insulin carbonyl carbon in the insulin-trehalose system is longer than in the insulin-dextran system, indicating that the molecular mobility of insulin is decreased by trehalose, since longer $T_{1\rho}$ indicates slower motion in the slow motional regime (Fig. 3).

Retardation of spin-lattice relaxation of protein carbonyl carbon brought about by the addition of sugars is also observed for the carbonyl carbon of β-galactosidase freeze-dried with sucrose, trehalose, or stachyose, as shown in Figure 11 (33). The molecular mobility of the protein is most effectively decreased by sucrose.

The T_1 and $T_{1\rho}$ of protein carbonyl carbon described above represent the average of T_1 and $T_{1\rho}$ for multiple carbonyl carbons present in the protein molecule. More detailed site-specific analysis becomes possible by the ^{13}C-labeling of an amino acid at a specific site of interest.

Laboratory and Rotating Frame Spin-Lattice Relaxation Times of Fluorine

^{19}F-NMR has high sensitivity and specificity and has been used to determine the molecular mobility of ^{19}F-labeled proteins (34) as well as small molecules containing ^{19}F (35). Figure 12 shows the temperature dependence of T_1 and $T_{1\rho}$ of

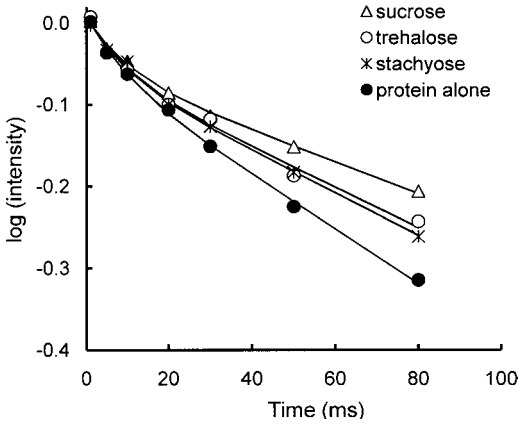

FIGURE 11 Time course of spin-lattice relaxation for carbonyl carbon of β-galactosidase freeze-dried with sucrose, trehalose, or stachyose at 25°C and 12% RH.

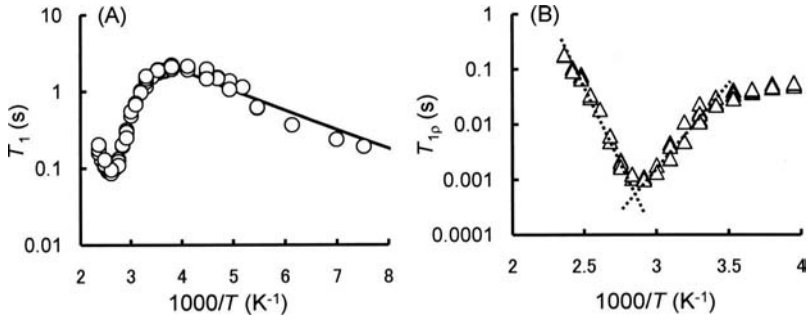

FIGURE 12 Temperature dependence of T_1 (**A**) and $T_{1\rho}$ (**B**) of flufenamic acid ^{19}F in solid dispersions with PVP. *Abbreviation*: PVP, polyvinylpyrrolidone.