 ppm) as the solvent. Chemical shift values are expressed as parts per million (ppm) and *J* values are in Hertz. Splitting patterns are indicated as s: singlet, d: doublet, t: triplet, q: quartet or combination thereof, br.s: broad singlet or m: multiplet. Solution IR spectra were recorded with a Perkin Elmer 1600 series FTIR-spectrophotometer. Mass spectra were determined with a Bruker MicroTOF mass spectrometer. pH measurements were recorded with a Philip Harris digital pH meter using a pH 7 standard buffer.

Transmission Electron Microscopy (TEM): TEM analysis was performed with a JEOL2100F field-emission gun microscope operating at 200 kV and equipped with a Gatan Orius camera. The Pd(0) nanoparticles were dispersed in water using an ultrasound bath and a suspension (3.5 µL) was deposited onto a holey carbon grid (Agar Scientific), which had previously been exposed to a low-temperature O_2/Ar plasma for five seconds in a Fischione Model 1020 Plasma Cleaner to make them hydrophilic. TEM image simulations was carried out using spherical aberration coefficient (*Cs*) = 1 mm.

EDX Transmission Electron Microscopy (EDX-TEM): EDX analysis was performed with a prototype Oxford Instruments Light Element 100 mm silicon drift detector with a JEOL 2100F operating at 200kV and the Aztec software. All spectra are acquired from regions not containing amorphous carbon supporting film. Cr, Fe and Co signals can originate from scatter from the polepiece and holder; Au signal can originate from scatter from the sample holder; Cu signal from the TEM supporting grid has been de-convolved from the quantification.

Nanoparticle Tracking Analysis (NTA): NTA was performed with a Nanosight LM10-HS instrument equipped with an electron multiplication charge coupled device camera mounted on an optical microscope system to track light scattered by particles that are present in a focused (80 µm) beam generated by a single-mode laser diode with a 60 mW blue laser illumination (405 nm). The solution containing the palladium(0) nanoparticles in a concentration of between 10^7 and 10^9 particles/mL was injected in a sample chamber of 0.5 mL size from which a volume of 120×80×20 microns was visualised under the microscope. The sample concentration was adjusted to ensure statistically significant number of particles under analysis. The Brownian motion of the nanoparticles was tracked at 30 frames/s. NTA 2.2 software was used to evaluate the mean square displacements of each visible particle (calibration 166 nm/pixel) and from the Strokes–Einstein equation the particle sizes were determined. All experiments were performed without filtering to ensure measurement of all particles.[35]

Dynamic Light Scattering (DLS): DLS experiments were performed with a Malvern Zetasizer ZS equipped with a He-Ne (633 nm, 5 mW) laser and an Avalanche photodiode detector at an angle of 173°. All DLS data were processed using Dispersion Technology Software (Malvern Instruments). All experiments were performed without filtering to ensure measurement of all particles.[36]

X-ray Photoelectron Spectroscopy (XPS): XPS spectra were recorded with a Kratos AXIS ULTRA with a monochromated Al Kα X-ray source (1486.6 eV) operated at 15mA emission current and 12kV anode potential – 180 W. Hybrid (magnet/electrostatic) optics (300×700 µm aperture), hemispherical analyser, multichannel plate and delay line detector (DLD) with a take-off angle of 90° and an acceptance angle of 30°. All scans were acquired under charge neutralisation conditions using a low-energy electron gun within the field of magnetic lens. Survey scans were taken with a pass energy of 80 eV and high-resolution scans with a pass energy of 20 eV. Data analysis was carried out using CASAXPS software with Kratos sensitivity factors to determine atomic % values from the peak areas.

Scanning Ion Occlusion Sensing (SIOS): SIOS measurements were carried out with a qNano instrument (Izon Science Ltd., Christchurch, NZ). A standard electrolyte buffer (SEB) of 0.1 M KCl, 10 mM Tris buffer, 0.01% Triton X-100, and 3 mM EDTA, pH 8.0, filtered through a 0.22 µm filter was used in all experiments. The membrane was wetted prior to sampling by applying a voltage (typically 0.3 V) and manually stretching the pore open (typically with a jaw stretch of 5 mm). Once a stable background current achieved, the fluid in the top half of the cell was replaced with a solution of the palladium(0) nanoparticles in the SEB (30–70 µL). The magnitude and duration of changes in the current signal were collected at a sampling frequency of 50 kHz. The instrument was calibrated using a solution of polystyrene particles (3000 series, 100 nm) in SEB.[37]

(*E*)-1-Methylstilbene[38] (3a) and 1-Methyl-4-(1-phenylvinyl)benzene[39] (4a)

Method 1: To a stirred solution of $Pd(OAc)_2$ (3.5 mg, 0.016 mmol) and glucose (70 mg, 0.39 mmol) and 4-iodotoluene (170 mg, 0.78 mmol) in degassed acetonitrile / degassed water (1:3, 4 mL) at r.t. was added styrene (87 µL, 0.79 mmol). The vial was sealed and the mixture was heated at 150 °C for 16 h. The mixture was cooled to r.t. and water (10 mL) and dichloromethane (10 mL) were added. The combined organic extracts were dried over Na_2SO_4 and the solvent was removed under reduced pressure. The crude residue was purified by flash column chromatography (silica gel, *n*-hexane/EtOAc, 5%) to give (*E*)-1-methylstilbene (**3a**) and 1-Methyl-4-(1-phenylvinyl)benzene (**4a**, 80 mg, ratio 88:12, 42% combined yield) as a white solid.

Method 2: To a stirred solution of $Pd(OAc)_2$ (3.5 mg, 0.016 mmol), glucose (70 mg, 0.39 mmol) and 4-iodotoluene (85 mg, 0.39 mmol) in degassed acetonitrile / degassed water (1:3, 4 mL) at r.t. were added 1-phenylethanol (97 mg, 0.79 mmol). The vial was sealed and the

mixture was heated at 150 °C for 16 h. The mixture was cooled to r.t. and water (10 mL) and dichloromethane (10 mL) were added. The combined organic extracts were dried over Na_2SO_4 and the solvent was removed under reduced pressure. The crude residue was purified by flash column chromatography (silica gel, *n*-hexane/EtOAc, 5%) to give (*E*)-1-methylstilbene (**3a**) and 1-methyl-4-(1-phenylvinyl)benzene (**4a**, 63 mg, ratio 85:15, 83% combined yield) as a white solid.

Method 3: To a stirred solution of $Pd(OAc)_2$ (3.5 mg, 0.016 mmol), glucose (70 mg, 0.39 mmol) and 4-iodotoluene (85 mg, 0.39 mmol) in degassed acetonitrile / degassed water (1:3, 4 mL) at r.t. were added 1-phenylethanol (97 mg, 0.79 mmol) and formic acid (33 µL, 0.87 mmol). The vial was sealed and the mixture was heated at 150 °C for 16 h. The mixture was cooled to r.t. and water (10 mL) and dichloromethane (10 mL) were added. The combined organic extracts were dried over Na_2SO_4 and the solvent was removed under reduced pressure. The crude residue was purified by flash column chromatography (silica gel, *n*-hexane/EtOAc, 5%) to give (*E*)-1-methylstilbene (**3a**) and 1-methyl-4-(1-phenylvinyl)benzene (**4a**, 71 mg, ratio 84:16, 93% combined yield) as a white solid.

(*E*)-1-Methylstilbene (3a)

^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.53 (d, *J* = 7.4 Hz, 2 H), 7.44 (d, *J* = 8.1 Hz, 2 H), 7.37 (t, *J* = 7.6 Hz, 2 H), 7.26 (m, 1 H), 7.18 (d, *J* = 7.9 Hz, 2 H), 7.13 (d, *J* = 16.4 Hz, 1 H), 7.08 (d, *J* = 16.5 Hz, 1 H), 2.38 (s, 3 H).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 137.5 (2 × C), 134.6, 129.4 (2 × C), 128.7 (2 × C), 128.6, 127.7, 127.4, 126.5 (2 × C), 126.4 (2 × C), 21.3.

IR ($CHCl_3$): 3020, 2915, 1593, 1508, 1493, 1448, 969, 803, 706 cm^{-1}.

HRMS (APPI): *m*/*z* calcd. for $[C_{15}H_{14}]^+$: 194.1090; found: 194.1087.

1-Methyl-4-(1-phenylvinyl)benzene (4a)

^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.35–7.32 (m, 5 H), 7.25 (d, *J* = 8.1 Hz, 2 H), 7.15 (d, *J* = 7.9 Hz, 2 H), 5.44 (d, *J* = 1.1 Hz, 2 H), 5.41 (d, *J* = 1.2 Hz, 2 H), 2.38 (s, 3 H).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 149.9, 141.7, 138.6, 137.5, 128.9 (2 × C), 128.3 (2 × C), 128.2 (2 × C), 128.1 (2 × C), 127.6, 113.7, 21.2.

