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Electronic Supplementary Information file

The effects of interactions between proline and carbon nanostructures on organocatalysis in the Hajos-Parrish-Eder-Sauer-Wiechert reaction

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S1. The effect of carbon nanostructures on the enantiopurity of the HPESW products

Table S1. The effect of carbon nanotubes on the enantiopurity of the products of the HPSEW reaction. Following extraction and chromatographic separation of **2** and **3** from the respective crude reaction mixtures, the enantiopurity of compounds **2** and **3** in the absence (entry 8, Table 1) and presence (entry 2, Table 1) of CoMoCAT SWNT were determined by polarimetry. These measurements show that the enantiopurity is unaffected by the presence of carbon nanotubes and indicates that interactions between carbon nanotubes and the endocyclic nitrogen of *S*-(-)-proline do not disrupt the translation of the chirality of the organocatalyst into the final product. This is consistent with a previous literature study [Yin, *J. Cat.*, 2013, **298** 138] which showed that the catalytic properties of proline in the asymmetric Aldol reaction are preserved upon physisorption on graphene oxide.

Product	**$[\alpha]_D$/° (ee/%)** [a]	
	with CoMoCAT SWNT	**without CoMoCAT SWNT**
2	+39.8 (70.3)	+39.1 (68.9)
3	+225.4 (71.6)	+224.7 (71.3)

[a] calculated from literature analogues [*Org. Bio. Chem.*, 2007, **5**, 3190].

S2. The effects of concentration and organocatalyst loading on the HPESW reaction

Effect of concentration

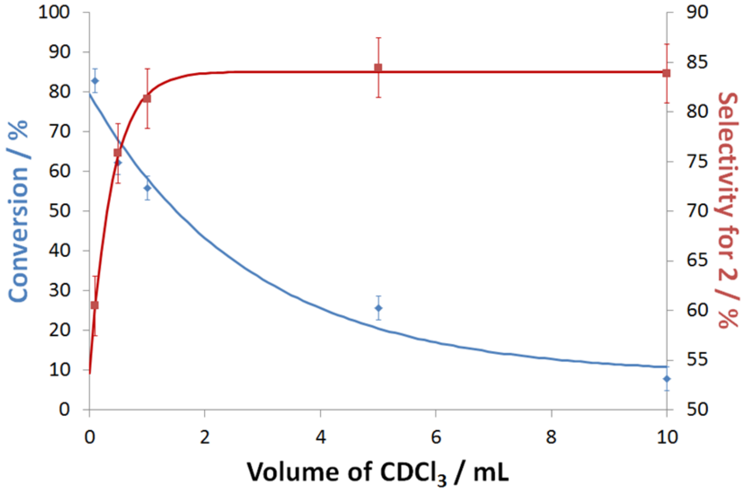

Fig. S1 The relationships between reactant concentration and conversion into products (y = 8.8 + 70.8e$^{-x/2.8}$, R^2 = 0.94) and selectivity for **2** (y = 84.1 – 30.4$^{-x/0.4}$, R^2 = 0.99) for data obtained from this series.

Effect of catalyst loading

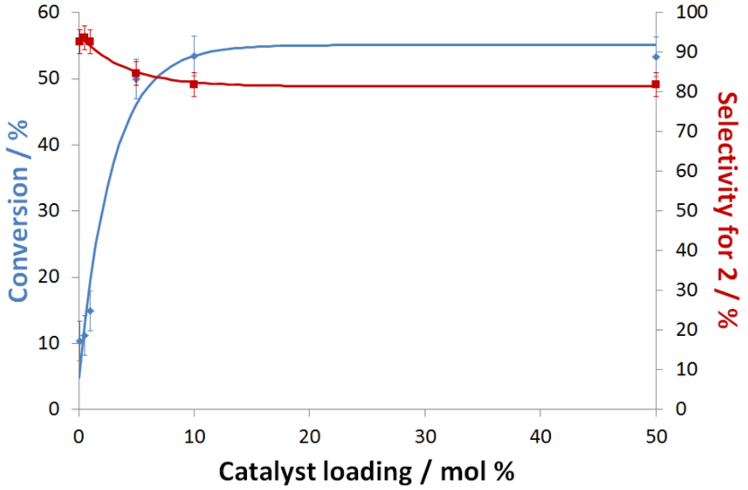

Fig. S2 The relationships between catalyst loading and conversion into products (y = 55.1 – 50.3e$^{-x/2.9}$, R^2 = 0.96) and selectivity for **2** (y = 81.4 + 13.1e$^{-x/4.0}$, R^2 = 0.95) for data obtained from this series.

