

Thermotropic and glass transition behaviors of *n*-alkyl β -D-glucosides

Shigesaburo Ogawa, Kouichi Asakura and Shuichi Osanai

Department of Applied Chemistry, Graduate School of Science and Technology, Keio University,
3-14-1 Hiyoshi, Kohoku-ku, Yokohama 223-8522, Japan

General and materials

β -Glucosidase from almonds (Lot number: T4CGN) was purchased from Tokyo Chemical Industry Co., Ltd. Boron trifluoride diethyl etherate ($\text{BF}_3\text{-Et}_2\text{O}$) was obtained from Sigma-Aldrich Inc. Ion exchange resin DOWEX 50WX4-100 (50-100 mesh, H form) was purchased from the Dow Chemical Company. All reagents were used without further purification. ^1H - and ^{13}C -NMR spectroscopy measurements were performed on a 300 MHz and 75 MHz MVX-300 (VARIAN Inc.), respectively. High performance liquid chromatography (HPLC) was carried out using a Inertsil NH_2 (GL Sciences Inc.) as a analysis column and the mixture of acetonitrile and water (85:15) as a eluent.

Anhydrous CnGlu ($n = 1\text{-}12$) were obtained as follows;

Methyl β -D-glucoside (C1Glu)

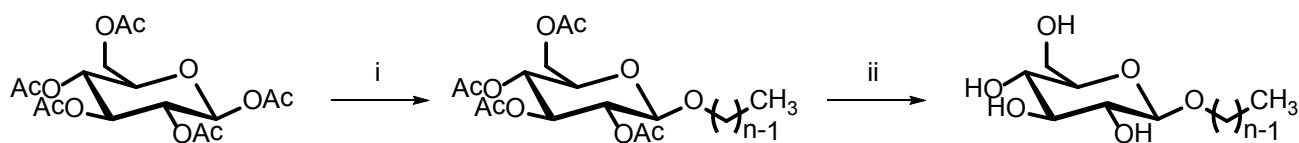
Methyl β -D-glucoside (C1Glu) was purchased from Sigma Inc. as a hemihydrates form. After the dehydration under refluxing in ethanol, it was concentrated by evaporation to afford anhydrous crystalline. The composition was confirmed by elemental analysis (Found: C, 43.40; H, 7.31. $\text{C}_7\text{H}_{14}\text{O}_6$ requires C, 43.30; H, 7.31%).

Ethyl β -D-glucoside (C2Glu)

C2Glu was prepared by enzymatic β -glycosidation according to the literature.^{S1} Since a little amount of isomer was confirmed by HPLC, the mixture was purified by the preparative silica gel chromatography (acetone: chloroform: methanol: water = 4:9:4:1). The structure and purity were confirmed by $^1\text{H-NMR}$, $^{13}\text{C-NMR}$, HPLC and elemental analysis ($^{13}\text{C-NMR}$, CD_3OD ; δ /ppm = 104.1 (C1), 78.1, 77.9, 75.06, 71.61, 66.15, 62.73, 15.45. Found: C, 45.95; H, 7.82. $\text{C}_8\text{H}_{16}\text{O}_6$ requires C, 46.15; H, 7.75%). The $^1\text{H-NMR}$ spectrum was in fair agreement with the authentic data.

S1

CnGlu (n = 3-12) (Scheme S1)^{S2}



Scheme S1 Syntheses of CnGlu ($n \geq 3$). (i) 1-Alcohol, $\text{BF}_3\text{-Et}_2\text{O}$ /distilled CH_2Cl_2 . (ii) NaOMe /distilled MeOH .

The mixture of 1, 2, 3, 4, 6-pentaacetyl β -D-glucopyranoside (5.0 g, 12.7 mmol) and the 1-alcohol (30.0 mmol) in distilled CH_2Cl_2 (120 ml) was treated with $\text{BF}_3\text{-Et}_2\text{O}$ (4.86 ml, 30.0 mmol) for 7 h with stirring at ambient temperature, and subsequently quenched with saturated aq. NaHCO_3 . After extracted with CH_2Cl_2 , the solution was dried with Na_2SO_4 . The filtrate was evaporated to dryness. The residue was re-acetylated with pyridine and acetic anhydride according to the conventional method. The reaction product was purified by the preparative silica gel chromatography (ethyl acetate: hexane = 1: 2~3), and finally recrystallized from ethanol to give 1-O-alkyl-2, 3, 4, 6-tetraacetyl β -D-glucopyranoside as a white crystal.