(*E*)-Stilbene[40] (3b), 1,1-Diphenylethene[41] (4b)

Method 1: To a stirred solution of $Pd(OAc)_2$ (3.5 mg, 0.016 mmol) and glucose (70 mg, 0.39 mmol) in degassed acetonitrile / degassed water (1:3, 4 mL) at r.t. were added iodobenzene (87 µL, 0.78 mmol) and styrene (87 µL, 0.79 mmol). The vial was sealed and the mixture was heated at 150 °C for 16 h. The mixture was cooled to r.t. and water (10 mL) and dichloromethane (10 mL) were added. The combined organic extracts were dried over Na_2SO_4 and the solvent was removed under reduced pressure. The crude residue was purified by flash column chromatography (silica gel, *n*-hexane/EtOAc, 5%) to give (*E*)-stilbene (**3b**) and 1,1-diphenylethene (**4b**, 136 mg, ratio 94:6, 97% combined yield) as a white solid.

Method 2: To a stirred solution of $Pd(OAc)_2$ (3.5 mg, 0.016 mmol) and glucose (70 mg, 0.39 mmol) in degassed acetonitrile / degassed water (1:3, 4 mL) at r.t. were added 1-phenylethanol (97 mg, 0.79 mmol) and iodobenzene (44 µL, 0.39 mmol). The vial was sealed and the mixture was heated at 150 °C for 16 h. The mixture was cooled to r.t. and water (10 mL) and dichloromethane (10 mL) were added. The combined organic extracts were dried over Na_2SO_4 and the solvent was removed under reduced pressure. The crude residue was purified by flash column chromatography (silica gel, *n*-hexane/EtOAc, 5%) to give (*E*)-stilbene (**3b**) and 1,1-diphenylethene (**4b**, 44 mg, ratio 94:6, 62% combined yield) as a white solid.

Method 3: To a stirred solution of $Pd(OAc)_2$ (3.5 mg, 0.016 mmol) and glucose (70 mg, 0.39 mmol) in degassed acetonitrile / degassed water (1:3, 4 mL) at r.t. were added 1-phenylethanol (97 mg, 0.79 mmol), iodobenzene (44 µL, 0.39 mmol) and formic acid (33 µL, 0.87 mmol). The vial was sealed and the mixture was heated at 150 °C for 16 h. The mixture was cooled to r.t. and water (10 mL) and dichloromethane (10 mL) were added. The combined organic extracts were dried over Na_2SO_4 and the solvent was removed under reduced pressure. The crude residue was purified by flash column chromatography (silica gel, *n*-hexane/EtOAc, 5%) to give (*E*)-stilbene (**3b**) and 1,1-diphenylethene (**4b**, 55 mg, ratio 93:7, 79% combined yield) as a white solid.

(*E*)-Stilbene (3b) and 1,1-Diphenylethene (4b)

^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.60–7.58 (m, 4 H), 7.45–7.39 (m, 5.57 H), 7.35–7.31 (m, 2 H), 7.18 (s, 2 H), 5.54 (s, 0.26 H).

^{13}C NMR (100 MHz, $CDCl_3$): δ (stillbene) = 137.4, 128.8, 127.7, 126.6.

IR ($CHCl_3$): 3021, 2915, 1494, 1451, 983, 808, 688 cm^{-1}.

HRMS (APPI): *m*/*z* calcd. for $C_{14}H_{12}$: 180.0934; found: 180.0932.

(*E*)-1-Styrylnaphthalene[42] (3c) and 1-(1-Phenylethenyl)naphthalene[43] (4c)

Method 2: To a stirred solution of $Pd(OAc)_2$ (3.5 mg, 0.016 mmol) and glucose (70 mg, 0.39 mmol) in degassed acetonitrile / degassed water (1:3, 4 mL) at r.t. were added 1-phenylethanol (97 mg, 0.79 mmol) and 1-iodonaphthalene (57 µL, 0.78 mmol). The vial was sealed and the mixture was heated at 150 °C for 16 h. The mixture was cooled to r.t. and water (10 mL) and dichloromethane (10 mL) were added. The combined organic extracts were dried over Na_2SO_4 and the solvent was removed under reduced pressure. The crude residue was purified by flash column chromatography (silica gel, *n*-hexane/EtOAc, 5%) to give (*E*)-1-styrylnaphthalene (**3c**) and 1-(1-phenylethenyl)naphthalene (**4c**, 45 mg, ratio 93:17, 90% combined yield) as a colourless oil.

Method 3: To a stirred solution of $Pd(OAc)_2$ (3.5 mg, 0.016 mmol) and glucose (70 mg, 0.39 mmol) in degassed acetonitrile / degassed water (1:3, 4 mL) at r.t. were added 1-phenylethanol (97 mg, 0.79 mmol), 1-iodonaphthalene (57 µL, 0.78 mmol) and formic acid (33 µL, 0.87 mmol). The vial was sealed and the mixture was heated at 150 °C for 16 h. The mixture was cooled to r.t. and water (10 mL) and dichloromethane (10 mL) were added. The combined organic extracts were dried over Na_2SO_4 and the solvent was removed under reduced pressure. The crude residue was purified by flash column chromatography (silica gel, *n*-hexane/EtOAc, 5%) to give (*E*)-1-styrylnaphthalene (**3c**) and 1-(1-phenylethenyl)naphthalene (**4c**, 85 mg, ratio 83:17, 94% combined yield) as a colourless oil.

(*E*)-1-Styrylnaphthalene (3c)

^{1}H NMR (500 MHz, $CDCl_3$): δ = 8.25 (d, *J* = 8.3 Hz, 1 H), 7.93–7.88 (m, 2 H), 7.83 (d, *J* = 8.2 Hz, 1 H), 7.77 (d, *J* = 7.1 Hz, 1 H), 7.63 (d, *J* = 7.3 Hz, 2 H), 7.58–7.50 (m, 3 H), 7.43 (t, *J* = 7.7 Hz, 3 H), 7.34–7.31 (m, 1 H), 7.18 (d, *J* = 16.0 Hz, 1 H).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 137.7, 135.1, 133.8, 131.8, 131.4, 128.8 (2 × C), 128.7, 128.1, 127.8, 126.7 (2 × C), 126.1, 125.9, 125.8, 125.7, 123.8, 123.5.

IR ($CHCl_3$): 3056, 2928, 2852, 1493, 1263, 959, 774, 734, 692 cm^{-1}.

HRMS (APPI): *m*/*z* calcd. for $[C_{18}H_{14}]^+$: 230.1090; found: 230.1089.

1-(1-Phenylethenyl)naphthalene (4c)

^{1}H NMR (500 MHz, $CDCl_3$): δ = 7.86–7.84 (m 2 H), 7.77–7.75 (m, 1 H), 7.51–7.48 (m, 1 H), 7.44–7.41 (m, 2 H), 7.34–7.30 (m, 3 H), 7.27–7.24 (m, 3 H), 5.98 (d, *J* = 1.4 Hz, 2 H), 5.39 (d, *J* = 1.4 Hz, 2 H).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 148.3, 141.1, 139.8, 133.7, 131.9, 128.4 (2 × C), 128.2, 128.0, 127.7, 127.2, 126.6 (2 × C), 126.4, 125.9, 125.7, 125.4, 116.3.

(*E*)-2-Methylstilbene[44] (3d) and 1-Methyl-2-(1-phenylvinyl)benzene[45] (4d)

Method 1: To a stirred solution of $Pd(OAc)_2$ (3.5 mg, 0.016 mmol) and glucose (70 mg, 0.39 mmol) in degassed acetonitrile / degassed water (1:3, 4 mL) at r.t. were added 2-iodotoluene (99 µL, 0.78 mmol) and styrene (99 µL, 0.79 mmol). The vial was sealed and the mixture was heated at 150 °C for 16 h. The mixture was cooled to r.t. and water (10 mL) and dichloromethane (10 mL) were added. The combined organic extracts were dried over Na_2SO_4 and the solvent was removed under reduced pressure. The crude residue was purified by flash column chromatography (silica gel, *n*-hexane/EtOAc, 5%) to give (*E*)-2-methylstilbene (**3d**) and 1-methyl-2-(1-phenylvinyl)benzene (**4d**, 71 mg, ratio 88:12, 47% combined yield) as a colourless oil.

