

# Nonreciprocal Mechanics in Active Hydrogel Metabeams: Statics and Dynamics

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## Abstract

Reciprocity is a general property of linear physical systems that manifests itself through symmetry relations. While this remarkable and fruitful property underpins powerful theoretical and experimental techniques, the additional constraints it introduces can represent an obstacle to desired behaviors or functionalities. In recent years, significant attention in the mechanics literature has turned to the realization of materials and systems that enable nonreciprocal wave transport, with applications to devices and structures that guide, damp, or control flows of energy and information. Current approaches to wave control in acoustic metamaterials rely on complex architectures, including sensors, actuators and control units. In this context, synthetic active materials offer a promising alternative route, by seamlessly integrating sensing, actuation and control at the material level. Using polyelectrolyte hydrogels as a representative example of artificial active materials, we combine theoretical, numerical and experimental methods in mutual dialogue to investigate the complex dynamics arising from the interplay between the electroactive response of the hydrogels and their interaction with a viscous environment. In this contribution, we consider a periodic structure assembled from polyelectrolyte hydrogel beams; building upon morphoelasticity theory, the active response of such metabeam to electric stimuli is modelled through the notion of spontaneous curvature, while accounting for viscous drag from the fluid environment. The periodic system exhibits nonreciprocal transmission both in the static and in the dynamic regime: by embedding internal activity,

the hydrogel metabeam breaks reciprocity at the constitutive level. Floquet-Bloch analysis reveals self-oscillating modes, nonreciprocal wave propagation and compensation of viscous losses, enabled by the material's ability to harvest energy from environmental stimuli. These properties are tunable by adjusting the magnitude of the applied electric potential. Experiments performed on millimeter-scale, finite-size realizations of the periodic structure corroborate the theoretical findings, demonstrating, within a parameter range consistent with the model, direction-dependent transmission both in the static and in the dynamic regime and near-lossless wave transmission.

**Keywords:**

Active materials Polyelectrolyte hydrogels Nonreciprocal mechanics Waveguides