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Converting Radical Oligomers to a Single Product

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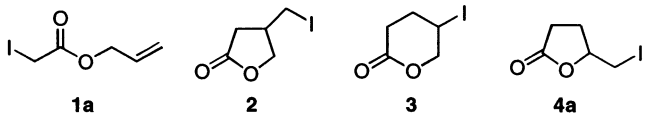
Free radical polymerizations are one of the most important tools in polymer synthesis.[1,2] Free radical reactions also find unique applications in organic synthesis.[3] However, radical oligomerizations have received little attention.[4] In most cases, low molecular weight radical oligomers are treated as undesired components in polymer synthesis. In the meantime, radical oligomers are considered useless in organic synthesis, and enormous efforts have been aimed at avoiding their formations. We report here that radical oligomers can be converted to a single product via rearrangemental *deoligomerization*, thus of synthetic value.

Our discovery originated from our investigation of the role of Lewis acids[5] in the atom-transfer cyclization reactions of allyl iodoacetate (**1a**). Atom-transfer radical additions and cyclization reactions with $(Bu_3Sn)_2$ or BEt_3/O_2 as the initiator,[3] first reported by Kharasch[6] and later developed by Curran[7] and others, have been proved to be some of the most important methods in free radical chemistry, and they are widely used in the studies of α-carbonyl radical cyclizations because of their great potential in organic synthesis.[3] Various techniques have been developed to carry out such transformations (e.g., **1a** to 4-iodomethyldihydro-2(3*H*)-furanone (**2**)), including high dilution,[8] elevated temperature[7] and solvent effect,[9,10] all by suppressing the intermolecular oligomerizations.



1a **2** **3** **4a**

Thus, with the presence of $BF_3{\cdot}OEt_2$ (3 equiv) as the catalyst and 10 mol % of $(Bu_3Sn)_2$ as the initiator, sunlamp irradiation of **1a** in CH_2Cl_2 (0.03 M) at room temperature led to the formations of oligomers, while no corresponding 5-exo cyclization product **2** could be isolated, indicating the failure of $BF_3{\cdot}OEt_2$ in promoting the cyclization. However, it happened that when *aged* $BF_3{\cdot}OEt_2$ (10 equiv) was used in the above reaction, a major product different from **2** was formed in 81% yield. The product was at first thought to be the 6-endo cyclization product, 5-iodotetrahydro-2(2*H*)-pyranone (**3**), but later was correctly characterized to be 5-iodomethyldihydro-2(3*H*)-furanone (**4a**).[11]

Apparently the formation of **4a** could not be explained by simple atom-transfer radical cyclization. Thinking that aged $BF_3{\cdot}OEt_2$ might be caused by the contamination of moisture, we prepared $BF_3{\cdot}H_2O$ to substitute for the aged $BF_3{\cdot}OEt_2$ in the above reaction. Indeed, **4a** was achieved in 78% yield when **1a** was photostimulated with $(Bu_3Sn)_2$ (10 mol %) and $BF_3{\cdot}H_2O$ (3 equiv) in CH_2Cl_2 at room temperature (rt) for 1 h. More interestingly, no oligomers could be detected in the reaction, which were otherwise always present in a considerable amount. This unusual phenomenon led to our assumption that **4a** might be formed via the decomposition of the oligomers. Thus, we deliberately prepared the oligomers **5** by treatment of **1a** in CH_2Cl_2 with BEt_3 (0.2 equiv)/O_2 (trace) as the initiator (Scheme 1). HPLC analysis of **5** indicated it contained a mixture of oligomers (Figure 1). The oligomeric mixture of **5** was treated with $BF_3{\cdot}H_2O$ at rt for 1 h, and **4a** was obtained in 85% yield. This result clearly demonstrated that **4a** was generated via the decomposition of the oligomers **5**. Our continued endeavors to understand the role of $BF_3{\cdot}H_2O$ showed that the oligomers **5** could be converted to **4a** in 92% yield by treatment with a catalytic amount of concentrated H_2SO_4 in CH_2Cl_2 at rt, indicating that $BF_3{\cdot}H_2O$ simply functioned as a strong acid (Scheme 1). Further investigation revealed that direct heating of **5** under N_2 atmosphere without any solvent at 90 °C for 1.5 h also furnished **4a**, albeit in 66% yield. Thus, various ω-alkenyl iodoacetates **1a**−**h** were oligomerized in CH_2Cl_2 at rt with BEt_3 (0.1 equiv)/O_2 (trace) as the initiator and then subjected to catalytic amount of concentrated H_2SO_4 in CH_2Cl_2 at rt for 4 h (Method A) or to heat (80−135 °C) under N_2 atmosphere without any solvent (Method B). Satisfactory yields of products **4a**−**h** were achieved in most cases, and the results are summarized in Table 1.

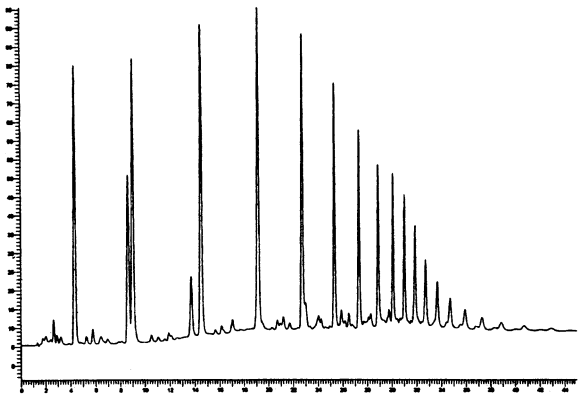
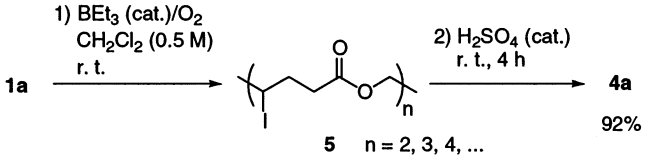


Figure 1. HPLC analysis of oligmers **5**.