Method 2: To a stirred solution of $Pd(OAc)_2$ (3.5 mg, 0.016 mmol) and glucose (70 mg, 0.39 mmol) in degassed acetonitrile / degassed water (1:3, 4 mL) at r.t. were added 1-phenylethanol (97 mg, 0.79 mmol) and 2-iodotoluene (50 µL, 0.39 mmol). The vial was sealed and the mixture was heated at 150 °C for 16 h. The mixture was cooled to r.t. and water (10 mL) and dichloromethane (10 mL) were added. The combined organic extracts were dried over Na_2SO_4 and the solvent was removed under reduced pressure. The crude residue was purified by flash column chromatography (silica gel, *n*-hexane/EtOAc, 5%) to give (*E*)-2-methylstilbene (**3d**) and 1-methyl-2-(1-phenylvinyl)benzene (**4d**, 28 mg, ratio 87:13, 37% combined yield) as a colourless oil.

Method 3: To a stirred solution of $Pd(OAc)_2$ (3.5 mg, 0.016 mmol) and glucose (70 mg, 0.39 mmol) in degassed acetonitrile / degassed water (1:3, 4 mL) at r.t. were added 1-phenylethanol (97 mg, 0.79 mmol), 2-iodotoluene (50 µL, 0.39 mmol) and formic acid (33 µL, 0.87 mmol). The vial was sealed and the mixture was heated at 150 °C for 16 h. The mixture was cooled to r.t. and water (10 mL) and dichloromethane (10 mL) were added. The combined organic extracts were dried over Na_2SO_4 and the solvent was removed under reduced pressure. The crude residue was purified by flash column chromatography (silica gel, *n*-hexane/EtOAc, 5%) to give (*E*)-2-methylstilbene **3d** and 1-methyl-2-(1-phenylvinyl)benzene **4d** (59 mg, ratio 88:12, 78% combined yield) as a colourless oil.

(*E*)-2-Methylstilbene (3d)

^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.65 (d, *J* = 7.1 Hz, 1 H), 7.58 (d, *J* = 7.5 Hz, 2 H), 7.41 (t, *J* = 7.6 Hz, 3 H), 7.37–7.23 (m, 5 H), 7.06 (d, *J* = 16.2 Hz, 1 H), 2.49 (s, 3 H).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 137.8, 136.5, 135.9, 130.5, 130.1, 128.8 (2 × C), 127.7, 127.6, 126.64 (2 × C), 126.61, 126.3, 125.4, 20.0.

IR ($CHCl_3$): 3023, 2923, 1540, 1494, 959, 756, 711 cm^{-1}.

HRMS (APPI): *m*/*z* calcd. for $[C_{15}H_{14}]^+$: 194.1090; found: 194.1088.

1-Methyl-2-(1-phenylvinyl)benzene (4d)

^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.32–7.17 (m, 9 H), 5.77 (d, *J* = 1.3 Hz, 1 H), 5.22 (d, *J* = 1.3 Hz, 1 H), 2.05 (s, 3 H).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 137.8, 136.5, 130.5, 130.1, 128.8 (2 × C), 127.7, 127.6, 126.64 (2 × C), 126.61, 126.3, 125.4, 20.0.

(*E*)-2,6-Dimethylstilbene[46] (3e) and 1,3-Dimethyl-2-(1-phenylvinyl)benzene[46] (4e)

Method 2: To a stirred solution of $Pd(OAc)_2$ (3.5 mg, 0.016 mmol) and glucose (70 mg, 0.39 mmol) in degassed acetonitrile / degassed water (1:3, 4 mL) at r.t. were added 1-phenylethanol (97 mg, 0.79 mmol) and 2-iodo-1,3-dimethylbenzene (57 µL, 0.39 mmol). The vial was sealed and the mixture was heated at 150 °C for 16 h. The mixture was cooled to r.t. and water (10 mL) and dichloromethane (10 mL) were added. The combined organic extracts were dried over Na_2SO_4 and the solvent was removed under reduced pressure. The crude residue was purified by flash column chromatography (silica gel, *n*-hexane/EtOAc, 5%) to give (*E*)-2,6-dimethylstilbene (**3e**) and 1,3-dimethyl-2-(1-phenylvinyl)benzene (**4e**, 17 mg, ratio 93:7, 21% combined yield) as a colourless oil.

Method 3: To a stirred solution of $Pd(OAc)_2$ (3.5 mg, 0.016 mmol) and glucose (70 mg, 0.39 mmol) in degassed acetonitrile / degassed water (1:3, 4 mL) at r.t. were added 1-phenylethanol (97 mg, 0.79 mmol), 2-iodo-1,3-dimethylbenzene (57 µL, 0.39 mmol) and formic acid (33 µL, 0.87 mmol). The vial was sealed and the mixture was heated at 150 °C for 16 h. The mixture was cooled to r.t. and water (10 mL) and dichloromethane (10 mL) were added. The combined organic extracts were dried over Na_2SO_4 and the solvent was removed under reduced pressure. The crude residue was purified by flash column chromatography (silica gel, *n*-hexane/EtOAc, 5%) to give (*E*)-2,6-dimethylstilbene (**3e**) and 1,3-dimethyl-2-(1-phenylvinyl)benzene (**4e**, 23 mg, ratio 93:7, 28% combined yield) as a colourless oil.

(*E*)-2,6-Dimethylstilbene (3e)

^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.54 (d, *J* = 7.3 Hz, 2 H), 7.40 (t, *J* = 7.9 Hz, 2 H), 7.31 (t, *J* = 7.3 Hz, 1 H), 7.17–7.11 (m, 4 H), 6.64 (d, *J* = 16.8 Hz, 1 H), 2.40 (s, 6 H).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 137.6, 137.0, 136.3 (2 × C), 134.0, 128.7 (2 × C), 127.7 (2 × C), 127.6, 127.0, 126.8, 126.3 (2 × C), 21.1 (2 × C).

IR ($CHCl_3$): 3023, 2922, 2853, 1595, 1464, 968, 766, 690 cm^{-1}.

HRMS (APPI): *m*/*z* calcd. for $[C_{16}H_{16}]^+$: 208.1247; found: 208.1248.

(*E*)-4-Methoxystilbene[47] (3f) and 1-Methoxy-4-(1-phenylvinyl)benzene[47] (4f)

Method 1: To a stirred solution of $Pd(OAc)_2$ (3.5 mg, 0.016 mmol) and glucose (70 mg, 0.39 mmol) and 4-iodoanisole (183 mg, 0.78 mmol) in degassed acetonitrile / degassed water (1:3, 4 mL) at r.t. was added styrene (87 µL, 0.79 mmol). The vial was sealed and the mixture was heated at 150 °C for 16 h. The mixture was cooled to r.t. and water (10 mL) and dichloromethane (10 mL) were added. The combined organic extracts were dried over Na_2SO_4 and the solvent was removed under reduced pressure. The crude residue was purified by flash column chromatography (silica gel, *n*-hexane/EtOAc, 5%) to give (*E*)-1-methoxystilbene (**3f**) and 1-methoxy-4-(1-phenylvinyl)benzene (**4f**, 152 mg, ratio 84:16, 93% combined yield) as a white solid.

Method 2: To a stirred solution of $Pd(OAc)_2$ (3.5 mg, 0.016 mmol), glucose (70 mg, 0.39 mmol) and 4-iodoanisole (91 mg, 0.39 mmol) in degassed acetonitrile / degassed water (1:3, 4 mL) at r.t. were added 1-phenylethanol (97 mg, 0.79 mmol). The vial was sealed and the mixture was heated at 150 °C for 16 h. The mixture was cooled to r.t. and water (10 mL) and dichloromethane (10 mL) were added. The combined organic extracts were dried over Na_2SO_4 and the solvent was removed under reduced pressure. The crude residue was purified by

flash column chromatography (silica gel, *n*-hexane/EtOAc, 5%) to give (*E*)-1-methoxystilbene (**3f**) and 1-methoxy-4-(1-phenylvinyl)benzene (**4f**, 64 mg, ratio 88:12, 67% combined yield) as a white solid.

Method 3: To a stirred solution of $Pd(OAc)_2$ (3.5 mg, 0.016 mmol), glucose (70 mg, 0.39 mmol) and 4-iodoanisole (91 mg, 0.39 mmol) in degassed acetonitrile / degassed water (1:3, 4 mL) at r.t. were added 1-phenylethanol (97 mg, 0.79 mmol) and formic acid (33 µL, 0.87 mmol). The vial was sealed and the mixture was heated at 150 °C for 16 h. The mixture was cooled to r.t. and water (10 mL) and dichloromethane (10 mL) were added. The combined organic extracts were dried over Na_2SO_4 and the solvent was removed under reduced pressure. The crude residue was purified by flash column chromatography (silica gel, *n*-hexane/EtOAc, 5%) to give (*E*)-1-methoxystilbene (**3f**) and 1-methoxy-4-(1-phenylvinyl)benzene (**4f**, 43 mg, ratio 86:14, 48% combined yield) as a white solid.