S3. Assessing the interactions between *S*-(-)-proline and carbon nanostructures by Raman spectroscopy and transmission electron microscopy

(i) Raman spectroscopy

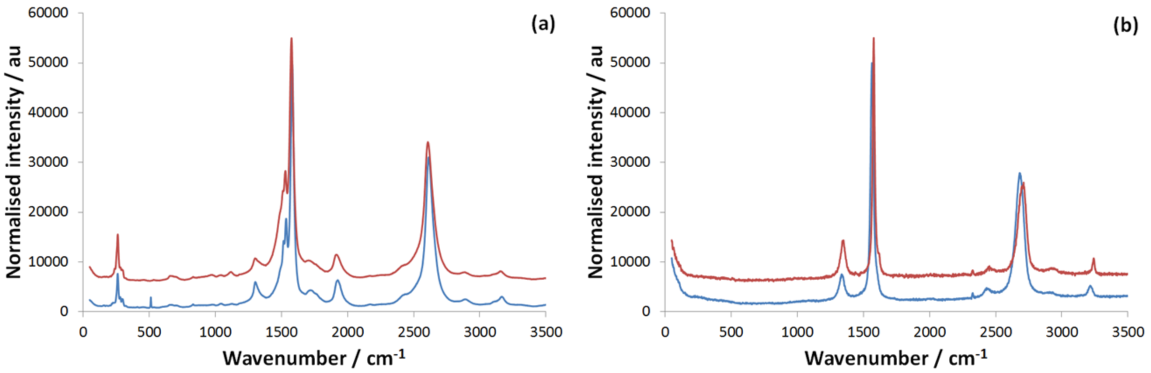

Fig. S3 Raman spectroscopy analysis of (a) CoMoCAT SWNT and (b) GNF before and after (blue, bottom and red, top respectively) the HPESW reaction.

Table S2. Analysis of carbon nanostructures before and after the HPESW reaction for nanostructures with both high and low pyramidalisation angles. The frequency of the radial breathing modes (ν_{RBM}) is sensitive to the adsorption of species on the exterior surfaces of carbon nanotubes, with downfield shifts and increases in intensity associated with physisorption. The G band arises due to vibrations of carbon atoms along the nanotube axis and the frequency of the G band (ν_G) can be affected by desymmetrisation from cylindrical morphology and/or charge transfer interactions with adsorbates. The ratio of the D band to the G band (I_D/I_G) is a measure of the ratio of sp^2/sp^3-hybridised carbons in an infinite graphene lattice and therefore can be used to quantify the extent of nanotube functionalisation. No significant changes in any of these parameters after the HPESW indicates that no physical adsorption or covalent bonding of *S*-(-)-proline to the carbon nanotube sidewall occurs under the conditions of the reaction [*J. Phys. Chem. C*, 2012, **116**, 1724] and this is consistent for nanostructures with high (CoMoCAT SWNT) and low (GNF) curvature.

Carbon nanotube	**ν_{RBM} / cm^{-1}**		**ν_G / cm^{-1}**		**I_D/I_G ratio**	
	before	**after**	**before**	**after**	**before**	**after**
CoMoCAT SWNT	260.8±0.9 281.9±0.9 294.9±1.5 301.4±0.9	261.6±1.1 282.4±0.9 295.4±0.9 302.4±1.5	1578.7±3.1	1580.7±3.8	0.11±0.01	0.12±0.01
GNF	-	-	1564.1±2.3	1567.2±1.7	0.15±0.03	0.16±0.05