This tetraacetate (6.0 mmol) was dissolved in distilled methanol (11 ml) and sodium methoxide methanol solution (91 mM: 1.9 ml 0.173 mmol) was added dropwise. It was stirred for 3.0 h and neutralized by the ion-exchange resin. The product solution was concentrated by evaporation under reduced pressure to give 1-*O*-alkyl β -D-glucopyranoside almost quantitatively. It was purified by the preparative silica gel chromatography (acetone: chloroform: methanol: water = 4:9:4:1) or recrystallized from acetone/hexane to give a white powder. Yield: 30~55% based on the starting per-acetate including purification. At this time, only butyl β -D-glucoside (C4Glu) was obtained as C4Glu•0.25H₂O form. It was confirmed by DTG (Figure S1) and elemental analysis (C4Glu•0.25H₂O; Found: C, 49.75; H, 8.79. C₁₀H₂₀O₆•0.25H₂O requires C, 49.89; H, 8.63%). Then, it was dehydrated by refluxing in EtOH and concentrated by evaporation to afford anhydrous form. The structures and purities of C_nGlu were identified by ¹H-NMR, ¹³C-NMR, thin-layer chromatography (TLC), HPLC and elemental analysis (Propyl β -D-glucoside: C3Glu; 30.0 %, ¹³C-NMR, CD₃OD; δ /ppm = 104.3 (C1), 78.1, 77.9, 75.1, 72.46, 71.62, 62.73, 23.94, 15.45. Found: C, 48.56; H, 8.23. C₉H₁₈O₆ requires C, 48.64; H, 8.16%. Butyl β -D-glucoside: C4Glu; 42.1 %, ¹³C-NMR, CD₃OD; δ /ppm = 104.3 (C1), 78.1, 77.9, 75.1, 71.62, 70.56, 62.72, 32.88, 23.94, 15.45. Found: C, 50.55; H, 8.53. C₁₀H₂₀O₆ requires C, 50.84; H, 8.53%. Pentyl β -D-glucoside: C5Glu; 30.3 %, ¹³C-NMR, CD₃OD; δ /ppm = 104.3 (C1), 78.1, 77.9, 75.1, 71.62, 70.86, 62.74, 30.49, 29.32, 23.6, 14.4. Found: C, 52.95; H, 8.77. C₁₁H₂₂O₆ requires C, 52.79; H, 8.86%. Hexyl β -D-glucoside: C6Glu; 34.3 %, ¹³C-NMR, CD₃OD; δ /ppm = 104.3 (C1), 78.1 77.9, 75.1, 71.6, 70.9, 62.7, 32.87, 30.75, 26.79, 23.6, 14.4. Found: C, 54.33; H, 9.06. C₁₂H₂₄O₆ requires C, 54.53; H, 9.15%. Heptyl β -D-glucoside: C7Glu; 30.6%, ¹³C-NMR, CD₃OD; δ /ppm = 104.3 (C1), 78.1, 77.9, 75.1, 71.6, 70.9, 62.7, 33.0, 30.8, 30.2, 27.0, 23.7, 14.4. Found: C, 56.34; H, 9.27. C₁₃H₂₆O₆ requires C, 56.10; H, 9.42%. Octyl β -D-glucoside: C8Glu; 45.3 %, ¹³C-NMR, CD₃OD; δ /ppm = Found: C, 57.27; H, 9.61. C₁₄H₂₈O₆ requires C, 57.51; H, 9.65%. Nonyl β -D-glucoside: C9Glu; 41.6 %, Found: C, 58.88; H, 9.74. C₁₅H₃₀O₆ requires C, 58.80; H, 9.87%. Decyl β -D-glucoside: C10Glu; 43.7 %, Found: C,