(*E*)-1-Methoxystilbene (3f)

^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.53–7.48 (m, 3 H), 7.37 (t, *J* = 7.6 Hz, 2 H), 7.28–7.22 (m, 2 H), 7.10 (d, *J* = 16.3 Hz, 1 H), 7.00 (d, *J* = 16.3 Hz, 1 H), 6.93 (d, *J* = 8.7 Hz, 2 H), 3.86 (s, 3 H).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 159.3, 137.7, 130.2, 128.7 (2 × C), 128.2, 127.7 (2 × C), 127.2, 126.6, 126.3 (2 × C), 114.1 (2 × C), 55.3.

IR ($CHCl_3$): 3022, 3002, 2933, 2836, 1600, 1508, 1266, 1028, 811, 686 cm^{-1}.

HRMS (APPI): *m*/*z* calcd. for $[C_{15}H_{14}O]^+$: 210.1039; found: 210.1039.

(*E*)-4-Fluorostilbene[44] (3g) and 1-Fluoro-4-(phenylvinyl)benzene[43] (4g)

Method 1: To a stirred solution of $Pd(OAc)_2$ (3.5 mg, 0.016 mmol) and glucose (70 mg, 0.39 mmol) in degassed acetonitrile / degassed water (1:3, 4 mL) at r.t. were added 4-fluoroiodobenzene (90 µL, 0.78 mmol) and styrene (87 µL, 0.79 mmol). The vial was sealed and the mixture was heated at 150 °C for 16 h. The mixture was cooled to r.t. and water (10 mL) and dichloromethane (10 mL) were added. The combined organic extracts were dried over Na_2SO_4 and the solvent was removed under reduced pressure. The crude residue was purified by flash column chromatography (silica gel, *n*-hexane/EtOAc, 5%) to give (*E*)-4-fluorostilbene (**3g**) and 1-fluoro-4-(1-phenylvinyl)benzene (**4g**, 83 mg, ratio 94:6, 54% combined yield) as a white solid.

Method 2: To a stirred solution of $Pd(OAc)_2$ (3.5 mg, 0.016 mmol) and glucose (70 mg, 0.39 mmol) in degassed acetonitrile / degassed water (1:3, 4 mL) at r.t. were added 1-phenylethanol (97 mg, 0.79 mmol) and 4-fluoroiodobenzene (45 µL, 0.39 mmol). The vial was sealed and the mixture was heated at 150 °C for 16 h. The mixture was cooled to r.t. and water (10 mL) and dichloromethane (10 mL) were added. The combined organic extracts were dried over Na_2SO_4 and the solvent was removed under reduced pressure. The crude residue was purified by flash column chromatography (silica gel, *n*-hexane/EtOAc, 5%) to give (*E*)-4-fluorostilbene (**3g**) and 1-fluoro-4-(1-phenylvinyl)benzene (**4g**, 60 mg, ratio 89:11, 60% combined yield) as a white solid.

Method 3: To a stirred solution of $Pd(OAc)_2$ (3.5 mg, 0.016 mmol) and glucose (70 mg, 0.39 mmol) in degassed acetonitrile / degassed water (1:3, 4 mL) at r.t. were added 1-phenylethanol (97 mg, 0.79 mmol), 4-fluoroiodobenzene (45 µL, 0.39 mmol) and formic acid (33 µL, 0.87 mmol). The vial was sealed and the mixture was heated at 150 °C for 16 h. The mixture was cooled to r.t. and water (10 mL) and dichloromethane (10 mL) were added. The combined organic extracts were dried over Na_2SO_4 and the solvent was removed under reduced pressure. The crude residue was purified by flash column chromatography (silica gel, *n*-hexane/EtOAc, 5%) to give (*E*)-4-fluoro-*trans*-stilbene (**3g**) and 1-fluoro-4-(1-phenylvinyl)benzene (**4g**, 42 mg, ratio 90:10, 55% combined yield) as a white solid.

(*E*)-4-Fluorostilbene (3g)

^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.53–7.48 (m, 4 H), 7.39 (t, *J* = 7.6 Hz, 2 H), 7.29 (t, *J* = 7.30 Hz, 1 H), 7.12–7.02 (m, 4 H).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 162.4 (d, *J* = 246.3 Hz), 137.2, 133.5 (d, *J* = 3.4 Hz), 128.7, 128.5 (d, *J* = 2.4 Hz), 128.0 (d, *J* = 8.0 Hz), 127.7, 127.5, 126.5, 115.6 (d, *J* = 21.7 Hz).

^{19}F NMR (376 MHz, $CDCl_3$): δ = –114.2 (s, 1 F).

IR ($CHCl_3$): 3022, 2923, 2851, 1592, 1504, 1226, 999, 822, 751 cm^{-1}.

HRMS (APPI): *m*/*z* calcd. for $C_{14}H_{12}F$: 198.0839; found: 198.0835.

(*E*)-1-Chloro-4-styrylbenzene[40] (3h), 1-Chloro-4-(1-phenylvinyl)benzene[41] (4h)

Method 2: To a stirred solution of $Pd(OAc)_2$ (3.5 mg, 0.016 mmol), glucose (70 mg, 0.39 mmol) and 4-chloroiodotoluene (93 mg, 0.39 mmol) in degassed acetonitrile / degassed water (1:3, 4 mL) at r.t. were added 1-phenylethanol (97 mg, 0.79 mmol). The vial was sealed and the mixture was heated at 150 °C for 16 h. The mixture was cooled to r.t. and water (10 mL) and dichloromethane (10 mL) were added. The combined organic extracts were dried over Na_2SO_4 and the solvent was removed under reduced pressure. The crude residue was purified by flash column chromatography (silica gel, *n*-hexane/EtOAc, 5%) to give (*E*)-1-chloro-4-styrylbenzene (**3h**) and 1-chloro-4-(1-phenylvinyl)benzene (**4h**, 46 mg, ratio 85:15, 55% combined yield) as a white solid.

Method 3: To a stirred solution of $Pd(OAc)_2$ (3.5 mg, 0.016 mmol), glucose (70 mg, 0.39 mmol) and 4-chloroiodotoluene (93 mg, 0.39 mmol) in degassed acetonitrile / degassed water (1:3, 4 mL) at r.t. were added 1-phenylethanol (97 mg, 0.79 mmol) and formic acid (33 µL, 0.87 mmol). The vial was sealed and the mixture was heated at 150 °C for 16 h. The mixture was cooled to r.t. and water (10 mL) and dichloromethane (10 mL) were added. The combined organic extracts were dried over Na_2SO_4 and the solvent was removed under reduced pressure. The crude residue was purified by flash column chromatography (silica gel, *n*-hexane/EtOAc, 5%) to give (*E*)-1-chloro-4-styrylbenzene (**3h**) and 1-chloro-4-(1-phenylvinyl)benzene (**4h**, 52 mg, ratio 85:15, 62% combined yield) as a white solid.

(*E*)-1-Chloro-4-styrylbenzene (3h)

^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.52 (d, *J* = 7.4 Hz, 2 H), 7.45 (d, *J* = 8.5 Hz, 2 H), 7.40–7.27 (m, 5 H), 7.12–7.03 (m, 2 H).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 137.0, 135.9, 133.2, 129.3, 128.9 (2 × C), 128.8 (2 × C), 127.9, 127.7 (2 × C), 127.4, 126.6 (2 × C).

IR ($CHCl_3$): 3055, 2987, 2928, 1558, 1540, 1264, 730, 701, 669 cm^{-1}.

GCMS (EI): *m*/*z* calcd. for $[C_{14}H_{11}Cl]^+$: 214.1; found: 214.0.

1-Chloro-4-(1-phenylvinyl)benzene (4h)

^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.33–7.26 (m 10 H), 5.47 (s, 1 H), 5.45 (s, 1 H).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 149.0, 141.02, 140.0, 133.6, 129.6 (2 × C), 128.4 (2 × C), 128.3 (2 × C), 128.2 (2 × C), 237.9, 114.7.

