Organogel formation and molecular imprinting by functionalized gluconamides and their metal complexes

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Functionalized gluconamides and their metal complexes are shown to give supramolecular assemblies, in some cases chiral, and to form organogels in a large variety of organic solvents, *e.g.* methacrylate mixtures which can be polymerized, as well as *o*-xylene, chloroform, ethyl acetate, ethanol and tetrahydrofuran.

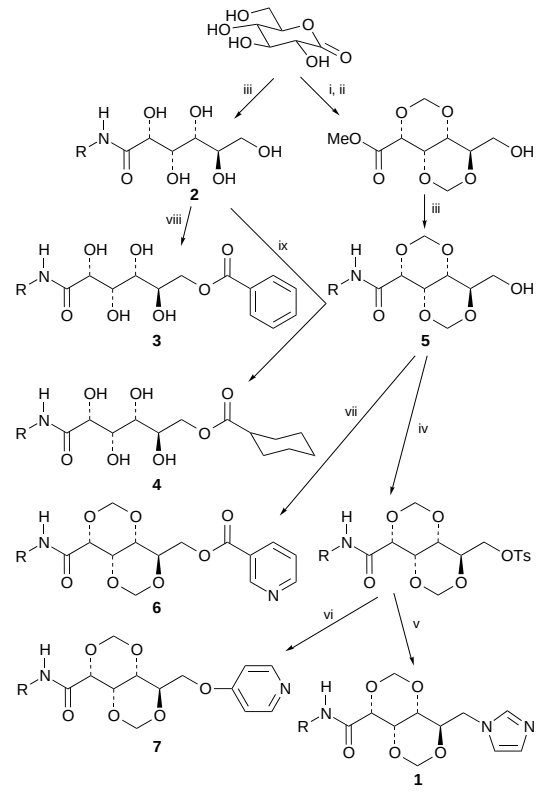
Gluconamides are known to form suprastructures in water.[1] We have recently shown[2] that the self-assembly behaviour of the imidazole-functionalized *N*-octylgluconamide **1a** in water can be tuned. Dispersion of the compound in water at pH 8.5 results in fibres and hollow tubuli, whereas at low pH vesicles are formed. We report here that further functionalization of gluconamides with different head-groups and the addition of metal ions result in diverse suprastructures which induce gelation in a large variety of organic solvents.

In recent years, a relatively broad range of compounds has been found to gelate organic solvents.[3] Gluconamide **2a** has been reported to aggregate into bilayer scrolls and form an unstable organogel in *o*-xylene.[4] We find, however, that a number of ester derivatives of **2a**, *viz*. the benzoate **3a** and the cyclohexanoate **4a** (*cf.* Scheme 1 for structures and outline of preparations)† form stable organogels in a number of solvents, *e.g.* *o*-xylene, chloroform, and ethyl acetate (Table 1). In chloroform, **3a** yields fibres or bundles of fibres which do not exhibit chirality [Fig. 1(*a*), (*b*)]. In contrast, **4a** in ethyl acetate [Fig. 1(*c*)] is able to express its molecular chirality in the suprastructure, resulting in helical fibres. From electron microscopic investigations, we propose that these fibres consist of double and multiple-stranded helices, and that the knobs at the end of the fibres represent hairpin-like turns of these helices.

In contrast to the functionalized gluconamides with free hydroxy groups, most of the bis-methylene protected *N*-*n*-octylgluconamide derivatives investigated, including the imidazolyl derivative **1a** as well as the 6-hydroxy analogue **5a** and the benzoate and picolinate (**6**) esters thereof, did not form organogels (Table 1). We decided to investigate the palladium(ii)[8] and platinum(ii) complexes of the pyridine-functionalized gluconamides **6** and **7**. *trans*-[Pd(**7b**)$_2$Cl$_2$] was soluble in chloroform but precipitated in water. In thf a rigid gel was obtained, which showed helical ribbons (width 36 nm) with a regular twist (pitch 110 nm) and a (maximum) aspect ratio of 25 [*cf.* Fig. 1(*d*)].