(ii) Transmission electron microscopy

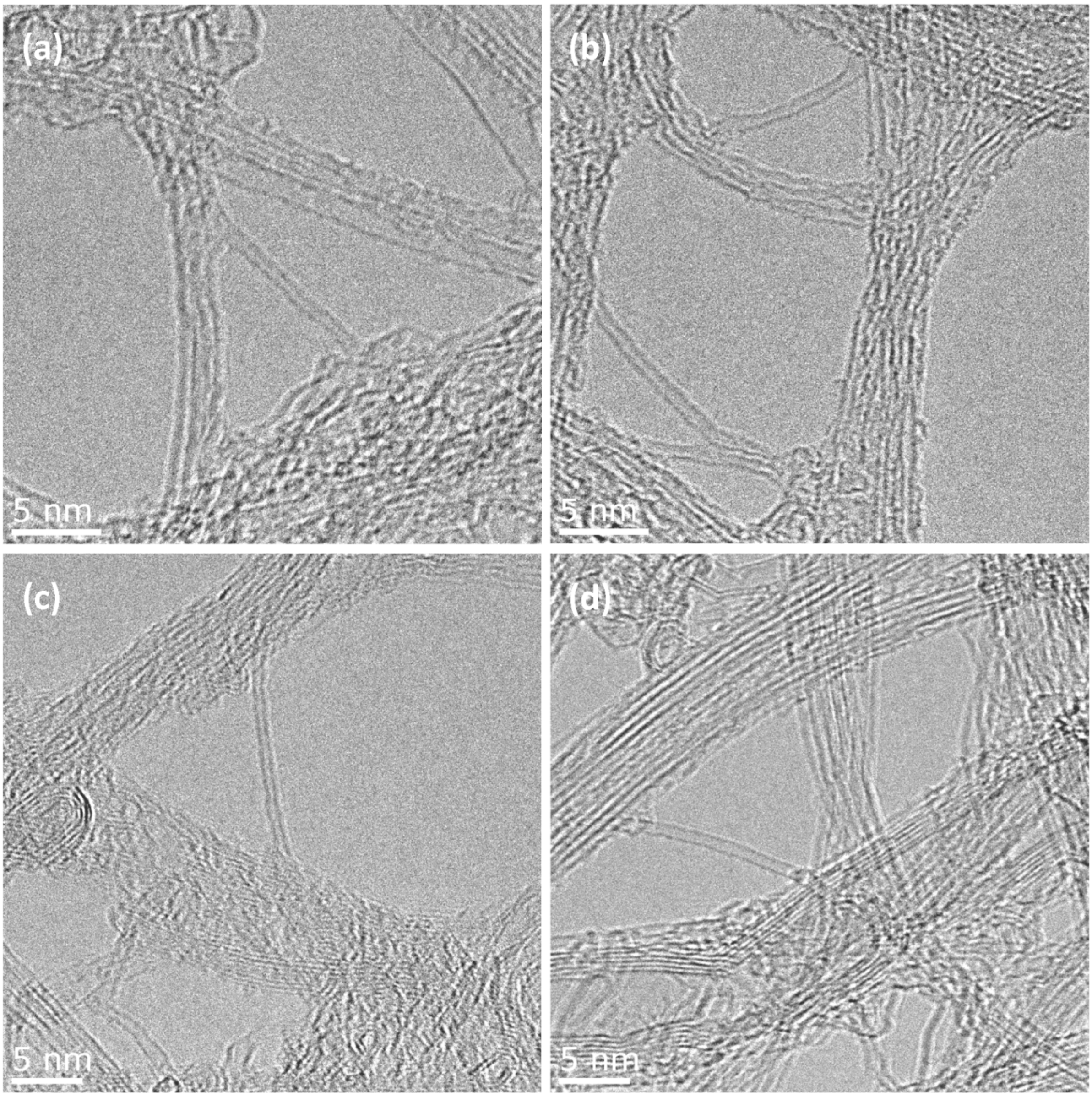

Fig. S4 Transmission electron microscopy analysis of CoMoCAT SWNT (a,b) before and (c,d) after the HPESW reaction. No changes in sidewall corrugation or bundling characteristics were observed subsequent to the HPESW reaction, supporting the evidence from Raman spectroscopy that no covalent bond formation of proline with SWNT occurs under the conditions of the reaction.