(*E*)-4-Bromostilbene[48] (3i) and 1-(4-Bromophenyl)-1-phenylethene[49] (4i)

Method 1: To a stirred solution of $Pd(OAc)_2$ (3.5 mg, 0.016 mmol), glucose (70 mg, 0.39 mmol) and 4-iodobromobenzene (221 mg, 0.78 mmol) in degassed acetonitrile / degassed water (1:3, 4 mL) at r.t. was added styrene (87 µL, 0.79 mmol). The vial was sealed and the mixture was heated at 150 °C for 16 h. The mixture was cooled to r.t. and water (10 mL) and dichloromethane (10 mL) were added. The combined organic extracts were dried over Na_2SO_4 and the solvent was removed under reduced pressure. The crude residue was purified by flash column chromatography (silica gel, *n*-hexane/EtOAc, 5%) to give (*E*)-4-bromo-stilbene (**3i**) and 1-bromo-4-(1-phenylvinyl)benzene (**4i**, 176 mg, ratio 86:14, 87% combined yield) as a white solid.

Method 2: To a stirred solution of $Pd(OAc)_2$ (3.5 mg, 0.016 mmol), glucose (70 mg, 0.39 mmol) and 4-iodobromobenzene (110 mg, 0.39 mmol) in degassed acetonitrile / degassed water (1:3, 4 mL) at r.t. was added 1-phenylethanol (97 mg, 0.79 mmol). The vial was sealed and the mixture was heated at 150 °C for 16 h. The mixture was cooled to r.t. and water (10 mL) and dichloromethane (10 mL) were added. The combined organic extracts were dried over Na_2SO_4 and the solvent was removed under reduced pressure. The crude residue was purified by flash column chromatography (silica gel, *n*-hexane/EtOAc, 5%) to give (*E*)-4-bromostilbene (**3i**) and 1-bromo-4-(1-phenylvinyl)benzene (**4i**, 67 mg, ratio 88:12, 66% combined yield) as a white solid.

Method 3: To a stirred solution of $Pd(OAc)_2$ (3.5 mg, 0.016 mmol), glucose (70 mg, 0.39 mmol) and 4-iodobromobenzene (110 mg, 0.39 mmol) in degassed acetonitrile / degassed water (1:3, 4 mL) at r.t. were added 1-phenylethanol (97 mg, 0.79 mmol) and formic acid (33 µL, 0.87 mmol). The vial was sealed and the mixture was heated at 150 °C for 16 h. The mixture was cooled to r.t. and water (10 mL) and dichloromethane (10 mL) were added. The combined organic extracts were dried over Na_2SO_4 and the solvent was removed under reduced pressure. The crude residue was purified by flash column chromatography (silica gel, *n*-hexane/EtOAc, 5%) to give (*E*)-4-bromostilbene (**3i**) and 1-bromo-4-(1-phenylvinyl)benzene (**4i**, 64 mg, ratio 88:12, 63% combined yield) as a white solid.

(*E*)-4-Bromostilbene (3i)

^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.53–7.46 (m, 4 H), 7.40–7.34 (m, 4 H), 7.30–7.25 (m, 1 H), 7.07 (dd, *J* = 16.4 Hz, *J* = 28.3 Hz, 2 H).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 137.0, 136.3, 131.8, 129.4, 128.8, 128.0, 127.9, 127.4, 126.6, 121.3.

IR ($CHCl_3$): 3025, 2921, 2852, 1485, 1072, 964, 840, 688 cm^{-1}.

HRMS (APPI): *m*/*z* calcd. for $[C_{14}H_{11}Br]^+$: 258.0039; found: 258.0029.

(*E*)-4-Styrylbenzaldehyde[50] (3j) and 4-(1-Phenylvinyl)benzaldehyde[43] (4j)

Method 1: To a stirred solution of $Pd(OAc)_2$ (3.5 mg, 0.016 mmol) and glucose (70 mg, 0.39 mmol) and 4-iodobenzaldehyde (170 mg, 0.78 mmol) in degassed acetonitrile / degassed water (1:3, 4 mL) at r.t. was added styrene (87 µL, 0.79 mmol). The vial was sealed and the mixture was heated at 150 °C for 16 h. The mixture was cooled to r.t. and water (10 mL) and dichloromethane (10 mL) were added. The combined organic extracts were dried over Na_2SO_4 and the solvent was removed under reduced pressure. The crude residue was purified by flash column chromatography (silica gel, *n*-hexane/EtOAc, 5%) to give (*E*)-4-styrylbenzaldehyde (**3j**) and 4-(1-phenylvinyl)benzaldehyde (**4j**, 63 mg, ratio 90:10, 39% combined yield) as a white solid.

Method 2: To a stirred solution of $Pd(OAc)_2$ (3.5 mg, 0.016 mmol), glucose (70 mg, 0.39 mmol) and 4-iodobenzaldehyde (85 mg, 0.39 mmol) in degassed acetonitrile / degassed water (1:3, 4 mL) at r.t. were added 1-phenylethanol (97 mg, 0.79 mmol). The vial was sealed and the mixture was heated at 150 °C for 16 h. The mixture was cooled to r.t. and water (10 mL) and dichloromethane (10 mL) were added. The combined organic extracts were dried over Na_2SO_4 and the solvent was removed under reduced pressure. The crude residue was purified by flash column chromatography (silica gel, *n*-hexane/EtOAc, 5%) to give (*E*)-4-styrylbenzaldehyde (**3j**) and 4-(1-phenylvinyl)benzaldehyde (**4j**, 35 mg, ratio 91:9, 43% combined yield) as a white solid.

Method 3: To a stirred solution of $Pd(OAc)_2$ (3.5 mg, 0.016 mmol), glucose (70 mg, 0.39 mmol) and 4-iodobenzaldehyde (85 mg, 0.39 mmol) in degassed acetonitrile / degassed water (1:3, 4 mL) at r.t. were added 1-phenylethanol (97 mg, 0.79 mmol) and formic acid (33 µL, 0.87 mmol). The vial was sealed and the mixture was heated at 150 °C for 16 h. The mixture was cooled to r.t. and water (10 mL) and dichloromethane (10 mL) were added. The combined organic extracts were dried over Na_2SO_4 and the solvent was removed under reduced pressure. The crude residue was purified by flash column chromatography (silica gel, *n*-hexane/EtOAc, 5%) to give (*E*)-4-styrylbenzaldehyde (**3j**) and 4-(1-phenylvinyl)benzaldehyde (**4j**, 50 mg, ratio 93:7, 61% combined yield) as a white solid.

(*E*)-4-Styrylbenzaldehyde (3j)

^{1}H NMR (400 MHz, $CDCl_3$): δ = 10.00 (s, 1 H), 7.87 (d, *J* = 8.2 Hz, 2 H), 7.66 (d, *J* = 8.1 Hz, 2 H), 7.55 (d, *J* = 7.5 Hz, 2 H), 7.40 (t, *J* = 7.5 Hz, 2 H), 7.34–7.25 (m, 2 H), 7.15 (t, *J* = 16.4 Hz, 1 H).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 191.6, 143.4, 136.6, 135.3, 132.2, 130.3, 128.9, 128.5, 127.3, 126.9 (2 × C).

IR ($CHCl_3$): 3028, 2820, 2729, 1692, 1590, 1209, 1166, 968, 816, 759, 688 cm^{-1}.

HRMS (Dual ESI): *m*/*z* calcd. for $[C_{15}H_{13}O]^+$: 209.0961; found: 209.0961.

(*E*)-1-(4-Styrylphenyl)ethan-1-one[48] (3k) and 1-(4-(1-Phenylvinyl)phenyl)ethan-1-one[51] (4k)

Method 1: To a stirred solution of $Pd(OAc)_2$ (3.5 mg, 0.016 mmol) and glucose (70 mg, 0.39 mmol) and 4-iodotoluene (170 mg, 0.78 mmol) in degassed acetonitrile / degassed water (1:3, 4 mL) at r.t. was added styrene (87 µL, 0.79 mmol). The vial was sealed and the mixture was heated at 150 °C for 16 h. The mixture was cooled to r.t. and water (10 mL) and dichloromethane (10 mL) were added. The combined organic extracts were dried over Na_2SO_4 and the solvent was removed under reduced pressure. The crude residue was purified by flash column chromatography (silica gel, *n*-hexane/EtOAc, 5%) to give (*E*)-1-(4-styrylphenyl)ethan-1-one (**3k**) and 1-(4-(1-phenylvinyl)phenyl)ethan-1-one (**4k**, 78 mg, ratio 93:7, 45% combined yield) as a white solid.

Method 2: To a stirred solution of $Pd(OAc)_2$ (3.5 mg, 0.016 mmol), glucose (70 mg, 0.39 mmol) and 4-iodotoluene (85 mg, 0.39 mmol) in degassed acetonitrile / degassed water (1:3, 4 mL) at r.t. was added 1-phenylethanol (97 mg, 0.79 mmol). The vial was sealed and the mixture was heated at 150 °C for 16 h. The mixture was cooled to r.t. and water (10 mL) and dichloromethane (10 mL) were added. The combined organic extracts were dried over Na_2SO_4 and the solvent was removed under reduced pressure. The crude residue was purified by flash column chromatography (silica gel, *n*-hexane/EtOAc, 5%) to give

(*E*)-1-(4-styrylphenyl)ethan-1-one (**3k**) and 1-(4-(1-phenylvinyl)phenyl)ethan-1-one (**4k**, 50 mg, ratio 90:10, 83% combined yield) as a white solid.