trans-[Pd(**6b**)Cl$_2$] dissolved in thf without giving a gel. It is not clear why [Pd(**7b**)$_2$Cl$_2$] forms an organogel in thf and [Pd(**6b**)$_2$]Cl$_2$ does not. A slight difference is expected between the conformations of [Pd(**7b**)$_2$Cl$_2$] and [Pd(**6b**)$_2$Cl$_2$], because in the latter compound the pyridyl ring is *meta*-substituted and the connection to the carbohydrate is *via* an ester group. These differences can cause a bend in the overall shape of the molecule which is not favourable for gelating solvents according to the rule of thumb: 'gelators of organic fluids should have the capability of adopting rodlike shapes in their extended conformations'.[9] We have also prepared the Pt complex, *trans*-[Pt(**7b**)$_2$Cl$_2$], and find that it gelates thf, toluene, and methanol at concentrations of 1, 2, and 5 mg ml^{-1}, respectively. For all gels, TEM showed fibres with approximately the same diameters as **7a**, but without a helical twist. In toluene, these non-helical fibres in turn self-assemble in a hierarchical process to give μm-sized twisted superstructures [Fig. 1(*e*)].

We were interested in using the organogels to prepare membranes with pores by the technique of 'imprinting'.[10] Using this approach, **3a** and **4a** (1% m/v) were dissolved in a warm mixture of methyl methacrylate and *n*-butyl methacrylate (1 : 4, v/v) containing 0.5% (m/v) polymerization catalyst (benzoin ethyl ether), as adapted from the literature.[11] Well defined aggregates with high aspect ratios were formed and gelated this solvent mixture. The organogel was transferred into gelatin cups and readily polymerized overnight with UV light (λ = 365 nm) in a refrigerator (5 °C), yielding a rigid polymer matrix. Using a glass knife and a diamond microtome, slabs of this polymer matrix were sliced in thin coupes (90 nm) which were allowed to float on a water surface before they were transferred



Scheme 1 R = *n*-octyl **a** or *n*-hexadecyl **b**. Outline of syntheses of gluconamide derivatives from gluconolactone. *Reagents and conditions*: i, trioxane, H_2O–H^+;[6] ii, H^+-MeOH;[7] iii, excess alkylamine;[1] iv, TsCl in pyridine, 0 °C; v, imidazole, $CHCl_3$, 15 kbar, 50 °C; vi, 4-hydroxypyridine, triethylamine, 115 °C; vii, picolinoyl chloride, $CHCl_3$, 0 °C; viii, benzoyl chloride, pyridine, 0 °C; ix, $C_6H_{11}C(O)Cl$, 0 °C.