Scheme 1. Preparations of **5** and **4a**



With acid catalysis (method A), high yields of **4** were achieved for the allyl esters **1a**−**e**. However, the yields were lowered for butenyl esters, while no expected product **4h** could be obtained in the case of **1h** with a longer ester chain. On the other hand, direct heating (Method B) proved to be a more general method. The reasons for the difference between the two methods are still unclear.

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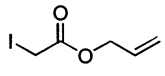
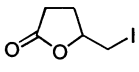
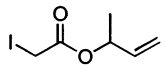
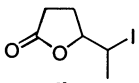
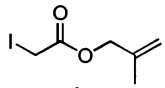
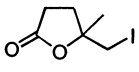
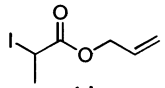
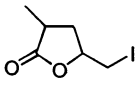
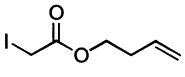
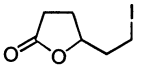
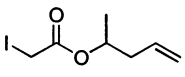
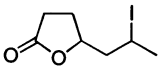
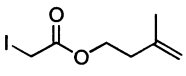
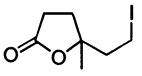
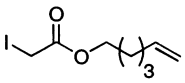
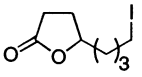
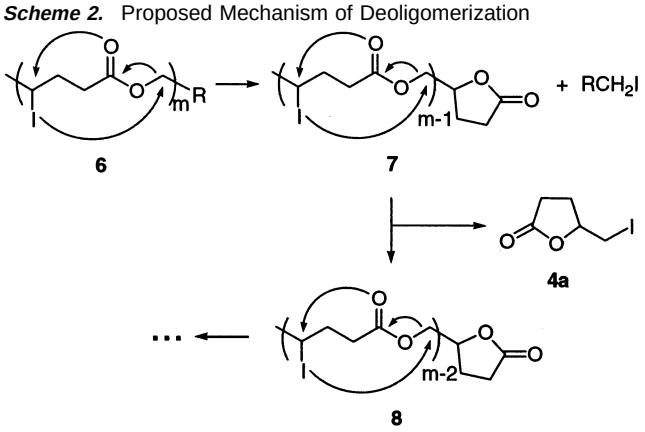
Table 1. Synthesis of γ-Lactones 4

Substrate	Product	Method[a]	Temp./Time (°C / h)	Yield (%)[b]
 **1a**	 **4a**	A		92
		B	90 / 1.5	66
 **1b**	 **4b**	A		76[c]
		B	80 / 2	54[c]
 **1c**	 **4c**	A		79
 **1d**	 **4d**	A		68[d]
 **1e**	 **4e**	A		73
		B	90 / 1.5	72
 **1f**	 **4f**	B	100 / 1.5	73[d]
 **1g**	 **4g**	B	80 / 2	48
 **1h**	 **4h**	A		0
		B	135 / 4	70

[a] See text. [b] Isolated yield based on **1**. [c] Two stereoisomers in 2.2:1 ratio. [d] Two stereoisomers in 1:1 ratio.

On the basis of the above results, a plausible mechanism could be outlined in Scheme 2. The weak C−I bond in an oligomer **6** breaks to form the corresponding carbocationic intermediate followed by the subsequent attack by the carbonyl oxygen. Further attack of iodide ion at the carbon adjacent to "ether" oxygen generates **7** having a γ-lactone unit.[12] The same process is repeated in each unit of the oligomer, leading to the formation of the same product **4a**. Since the oligomers of different sizes contain the same unit ($-CH_2CO_2CH_2CHICH_2-$), the same product is generated via this *deoligomerization* process, regardless of the degree of oligomerization. To provide further evidence for the mechanism, the oligomers **5** were treated with $AlCl_3$ (1 equiv) or CuI (1 equiv) or concentrated HCl (cat.) in CH_2Cl_2 at 10 °C, and **4a** was isolated in 76, 68, and 81% yield, respectively, indicating the cationic nature of the rearrangement. We also isolated the cyclic dimer[8] and trimer[8] from the oligomers **5** (see Supporting Information) and subjected

Scheme 2. Proposed Mechanism of Deoligomerization



these compounds to acid treatment, respectively. Quantitative yield of **4a** was achieved in both cases. This result also implies that, with more complete oligomerization, higher yields of deoligomerization product should be achieved. Thus, high concentration and relatively low temperature, which are not only easily operational but also economical, are preferable rather than the opposite in the radical cyclization reactions.[7,8]

While radical oligomerizations are the fundamentally preferred mode of reactions in many cases, it is more logical to develop them into useful synthetic methodologies. Our results clearly demonstrate that radical oligomers can serve as useful intermediates in organic synthesis rather than useless byproducts.

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Supporting Information Available: Typical procedures for the synthesis of **4**, characterizations of **1d,f**−**h**, **4g**,**h**, and **5** (PDF). This material is available free of charge via the Internet at http://pubs.acs.org.

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