S4. Assessing the interactions between molecules and carbon nanostructures by simple titration

2-methyl-2-(3-oxobutyl)cyclopentane-1,3-dione 1 and carbon nanostructures

Methodology

To **1** (15.8 mg) in deuterated chloroform (1 mL) was added carbon nanostructures (5 mg) and the combined suspension homogenised by bath sonication at room temperature for 30 min. The carbon nanostructures were removed from the suspension by syringe filtration (0.45 µm PTFE membrane) and the filtrate analysed by ^{1}H NMR spectroscopy. The characteristic peaks corresponding to the methyl protons were then integrated relative to the solvent.

Table S3. The affinity of **1** for carbon nanostructures. The low percentage of **1** sequestered by carbon nanostructures indicates that changes in concentration associated with adsorption is not a viable explanation for the observed change in yields and product distribution of the HSEPW reaction upon addition of carbon nanostructures. It is important to note that similar titration measurements assessing the affinity of the organocatalyst for carbon nanostructures could not be conducted due to the inherently low solubility of proline in chloroform [*Angew. Chem. Int. Ed.*, 2006, **45**, 4593]. As such the reaction solvent is saturated with proline and thus the addition of nanotubes will have no measurable effect on the concentration of the organocatalyst in bulk solution.

Carbon nanotube	**Pyramidalisation angle / º**	**Adsorption of 1 / mg (%)**	**Affinity / µmol mg^{-1}**
CoMoCAT SWNT	4.72	0.20 (1.2)	0.22
GNF	0.01	0.32 (1.9)	0.35

S5. Assessing the solubility of carbon nanostructures in chloroform

Methodology

To carbon nanostructures (0.5 mg, CoMoCAT SWNT or GNF) was added chloroform (5 mL) and the combined suspension homogenised by bath sonication at room temperature for 30 min. The suspension was then left to settle at room temperature for 4 hr with no agitation and the pale grey supernatant analysed by UV-vis spectroscopy and dynamic light scattering (DLS).

