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Triphenylphosphine-catalysed conversion of maleic anhydride into acrylate esters

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Abstract—Maleic anhydride has been converted into a range of acrylate esters on treatment with a suitable alcohol using triphenylphosphine as a catalyst.

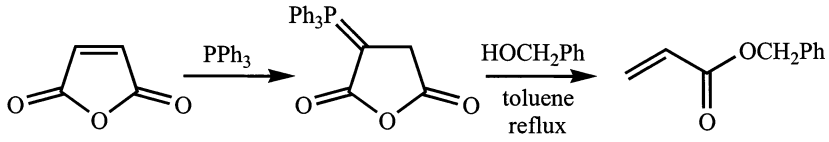
We have recently reported an indirect Wittig reaction of alcohols with phosphonium ylides, proceeding via a catalysed alcohol–aldehyde–alkene–alkane sequence.[1] Whilst trying to expand the scope of this process, we considered using phosphonium ylide **2**,[2] which is readily prepared by the addition of triphenylphosphine to maleic anhydride **1**.[3] However, we found that, even in the absence of any catalyst, the phosphonium ylide **2** reacts with benzyl alcohol to afford benzyl acrylate **3**, along with triphenylphosphine as a by-product (Scheme 1).

Since triphenylphosphine is required for the conversion of maleic anhydride **1** into ylide **2**, and is then recovered in the subsequent formation of acrylate ester **3**, we reasoned that it should be possible to use triphenylphosphine as a catalyst for the direct conversion of maleic anhydride **1** into acrylate ester **3**. Indeed this process was successfully achieved using 10 mol% triphenylphosphine and a variety of alcohols to provide a range of acrylate esters **4**, as identified in Scheme 2 and Table 1.

This simple procedure involves adding a small excess of the alcohol to maleic anhydride in toluene, addition of the phosphine catalyst and heating to reflux in toluene for 24 hours. The reaction was readily accomplished with primary and unhindered secondary alcohols. In the case of more sterically hindered alcohols the reaction was either slower or failed under the reaction conditions employed.

Two possible mechanisms for acrylate formation are presented in Scheme 3. Protonation of ylide **2** would lead to the phosphonium salt **5**, which could undergo ring-opening to provide phosphonium carboxylates **6** and/or **7** via path A and/or path B. Decomposition of these carboxylates would lead to the observed acrylate product **4**, liberating the phosphine catalyst.

Phosphines have previously been used as a nucleophilic catalyst in Baylis–Hillman reactions,[5] and other processes.[6,7] We were interested to see if other nucleophilic catalysts could be employed in the maleic anhydride transformation. Interestingly, whilst an alternative phosphine (BINAP-*rac*-2,2′-bis(diphenylphosphino)-1,1′-binaphthyl) proved to be effective, other potential nucleophilic catalysts were not suitable, as shown in Scheme 4 and Table 2. Triethylamine and DABCO (1,4-diazabicyclo[2.2.2]-octane) afforded no acrylate products, although some ring-opened product was formed. DMAP (4-(*N*,*N*-dimethylamino)pyridine) did



Scheme 1. Two-step conversion of maleic anhydride into benzyl acrylate.

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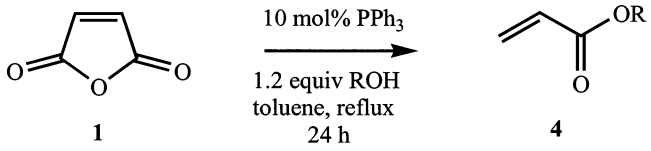


Scheme 2. Phosphine-catalysed conversion of maleic anhydride into acrylates.

Table 1. Conversion of maleic anhydride into acrylate esters

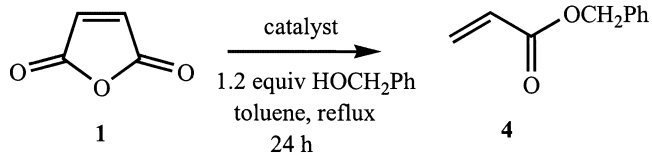
Alcohol	Isolated yield (%)
$PhCH_2OH$	79
MeOH	75[a]
$PhCH{=}CHCH_2OH$	87
$C_{11}H_{23}OH$	79
$Ph(CH_3)CHOH$	60
(−)-Menthol	51
(+)-Fenchyl alcohol	0
t-BuOH	0
$Ph(CH_3)_2COH$	0

[a] Due to the volatility of the product in this example, the yield was calculated from analysis of the ^{1}H NMR spectrum, using dimethylfuran as an internal standard.[4]

provide a small amount of acrylate product, but was clearly less efficient than the phosphine catalysts.

Since non-phosphine based nucleophiles would be less able to support the formation of an ylide, this suggests that the formation of an intermediate ylide may be involved in the phosphine-catalysed reaction. This is therefore consistent with path B.