Method 3: To a stirred solution of $Pd(OAc)_2$ (3.5 mg, 0.016 mmol), glucose (70 mg, 0.39 mmol) and 4-iodotoluene (85 mg, 0.39 mmol) in degassed acetonitrile / degassed water (1:3, 4 mL) at r.t. were added 1-phenylethanol (97 mg, 0.79 mmol) and formic acid (33 µL, 0.87 mmol). The vial was sealed and the mixture was heated at 150 °C for 16 h. The mixture was cooled to r.t. and water (10 mL) and dichloromethane (10 mL) were added. The combined organic extracts were dried over Na_2SO_4 and the solvent was removed under reduced pressure. The crude residue was purified by flash column chromatography (silica gel, *n*-hexane/EtOAc, 5%) to give (*E*)-1-(4-styrylphenyl)ethan-1-one (**3k**) and 1-(4-(1-phenylvinyl)phenyl)ethan-1-one (**4k**, 50 mg, ratio 90:10, 58% combined yield) as a white solid.

(*E*)-1-(4-Styrylphenyl)ethan-1-one (3k)

^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.96 (d, *J* = 8.3 Hz, 2 H), 7.59 (d, *J* = 8.3 Hz, 2 H), 7.54 (d, *J* = 7.5 Hz, 2 H), 7.39 (t, *J* = 7.5 Hz, 2 H), 7.33–7.29 (m, 1 H), 7.26–7.22 (m, 1 H), 7.14 (d, *J* = 16.4 Hz, 1 H), 2.61 (s, 3 H).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 197.5, 136.7, 136.0, 131.5, 128.9 (2 × C), 128.8 (2 × C), 128.3, 127.5, 126.8 (2 × C), 126.5 (2 × C), 26.6.

IR ($CHCl_3$): 3010, 2922, 2853, 1673, 1633, 1410, 1356, 1260, 999, 843, 753, 688, 610 cm^{-1}.

HRMS (APPI): *m*/*z* calcd. for $[C_{16}H_{14}O]^+$: 222.1039; found: 222.1039.

(*E*)-4-Trifluoromethylstilbene[40] (3l) and 1-(1-Phenylvinyl)-4-trifluoromethylbenzene[41] (4l)

Method 1: To a stirred solution of $Pd(OAc)_2$ (3.5 mg, 0.016 mmol) and glucose (70 mg, 0.39 mmol) in degassed acetonitrile / degassed water (1:3, 4 mL) at r.t. were added 4-iodobenzotrifluoride (114 µL, 0.78 mmol) and styrene (87 µL, 0.79 mmol). The vial was sealed and the mixture was heated at 150 °C for 16 h. The mixture was cooled to r.t. and water (10 mL) and dichloromethane (10 mL) were added. The combined organic extracts were dried over Na_2SO_4 and the solvent was removed under reduced pressure. The crude residue was purified by flash column chromatography (silica gel, *n*-hexane/EtOAc, 5%) to give (*E*)-4-trifluoromethylstilbene (**3l**) and 1-(1-phenylvinyl)-4-(trifluoromethyl)benzene (**4l**, 172 mg, ratio 87:13, 89% combined yield) as a white solid.

Method 2: To a stirred solution of $Pd(OAc)_2$ (3.5 mg, 0.016 mmol) and glucose (70 mg, 0.39 mmol) in degassed acetonitrile / degassed water (1:3, 4 mL) at r.t. were added 1-phenylethanol (97 mg, 0.79 mmol) and 4-iodobenzotrifluoride (57 µL, 0.78 mmol). The vial was sealed and the mixture was heated at 150 °C for 16 h. The mixture was cooled to r.t. and water (10 mL) and dichloromethane (10 mL) were added. The combined organic extracts were dried over Na_2SO_4 and the solvent was removed under reduced pressure. The crude residue was purified by flash column chromatography (silica gel, *n*-hexane/EtOAc, 5%) to give (*E*)-4-trifluoromethylstilbene (**3l**) and 1-(1-phenylvinyl)-4-(trifluoromethyl)benzene (**4l**, 67 mg, ratio 89:11, 69% combined yield) as a white solid.

Method 3: To a stirred solution of $Pd(OAc)_2$ (3.5 mg, 0.016 mmol) and glucose (70 mg, 0.39 mmol) in degassed acetonitrile / degassed water (1:3, 4 mL) at r.t. were added 1-phenylethanol (97 mg, 0.79 mmol), 4-iodobenzotrifluoride (57 µL, 0.78 mmol) and formic acid (33 µL, 0.87 mmol). The vial was sealed and the mixture was heated at 150 °C for 16 h. The mixture was cooled to r.t. and water (10 mL) and dichloromethane (10 mL) were added. The combined organic extracts were dried over Na_2SO_4 and the solvent was removed under reduced pressure. The crude residue was purified by flash column chromatography (silica gel, *n*-hexane/EtOAc, 5%) to give (*E*)-4-trifluoromethylstilbene (**3l**) and 1-(1-phenylvinyl)-4-(trifluoromethyl)benzene (**4l**, 86 mg, ratio 87:13, 89% combined yield) as a white solid.

(*E*)-4-Trifluoromethylstilbene (3l)

^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.64–7.59 (m, 4 H), 7.55 (d, *J* = 7.04 Hz, 2 H), 7.41 (t, *J* = 7.48 Hz, 2 H), 7.33 (t, *J* = 7.28 Hz, 1 H), 7.21 (d, *J* = 16.4 Hz, 1 H), 7.13 (d, *J* = 16.3 Hz, 1 H).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 140.8, 136.6, 131.2, 129.7, 129.4, 129.1, 128.8, 127.1, 126.8, 126.6, 125.7 (q, 2 × C), 122.9, 123.2.

^{19}F NMR (376 MHz, $CDCl_3$): δ = –62.4 (s, 3 F).

IR ($CHCl_3$): 3028, 2928, 2854, 1612, 1450, 1321, 1164, 1105, 1066, 843, 756, 692 cm^{-1}.

HRMS (APPI): *m*/*z* calcd. for $[C_{15}H_{11}F_3]^+$: 248.0807; found: 248.0809.

1-(1-Phenylvinyl)-4-(trifluoromethyl)benzene (4l)

^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.62 (d, *J* = 8.2 Hz, 2 H), 7.47 (d, *J* = 8.1 Hz, 2 H), 7.39–7.32 (m, 5 H), 5.58 (s, 1 H), 5.54 (s, 1 H).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 149.0, 140.6, 128.8, 128.6 (2 × C), 128.4 (2 × C), 128.2 (2 × C), 128.1, 126.8, 126.6, 125.2 (q, 2 × C), 115.9.

^{19}F NMR (376 MHz, $CDCl_3$): δ = –62.5 (s, 3 F).

(*E*)-4-Styrylbenzonitrile[40] (3m) and 4-(1-Phenylvinyl)benzonitrile[45] (4m)

Method 2: To a stirred solution of $Pd(OAc)_2$ (3.5 mg, 0.016 mmol), glucose (70 mg, 0.39 mmol) and 4-iodotoluene (85 mg, 0.39 mmol) in degassed acetonitrile / degassed water (1:3, 4 mL) at r.t. was added 1-phenylethanol (97 mg, 0.79 mmol). The vial was sealed and the mixture was heated at 150 °C for 16 h. The mixture was cooled to r.t. and water (10 mL) and dichloromethane (10 mL) were added. The combined organic extracts were dried over Na_2SO_4 and the solvent was removed under reduced pressure. The crude residue was purified by flash column chromatography (silica gel, *n*-hexane/EtOAc, 5%) to give (*E*)-4-styrylbenzonitrile (**3m**) and 4-(1-phenylvinyl)benzonitrile (**4m**, 56 mg, ratio 90:10, 70% combined yield) as a white solid.