59.94; H, 9.99. $C_{16}H_{32}O_6$ requires C, 59.97; H, 10.07%. Undecyl β -D-glucoside: C11Glu; 47.4 %, Found: C, 60.78; H, 10.21. $C_{17}H_{34}O_6$ requires C, 61.05; H, 10.25%. Dodecyl β -D-glucoside: C12Glu; 52.3 %, Found: C, 61.92; H, 10.38. $C_{18}H_{36}O_6$ requires C, 62.04; H, 10.41%). The ^{13}C -NMR signals for CnGlu ($n \geq 8$) were obtained similarly to that of C7Glu for it was difficult to distinguish the additional hydrophobic carbon atoms with that of neighboring in the methylene units. The 1H -NMR spectra were in fair agreement with the authentic data.^{S3, S4} Absence of the α -anomer was confirmed by the 1H -NMR spectra and HPLC.

General methods

Simultaneous differential thermal analysis and thermogravimetry analysis (DTA-TG)

DTA/TG was performed on a DTG 60 (SHIMADZU Corp.). The sample was heated at 5 °C/min from 30 to 200 °C under dry nitrogen of 60 mL/min.

Thermal arrest measurement^{S2}

A digital thermometer (CT-1200D, CUSTOM Co., Ltd.) equipped with a thermocouple sensor (LK-300S) was used throughout the thermal arrest measurement. Freezing depression point of ice was obtained as the sudden increase as the end point of melting in the thawing curve.

Differential scanning calorimetry (DSC)

The cooling process of the IL of anhydrous C6Glu was recorded on a DSC 60 (SHIMAZU Corp.) equipped with a cooling accessory. IL of C6Glu was cooled from 100 °C at -10 °C/min and then it was heated up to 100 °C at 10 °C/min.

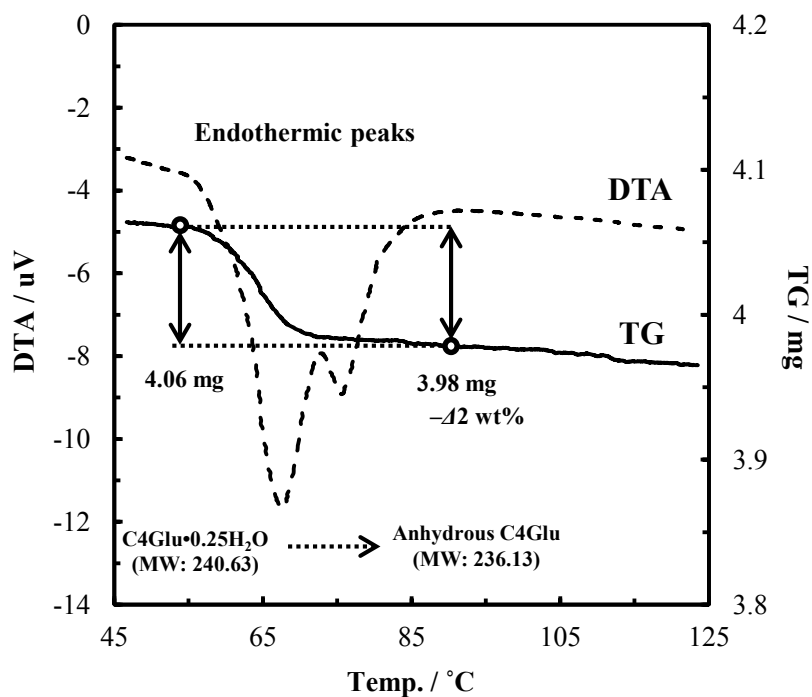


Figure S1. DTA-TG analysis of $\text{C4Glu} \cdot 0.25\text{H}_2\text{O}$. Solid line indicates TG curve, and dotted line represents DTA curve.