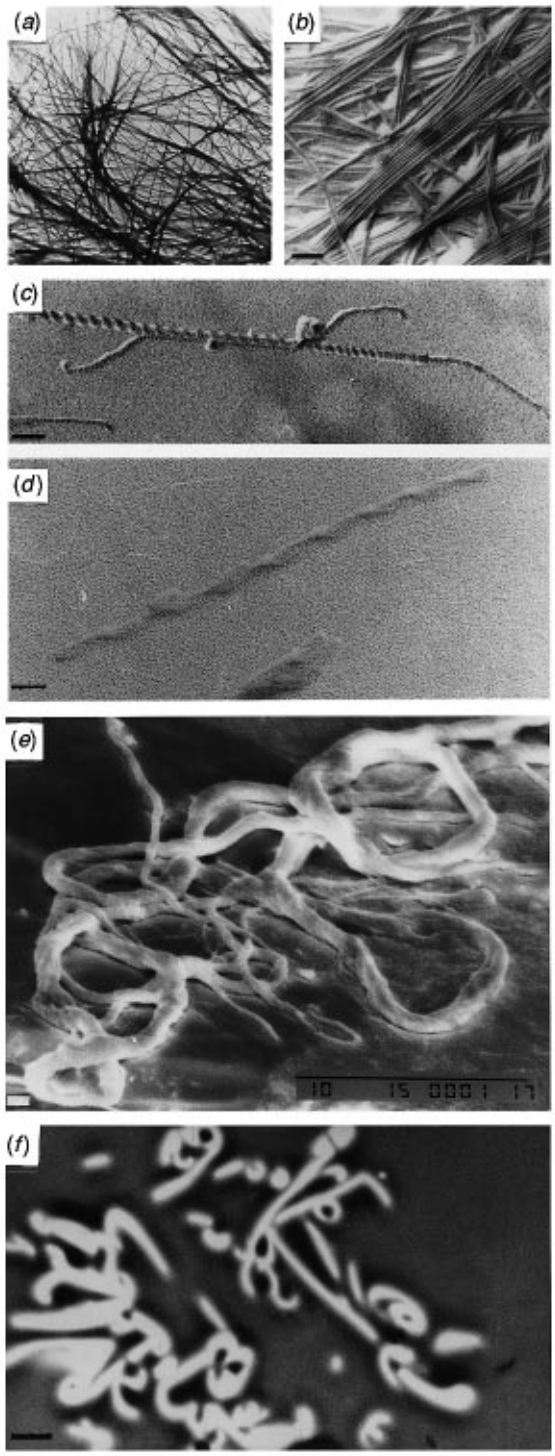


Fig. 1 TEM pictures (Pt shadowing) of a dried gel of **3a** in chloroform: (*a*) network of fibres (bar 1.5 μm), (*b*) bundles of whisker-type fibres (bar 240 nm), (*c*) TEM picture (Pt shadowing, bar 110 nm) of a dried gel of **4a** in ethyl acetate, (*d*) TEM picture (Pt shadowing, bar 63 nm) of a helical ribbon formed by the complex [Pd(**7b**)$_2$Cl$_2$] in thf, (*e*) SEM picture (Au coated, white bar 1 μm) of super helices formed on slowly cooling a gel of [Pt(**7b**)$_2$Cl$_2$] in toluene (*f*) TEM pictures of imprinted pores of **4a** (bar 1.35 μm)

to electron microscopy grids. According to TEM the coupes show well defined pores [Fig. 1(*f*)]. Apparently, the gluconamide suprastructures disassemble and are removed from the polymeric matrix in water. Although dispersions of compound **4a** form helical aggregates [Fig. 1(*c*)], the pores observed in the polymeric matrix did not have helical charcter [Fig. 1(*f*)]. It should be noted that the size of the pores is approximately one order of magnitude larger than that of the helical fibres. The increase in size as well as the loss of chirality are probably due to shrinking of the methacrylate gel during polymerization.

Table 1 Gelation behaviour of functionalized gluconamides in organic solvents[a]

Compound/ solvent	*o*-Xylene	$CHCl_3$	EtOAc	EtOH
1a	R	S	S	S
2a	G	I	I	R
3a[b]	G	G	G	G
4a	G	G	G	S
5a	T	S	S	S
6a	S	S	S	S

[a] G, gelates forming a high-viscosity mixture upon cooling; I, insoluble; R, recrystallizes within 1 h upon cooling; S, dissolves without gelation; T, gives a turbid mixture with slightly increased viscosity upon cooling. [b] Compound **3a** also forms gel in methanol, acetonitrile, acetone, dioxane, dichloromethane, toluene and benzene. It recrystallizes from water, dissolves without gelation in thf, and is insoluble in *n*-hexane and in diethyl ether.

In conclusion, we have shown that functionalized gluconamides and their metal complexes form a variety of chiral and non-chiral aggregates in a large variety of organic solvents and polymerizable methacrylate mixtures, and that it is possible to make imprints of the gluconamide assemblies.

We thank Professor R. G. Weiss (Georgetown, USA) for discussing his results with us prior to publication, and agreeing to concurrent publication of their work[12] and ours.

Footnote

† The preparations of 6-deoxy-6-(1-imidazolyl)-*N*-*n*-octyl-d-gluconamide **1a**,[2] *N*-*n*-octyl-d-gluconamide **2a**,[1a] and 2,4 : 3,5-dimethylene-*N*-*n*-octyl-d-gluconamide **5**[2] are in the literature. The syntheses and characterizations of *N*-*n*-octyl-d-gluconamide-6-benzoate **3a**, *N*-*n*-octyl-d-gluconamide-6-cyclohexanoate **4a**, 2,4;3,5-dimethylene-*N*-*n*-hexadecyl-d-gluconamide-6-pyridylcarboxylic acid ester **6b** and 6-(4-pyridyl)-2,4;3,5-dimethylene-*N*-*n*-hexadecyl-d-gluconamide **7b**, and their Pd^{II} and Pt^{II} complexes are described elsewhere.[5] The purity and assigned structures of all compounds are fully supported by spectroscopy and elemental analyses.

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