Method 3: To a stirred solution of $Pd(OAc)_2$ (3.5 mg, 0.016 mmol), glucose (70 mg, 0.39 mmol) and 4-iodotoluene (85 mg, 0.39 mmol) in degassed acetonitrile / degassed water (1:3, 4 mL) at r.t. were added 1-phenylethanol (97 mg, 0.79 mmol) and formic acid (33 µL, 0.87 mmol). The vial was sealed and the mixture was heated at 150 °C for 16 h. The mixture was cooled to r.t. and water (10 mL) and dichloromethane (10 mL) were added. The combined organic extracts were dried over Na_2SO_4 and the solvent was removed under reduced pressure. The crude residue was purified by flash column chromatography (silica gel, *n*-hexane/EtOAc, 5%) to give (*E*)-4-styrylbenzonitrile (**3m**) and 4-(1-phenylvinyl)benzonitrile (**4m**, 41 mg, ratio 90:10, 51% combined yield) as a white solid.

(*E*)-4-Styrylbenzonitrile (3m)

^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.67–55 (m, 6 H), 7.44 (t, *J* = 7.4 Hz, 2 H), 7.37–7.33 (m, 1 H), 7.24 (d, *J* = 16.4 Hz, 1 H), 7.11 (d, *J* = 16.3 Hz, 1 H).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 141.9, 136.3, 132.5 (2 × C), 132.4, 128.9 (2 × C), 128.7, 126.93 (2 × C), 126.88 (2 × C), 126.7, 119.1, 110.6.

IR ($CHCl_3$): 3023, 2920, 2854, 2223, 1600, 1503, 972, 823, 756, 689 cm^{-1}.

HRMS (APPI): *m*/*z* calcd. for $[C_{15}H_{11}N]^+$: 205.0886; found: 205.0890.

(*E*)-4-Nitro-stilbene[52] (3n) and 1-Nitro-4-(1-phenylvinyl)benzene[45] (4n)

Method 1: To a stirred solution of $Pd(OAc)_2$ (3.5 mg, 0.016 mmol), glucose (70 mg, 0.39 mmol) and 4-iodonitrobenzene (194 mg, 0.78 mmol) in degassed acetonitrile / degassed water (1:3, 4 mL) at r.t. was added styrene (87 µL, 0.79 mmol). The vial was sealed and the mixture was heated at 150 °C for 16 h. The mixture was cooled to r.t. and water (10 mL) and dichloromethane (10 mL) were added. The combined organic extracts were dried over Na_2SO_4 and the solvent was removed under reduced pressure. The crude residue was purified by flash column chromatography (silica gel, *n*-hexane/EtOAc, 5%) to give (*E*)-1-nitrostilbene (**3n**) and 1-nitro-4-(1-phenylvinyl)benzene (**4n**, 159 mg, ratio 92:8, 90% combined yield) as a yellow solid.

Method 2: To a stirred solution of $Pd(OAc)_2$ (3.5 mg, 0.016 mmol), glucose (70 mg, 0.39 mmol) and 4-iodonitrobenzene (97 mg, 0.39 mmol) in degassed acetonitrile / degassed water (1:3, 4 mL) at r.t. was added 1-phenylethanol (97 mg, 0.79 mmol). The vial was sealed and the mixture was heated at 150 °C for 16 h. The mixture was cooled to r.t. and water (10 mL) and dichloromethane (10 mL) were added. The combined organic extracts were dried over Na_2SO_4 and the solvent was removed under reduced pressure. The crude residue was purified by flash column chromatography (silica gel, *n*-hexane/EtOAc, 5%) to give (*E*)-1-nitrostilbene (**3n**) and 1-nitro-4-(1-phenylvinyl)benzene (**4n**, 62 mg, ratio 90:10, 83% combined yield) as a yellow solid.

Method 3: To a stirred solution of $Pd(OAc)_2$ (3.5 mg, 0.016 mmol), glucose (70 mg, 0.39 mmol) and 4-iodonitrobenzene (97 mg, 0.39 mmol) in degassed acetonitrile / degassed water (1:3, 4 mL) at r.t. were added 1-phenylethanol (97 mg, 0.79 mmol) and formic acid (33 µL, 0.87 mmol). The vial was sealed and the mixture was heated at 150 °C for 16 h. The mixture was cooled to r.t. and water (10 mL) and dichloromethane (10 mL) were added. The combined organic extracts were dried over Na_2SO_4 and the solvent was removed under reduced pressure. The crude residue was purified by flash column chromatography (silica gel, *n*-hexane/EtOAc, 5%) to give (*E*)-1-nitrostilbene (**3n**) and 1-nitro-4-(1-phenylvinyl)benzene (**4n**, 19 mg, ratio 90:10, 22% combined yield) as a yellow solid.

(*E*)-1-Nitrostilbene (3n)

^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.22 (d, *J* = 8.8 Hz, 2 H), 7.64 (d, *J* = 8.8 Hz, 2 H), 7.56 (d, *J* = 7.3 Hz, 2 H), 7.42 (t, *J* = 7.4 Hz, 2 H), 7.36–7.32 (m, 1 H), 7.28 (d, *J* = 16.3 Hz, 2 H), 7.15 (d, *J* = 16.3 Hz, 2 H).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 146.8, 143.9, 136.2, 133.3, 128.9 (2 × C), 128.8, 127.0 (2 × C), 126.9 (2 × C), 126.3, 124.2 (2 × C).

IR ($CHCl_3$): 3089, 2920, 1593, 1569, 1505, 1336, 1105, 849, 692 cm^{-1}.

HRMS (APPI): *m*/*z* calcd. for $[C_{14}H_{11}NO_2]^+$: 225.0784; found: 225.0778.

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Supporting Information

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References

(1) For recent examples, see: (a) Cheng, G.; Wang, P.; Yu, J.-Q. *Angew. Chem. Int. Ed.* **2017**, *56*, 8183. (b) Bao, X.; Wang, Q.; Zhu, J. *Angew. Chem. Int. Ed.* **2017**, *56*, 9577. (c) Qi, X.; Chen, P.; Liu, G. *Angew. Chem. Int. Ed.* **2017**, *56*, 9517.

(2) (a) Heck, R. F. *Acc. Chem. Res.* **1979**, *12*, 146. (b) Dounay, A. B.; Overman, L. E. *Chem. Rev.* **2003**, *103*, 2945.

(3) (a) Czaplik, W. M.; Mayer, M.; Cvengros, J.; von Wangelin, A. J. *ChemSusChem* **2009**, *2*, 396. (b) McGuinness, D. S.; Cavell, K. J.; Skelton, B. W.; White, A. H. *Organometallics* **1999**, *18*, 1596. (c) Yin, L.; Liebscher, J. *Chem. Rev.* **2007**, *107*, 133. (d) Beletskaya, I. P.; Cheprakov, A. V. *Coord. Chem. Rev.* **2004**, *248*, 2337.

(4) (a) Dupont, J.; de Souza, R. F.; Suares, P. A. Z. *Chem. Rev.* **2002**, *102*, 3667. (b) Li, C.-J. *Chem. Rev.* **2005**, *105*, 3095. (c) Lamblin, M.; Nassar-Hardy, L.; Hierso, J.-C.; Fouquet, E.; Felpin, F.-X. *Adv. Synth. Catal.* **2010**, *352*, 33.

(5) (a) Kappe, C. O. *Angew. Chem. Int. Ed.* **2004**, *43*, 6250. (b) Fu, G. C. *Acc. Chem. Res.* **2008**, *41*, 1555. (c) Carmichael, A. J.; Earle, M. J.; Holbrey, J. D.; McCormac, P. B.; Sneddon, K. R. *Org. Lett.* **1999**, *1*, 997. (d) Deshmukh, R. R.; Rajagopal, R.; Srinivasan, K. V. *Chem. Commun.* **2001**, 1544.

(6) (a) Taylor, J. G.; Moro, A. V.; Correia, C. R. D. *Eur. J. Org. Chem.* **2011**, 1403. (b) Beletskaya, I. P.; Cheprakov, A. V. *Chem. Rev.* **2000**, *100*, 3009.

(7) (a) Li, Z.; Gelbaum, C.; Fisk, J. S.; Holden, B.; Jaganathan, A.; Whiteker, G. T.; Pollet, P.; Liotta, C. L. *J. Org. Chem.* **2016**, *81*, 8520. (b) Kantam, M. L.; Reddy, P. V.; Srinivas, P.; Bhargava, S. *Tetrahedron Lett.* **2011**, *52*, 4490.

(8) (a) Saiyed, A. S.; Bedekar, A. V. *Tetrahedron Lett.* **2010**, *51*, 6227. (b) Meng, G.; Szostak, M. *Angew. Chem. Int. Ed.* **2015**, *54*, 14518.

(9) Ruan, J.; Li, X.; Saidi, O.; Xiao, J. *J. Am. Chem. Soc.* **2008**, *130*, 2424.

(10) For a related example of dehalogenative cross-coupling, see: Jha, A. K.; Kishor, S.; Jain, N. *RSC Adv.* **2015**, *5*, 55218.