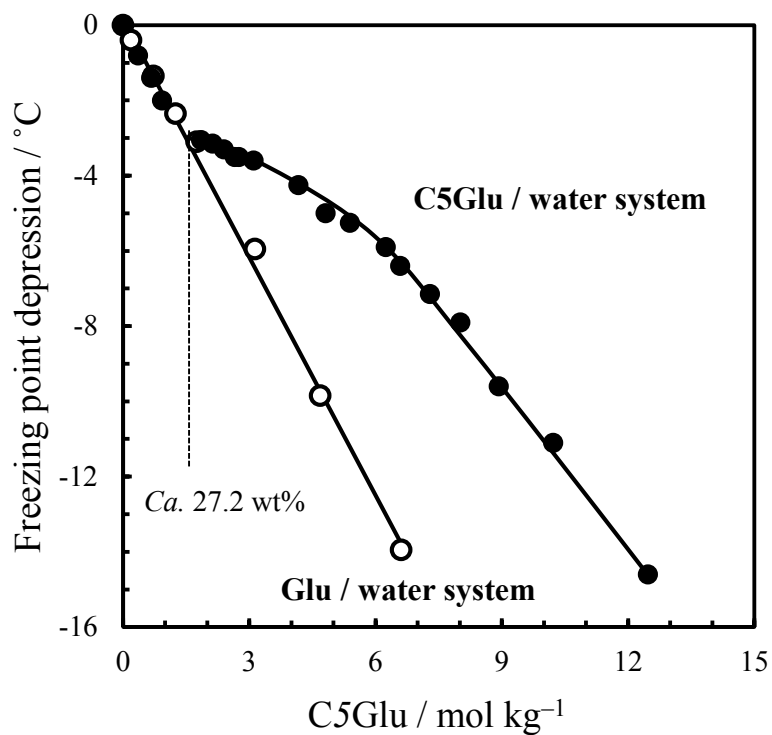


Figure S2. Thermal arrest measurement of aqueous C5Glu solution.

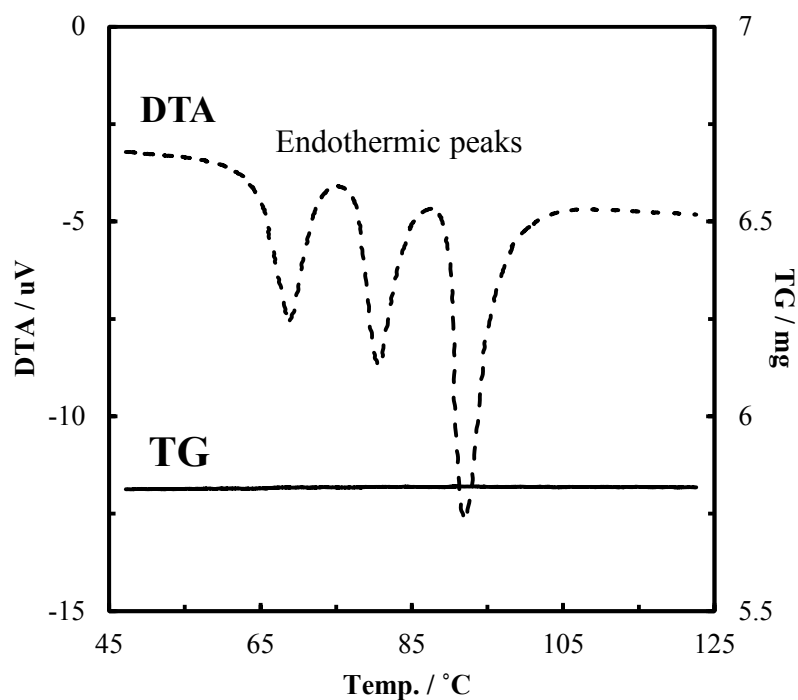


Figure S3. DTA-TG analysis of C6Glu-Solid A. Solid line indicates TG curve, and dotted line indicates DTA curve.

