

# Behavior of thermo- and pH-responsive copolymer of *N*-isopropylacrylamide and maleic acid in aqueous solutions

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#### ABSTRACT

A thermo- and pH-responsive copolymer of *N*-isopropylacrylamide with maleic acid was studied using light scattering and turbidimetry methods. Aqueous solutions with pH values from 1.8 to 10.9 and in the concentration range from 0.001 to 0.015 g/cm<sup>3</sup> were investigated. At all pH values and concentrations, phase separation was observed at temperatures  $T > 33^{\circ}$ C. The temperatures of the start and the width of the phase separation interval increased with decrease of copolymer concentration and increase in pH. The redistribution of scattering entities, namely, macromolecular unimers, micelle-like structures, and loose aggregates, and growth of aggregate hydrodynamic radius took place during heating.

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## Introduction

Copolymers of *N*-isopropylacrylamide with maleic acid (poly(NIPAAm-*co*-MA)) represent a promising class of the double stimuli–responsive polymers. Stimuli-responsive polymers reveal broad application potential in various fields as molecular sensors.<sup>[1–7]</sup> Polymers sensitive to temperature can be used, for example, in sensing devices in optics, membranes, and electronics. In aqueous solutions, the macromolecules of stimuli-responsive polymers can transit to the soluble or insoluble state depending on the medium characteristics. This property defines the perspectives of their use in aqueous media important in human medicine.

Poly(*N*-isopropylacrylamide) (poly(NIPAAm)) is one of the most studied thermo-responsive water-soluble polymers; its lower critical solution temperature in water is close to human body temperature. Near the cloud point its macromolecules form aggregates due to the loss of solubility.<sup>[8]</sup>

The combination of thermosensitivity with another response trigger such as pH sensitivity widens the application fields, especially for biological and medical purposes.<sup>[9–11]</sup> Such polymers can be used for drug delivery, bio-separation, and so on. Double stimuli–responsive polymers can be synthesized by means of copolymerization of monomers possessing the respective sensitive properties or by development of new double-sensitive monomers. The first way is the most easily carried out and is more often used. In particular, copolymerization of NIPAAm with maleic acid (MA) units imparts to the copolymer sensitivity to pH due to the presence of -COOH groups in the MA structure. Poly (NIPAAm-*co*-MA) should possess interesting properties in solutions due to the diprotic character of MA and should be candidates for biomedical use. Properties of poly(NIPAAm-*co*-MA) and poly (NIPAAm/dextran-*co*-MA) hydrogels have been studied and their potential use for controlled drug delivery or dye uptake have been shown.<sup>[12–14]</sup>

Linear poly(NIPAAm-co-MA) macromolecules, being self-assembled/disassembled as pH and/or temperature changes, probably can be used as nano-containers for medical purposes. However, to