(11) Colbon, P.; Barnard, J. H.; Purdie, M.; Mulholland, K.; Kozhevnikoc, I.; Xiao, J. *Adv. Synth. Catal.* **2012**, *354*, 1395.

(12) For the dehydration of aryl alcohols in Mizoroki–Heck reactions in ionic liquids, see: Kumar, R.; Shard, A.; Bharti, R.; Thopate, Y.; Sinha, A. K. *Angew. Chem. Int. Ed.* **2012**, *51*, 2636.

(13) Shad, A.; Rawat, K.; Sinha, A. K.; Padwad, Y.; Kumar, D. *Eur. J. Org. Chem.* **2016**, 5941.

(14) Andhare, N. H.; Thopate, Y.; Shamsuzzama Kumar, L.; Sharma, T.; Siddiqi, M. I.; Sinha, A. K.; Nazir, A. *Tetrahedron* **2018**, *74*, 1655.

(15) Buijink, J. K. F.; Lange, J. P.; Bos, A. N. R.; Horton, A. D.; Niele, F. G. M. In *Mechanisms in Homogenous and Heterogeneous Epoxidation Catalysts*; Oyama, S. T., Ed.; Elsevier: Amsterdam, **2008**, 355.

(16) Cavani, F.; Trifiró, F. *Appl. Catal., A.* **1995**, *133*, 219.

(17) (a) Ward, J. K.; Gardner, J. B. US Pat 4,161,554, **1979**. (b) *Safe Handling and Storage of Styrene Monomer*; Chevron Phillips Chemical Company LP, **2010**.

(18) Kogevinas, M.; Gwinn, W. M.; Kriebel, D.; Phillips, D. H.; Sim, M.; Bertke, S. J.; Calaf, G. M.; Colosio, C.; Fritz, J. M.; Fukushima, S.; Hemminki, K.; Jensen, A. A.; Kolstad, H.; Mráz, J.; Nesnow, S.; Nylander-French, L. A.; Parent, M. E.; Sandy, M.; Smith-Roe, S. L.;

Stoner, G.; Suzuki, T.; Teixeira, J. P.; Vodicka, P.; Tornero-Velez, R.; Guyton, K. Z.; Grosse, Y.; El Ghissassi, F.; Bouvard, V.; Benbrahim-Tallaa, L.; Guha, N.; Vilahur, N.; Driscoll, T.; Hall, A.; Middleton, D.; Jaillet, C.; Mattock, H.; Straif, K. *Lancet Oncol.* **2018**, DOI: 10.1016/ S1470-2045(18)30316-4.

(19) (a) Camp, J. E.; Dunsford, J. J.; Cannons, E. P.; Restorick, W. J.; Gadzhieva, A.; Fay, M. W.; Smith, R. J. *ACS Sustainable Chem. Eng.* **2014**, *2*, 500. (b) Monopoli, A.; Calò, V.; Ciminale, F.; Cotugno, P.; Angelici, C.; Cioffi, N.; Nacci, A. *J. Org. Chem.* **2010**, *75*, 3908.

(20) For a review, see: Kyne, S.; Camp, J. E. *ACS Sustainable Chem. Eng.* **2017**, *5*, 41.

(21) Camp, J. E.; Dunsford, J. J.; Dacosta, O. S. G.; Blundell, R. K.; Adams, J.; Britton, J.; Smith, R. J.; Bousfield, T. W.; Fay, M. K. *RSC Adv.* **2016**, *6*, 16115.

(22) Stahl, S. S. *Science* **2005**, *309*, 1824.

(23) See the Supporting Information for full details.

(24) Ruan, J.; Xiao, J. *Acc. Chem. Res.* **2011**, *44*, 614.

(25) (a) Qin, L.; Ren, X.; Lu, Y.; Li, Y.; Zhou, J. *Angew. Chem. Int. Ed.* **2012**, *51*, 5915. (b) Qin, L.; Hirao, H.; Zhou, J. *Chem. Commun.* **2012**, 10236.

(26) McGonagle, F. I.; Sneddon, H. F.; Jamieson, C.; Watson, A. J. B. *ACS Sustainable Chem. Eng.* **2014**, *2*, 523.

(27) For recent examples of Mol. E% calculations, see: (a) Malferrari, D.; Armenise, N.; Decesari, S.; Galletti, P.; Tagiavini, E. *ACS Sustainable Chem. Eng.* **2015**, *3*, 1579. (b) Agrawal, N. R.; Bahekar, S. P.; Sarode, P. B.; Zade, S. S.; Chandak, H. S. *RSC Adv.* **2015**, *5*, 47053. (c) Reid, B. T.; Reed, S. M. *Green Chem.* **2016**, *18*, 4263. (d) Mistry, L.; Mapesa, K.; Bousfield, T. W.; Camp, J. E. *Green Chem.* **2017**, *19*, 2123.

(28) Rohilla, S.; Pant, P.; Jain, N. *RSC Adv.* **2015**, *5*, 31311.

(29) Littke, A. F.; Fu, G. C. *J. Am. Chem. Soc.* **2001**, *123*, 6989.

(30) (a) Comotti, M.; Pella, C. D.; Falletta, E.; Rossi, M. *Adv. Synth. Catal.* **2006**, *348*, 313. (b) Panigrahi, S.; Kundu, S.; Ghosh, S. K.; Nath, S.; Pal, T. *Colloids Surf. A* **2005**, *264*, 133.

(31) Abbadi, A.; van Bekkum, H. *J. Mol. Catal. A: Chem.* **1995**, *97*, 111.

(32) Rich, P. R. *Biochem. Soc. Trans.* **2003**, *31*, 1095.

(33) Reetz, M. T.; Westermann, E. *Angew. Chem. Int. Ed.* **2000**, *39*, 165.

(34) Fujimori, K. *Aust. J. Chem.* **1977**, *30*, 685.

(35) Filipe, V.; Hawe, A.; Jiskoot, J. *Pharm. Res.* **2010**, *27*, 796.

(36) Schätzel, K.; Drewel, M.; Ahrens, J. *J. Phys.: Condens. Matter* **1990**, *2*, SA393.

(37) Roberts, G. S.; Kozak, D.; Anderson, W.; Broom, M. F.; Vogel, R.; Trau, M. *Small* **2010**, *6*, 2653.

(38) Peng, Z.-Y.; Ma, F.-F.; Zhu, L.-F.; Xie, X.-M.; Zhang, Z. *J. Org. Chem.* **2009**, *74*, 6855.

(39) Ganapathy, D.; Sekar, G. *Org. Lett.* **2014**, *16*, 3856.

(40) Fu, S.; Chen, N.-Y.; Liu, X.; Shao, Z.; Luo, S.-P.; Liu, Q. *J. Am. Chem. Soc.* **2016**, *138*, 8588.

(41) Lei, C.; Yip, Y. J.; Zhou, J. S. *J. Am. Chem. Soc.* **2017**, *139*, 6086.

(42) Niwa, T.; Nakada, M. *J. Am. Chem. Soc.* **2012**, *134*, 13538.

(43) Tang, J.; Hackenberger, D.; Goossen, L. J. *Angew. Chem. Int. Ed.* **2016**, *55*, 11296.

(44) Cahiez, G.; Gager, O.; Lecomte, F. *Org. Lett.* **2008**, *10*, 5255.

(45) Agasti, S.; Dey, A.; Maiti, D. *Chem. Commun.* **2016**, 12191.

(46) Yu, J.-Y.; Shimizu, R.; Kuwano, R. *Angew. Chem. Int. Ed.* **2010**, *49*, 6396.

(47) Alacid, E.; Nájera, C. *J. Org. Chem.* **2008**, *73*, 2315.

(48) Zhong, J.-J.; Liu, Q.; Wu, C.-J.; Meng, Q.-Y.; Gao, X.-W.; Li, Z.-J.; Chen, B.; Tung, C.-H.; Wu, L.-Z. *Chem. Commun.* **2016**, 1800.

(49) Gonzalez-de-Castro, A.; Xiao, J. *J. Am. Chem. Soc.* **2015**, *137*, 8206.

(50) Hansmann, M. H.; López-Andarias, A.; Rettenmeier, E.; Egler-Lucas, C.; Rominger, F.; Hashmi, A. S. L.; Romero-Nieto, C. *Angew. Chem. Int. Ed.* **2016**, *55*, 1196.

(51) Wu, G.; Zhao, X.; Ji, W.; Zhang, Y.; Wang, J. *Chem. Commun.* **2016**, 1961.

(52) Sore, H. F.; Blackwell, D. T.; MacDonald, S. J.; Spring, D. R. *Org. Lett.* **2010**, *12*, 2806.