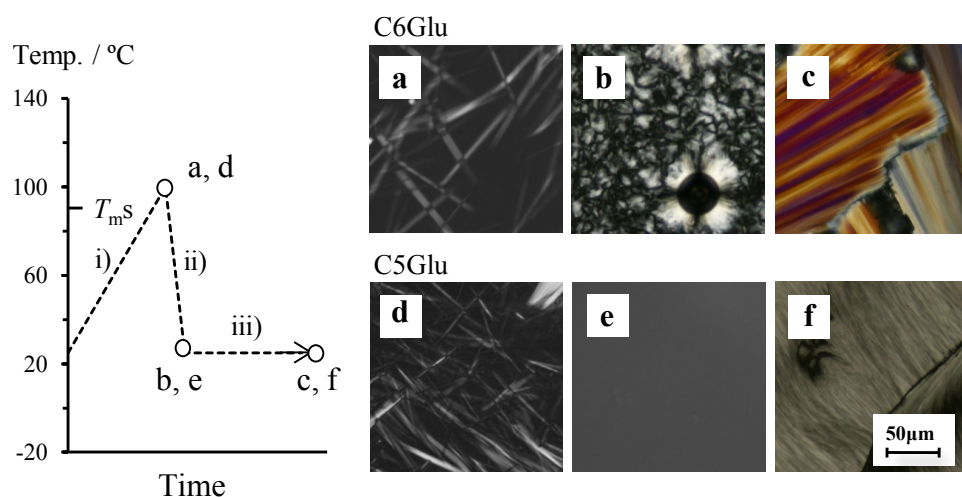


Figure S4. (Left) Schematic of the sequence POM observation of i) melting, ii) supercooled, and iii) crystallization processes. (Right) Photographs of various stages of C5Glu and C6Glu obtained through POM observation; Melting processes of (a) Solid B for C6Glu and (d) C5Glu; Supercooled states at 25 °C obtained by cooling from IL for (b) C6Glu and (e) C5Glu. Crystallites of (c) Solid A of C6Glu and (f) C5Glu obtained by crystallizing at room temperature.

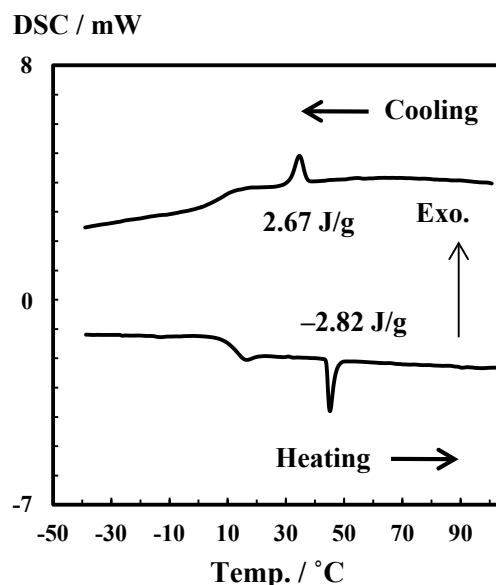


Figure S5. DSC thermograms of C6Glu during cooling and heating measurement.

The polymorphism of C6Glu was discussed by POM observation under controlled temperatures. As Figure S4a and S4d shows, similar needle-like crystals were observed during melting process of Solid B of C6Glu and C5Glu. Such needle-like crystals were regarded as the crystal formed in isotropic liquid (IL).^{S5} After the individual IL was cooled to room temperature, the photographs showed that C5Glu was the isotropic and C6Glu was the anisotropic structure in the photograph obtained by grinding, indicating the formation of mesophase for C6Glu under supercooled state (Figure S4b and S4e). Such anisotropies were observable below around 40 °C during cooling process of the IL of C6Glu and DSC measurement for the IL sample of C6Glu supported the monotropic formation of metastable mesophase without the recrystallization (Figure S5). After standing each supercooled samples of Figure S4b and S4e, respectively, for several days to crystallize, C6Glu exhibited the texture of spherulite crystalline which was often observed for the crystalline morphology formed in SmA phase (Figure S4c)^{S5}, while C5Glu exhibited the texture of aggregation of needle-like crystals (Figure S4f) similar to Figure S4a and S4d. From these set of observations, we can say that two types of crystalline of C6Glu, Solid A and Solid B, were identified. The one is obtained in the supercooled mesophase and the other is more thermodynamically stable crystalline

obtained by annealing the former crystalline around 80 °C.

References

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