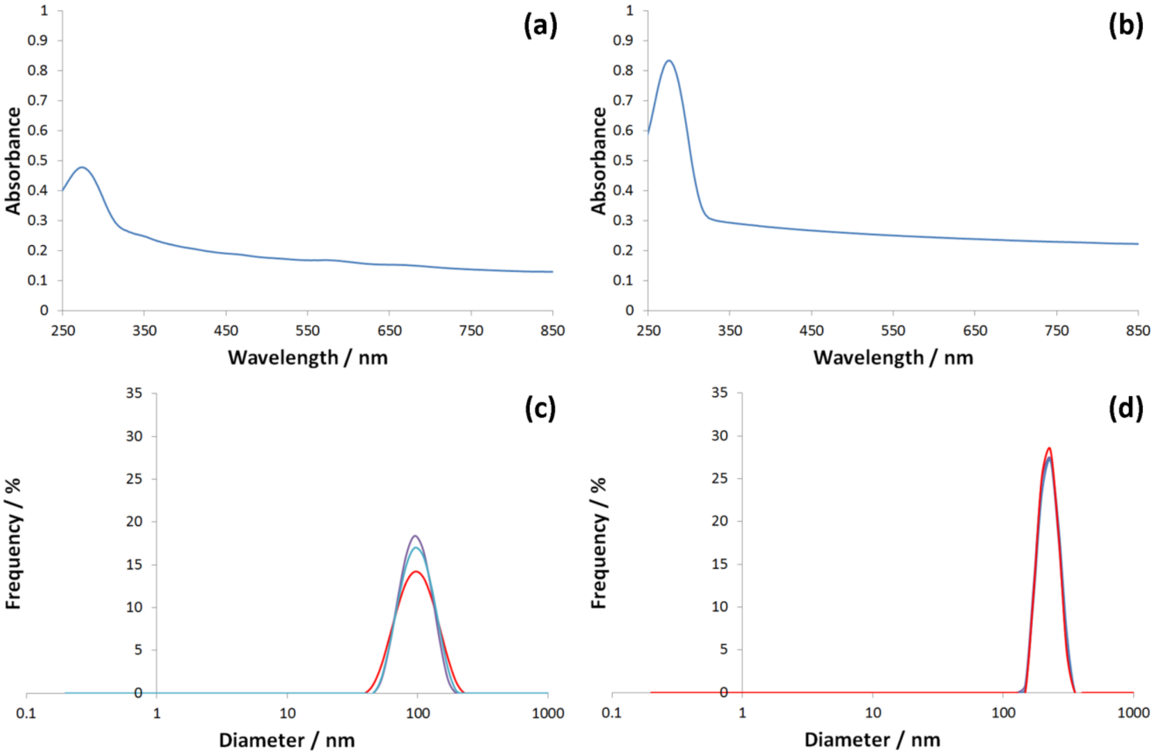

Fig. S5 UV-vis spectroscopy analysis of stable suspensions of (a) CoMoCAT SWNT and (b) GNF in chloroform. The optical density and thus concentration of stable suspensions of both CoMoCAT SWNT and GNF are both low (in the range 0.01-0.02 mg mL^{-1}) and as such the reaction solvent is effectively saturated with carbon nanostructures in all experiments. The specific absorbance at the spectral maximum (and across the entire spectral range) is slightly higher for GNF (0.831) than for CoMoCAT SWNT (0.478) and indicates that GNF possess a slightly higher solubility in chloroform than CoMoCAT SWNT. This observation implies that solubility alone cannot account for the recorded difference in the properties of reactions performed in the presence of these carbon nanostructures, as the opposite behaviour would be expected. Dynamic light scattering analysis of stable suspensions of (c) CoMoCAT SWNT and (d) GNF in chloroform. The mean diameter of structures determined by DLS can be used to describe the bundling characteristics of carbon nanostructures in stable suspension [*J. Nanosci. Nanotech.*, 2005, **5**, 1045]. Mean bundle sizes of 100.8±14.5nm and 224.7±18.0nm, corresponding to 50-500 (large bundle) and 2-3 (very small bundle) carbon nanostructures per bundle, for CoMoCAT SWNT and GNF respectively were recorded and implies that surface area effects can also be largely disregarded.

S6. The effect of carbon nanostructures on organocatalysis

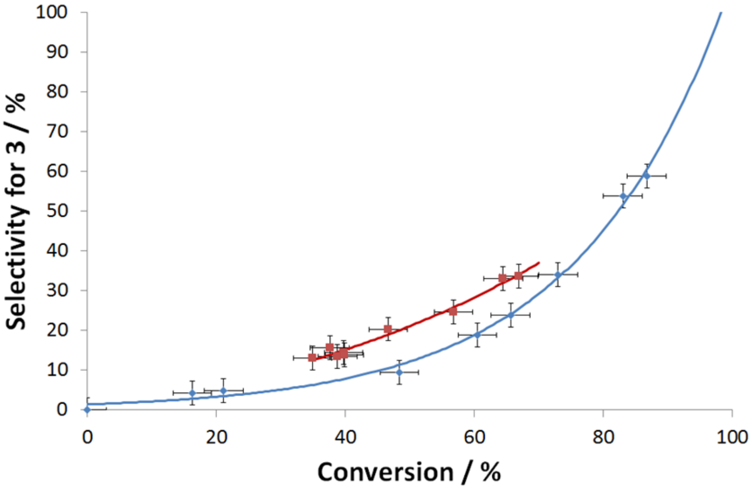

Fig. S6 The relationship between conversion and selectivity for **3** in the absence (blue, $y = -0.04 + 1.38e^{x/22.91}$, $R^2 = 0.99$) and presence (red, $y = -12.90 + 12.98e^{x/51.97}$, $R^2 = 0.98$) of carbon nanostructures. This plot clearly shows that whilst the addition of carbon nanotubes does not fundamentally change the relationship between conversion and selectivity for **3**, i.e. selectivity for **3** remains exponentially dependent on conversion, the selectivity for **3** at any given conversion of reactants into total products is higher in the presence of carbon nanostructures. Thus is due to increases in the acidity of the carboxylic acid proton of proline upon association of the organocatalyst with the external surfaces of carbon nanostructures.