The formation of substituted acrylates was attempted using substituted maleic anhydrides **8** and **9** (Scheme 5).



Scheme 4. Alternatives to PPh_3 as catalysts for acrylate formation.

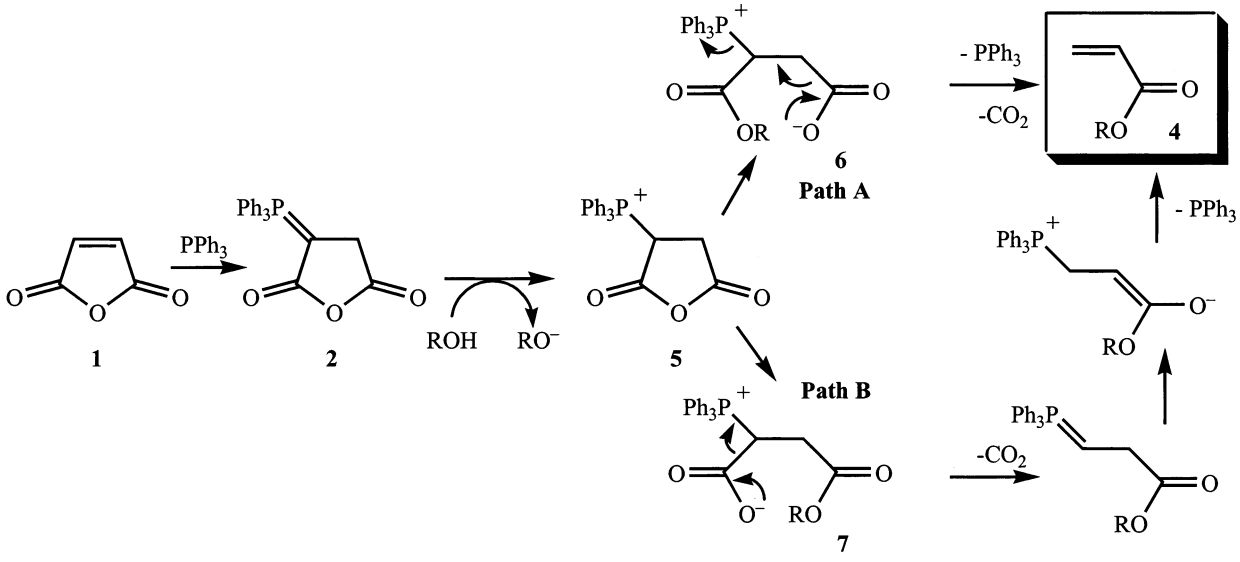
Table 2. Use of alternative catalysts

Catalyst	Conversion (%)[a]
PPh_3 (25 mol%)	100
BINAP (25 mol%)	100
Et_3N (100 mol%)	0
DABCO (100 mol%)	0
DMAP (100 mol%)	21
Bu_4NI (100 mol%)	0

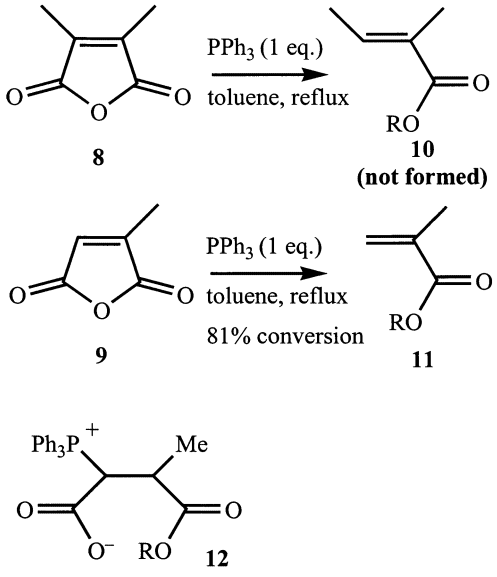
[a] Conversion of maleic anhydride into benzyl acrylate—determined by analysis of the ^{1}H NMR spectrum.

In these examples, one equivalent of phosphine was employed as these reactions were found to be slower than for the unsubstituted case. Dimethylmaleic anhydride **8** was found to be inert under these reaction conditions. The monomethylmaleic anhydride (citraconic anhydride) **9**, afforded α-methyl substituted acrylate **11** as the only observed product. The regiochemistry observed in this process is consistent with intermediate **12**—the methyl substituted analogue of intermediate **7** in Scheme 3, again suggesting that path B is preferred.

In summary, we have discovered an unusual phosphine-catalysed process for the conversion of maleic anhydride into acrylate esters.



Scheme 3. Possible mechanistic pathways for the phosphine-catalysed formation of acrylates.



Scheme 5. Formation of substituted acrylates.

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