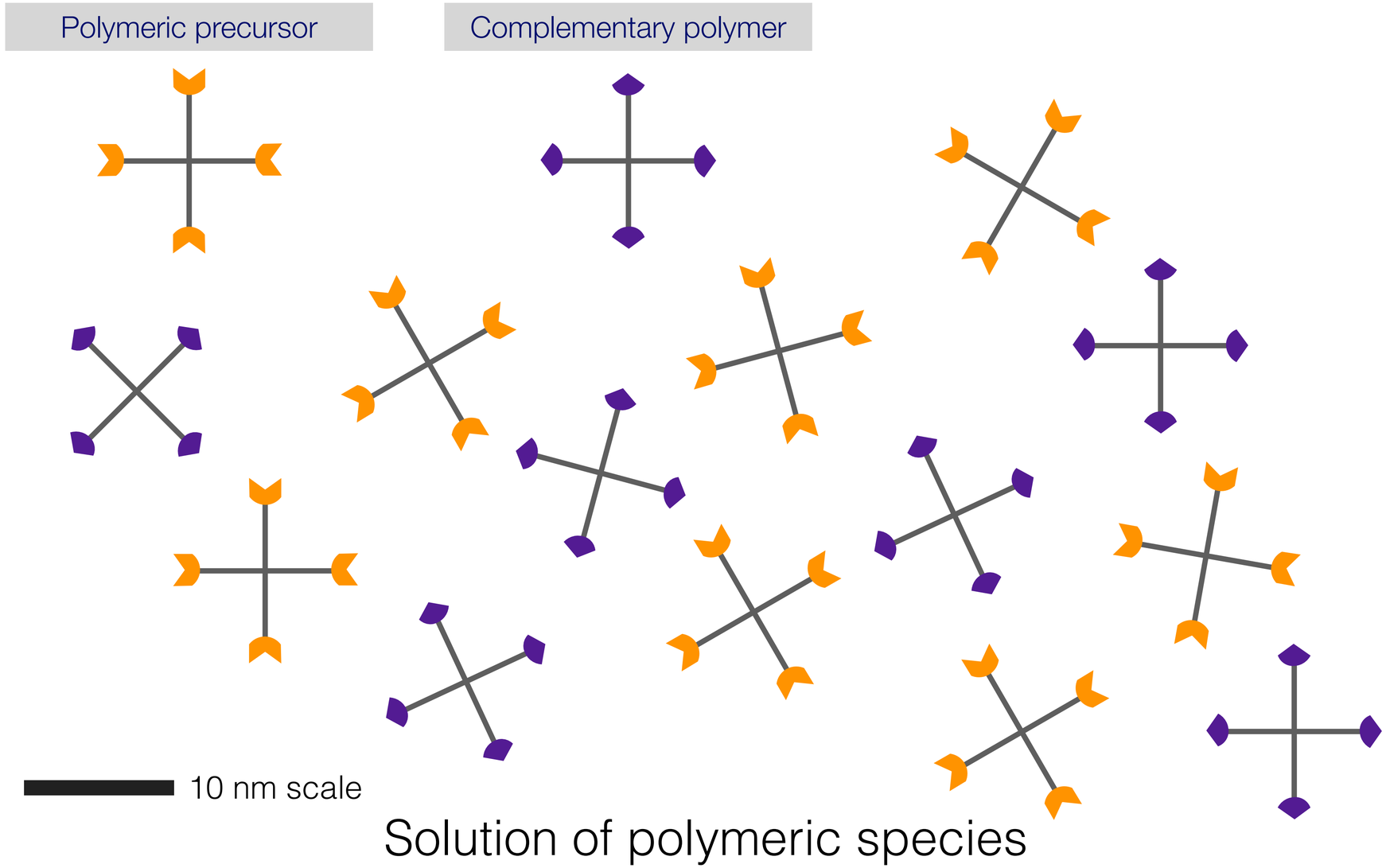
ETH zürich

Macromolecular Engineering: Networks and Gels

Lecture 15: Network Formation

Prof. Dr. Mark W. Tibbitt, 12. April 2022

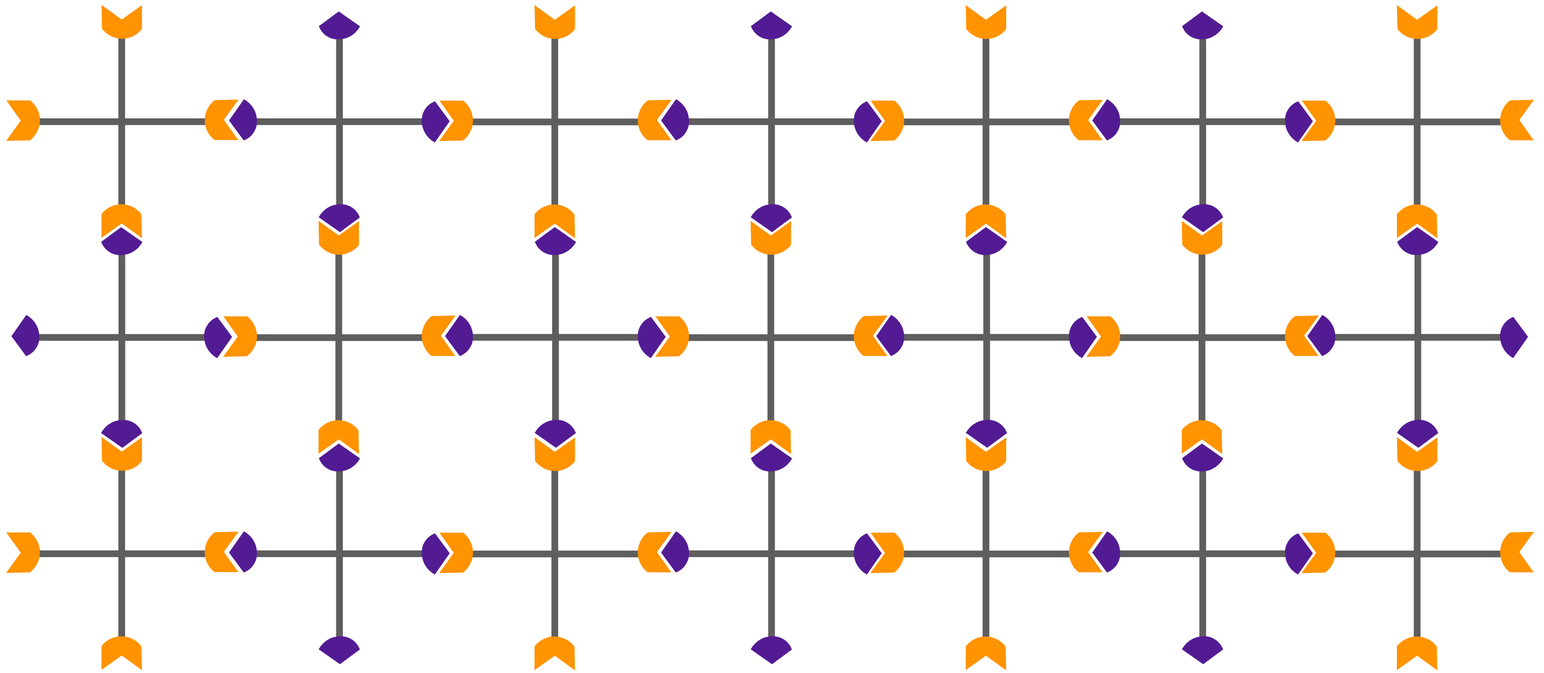
Macromolecular engineering of networks and gels



Solution of polymeric species

Macromolecular engineering of networks and gels

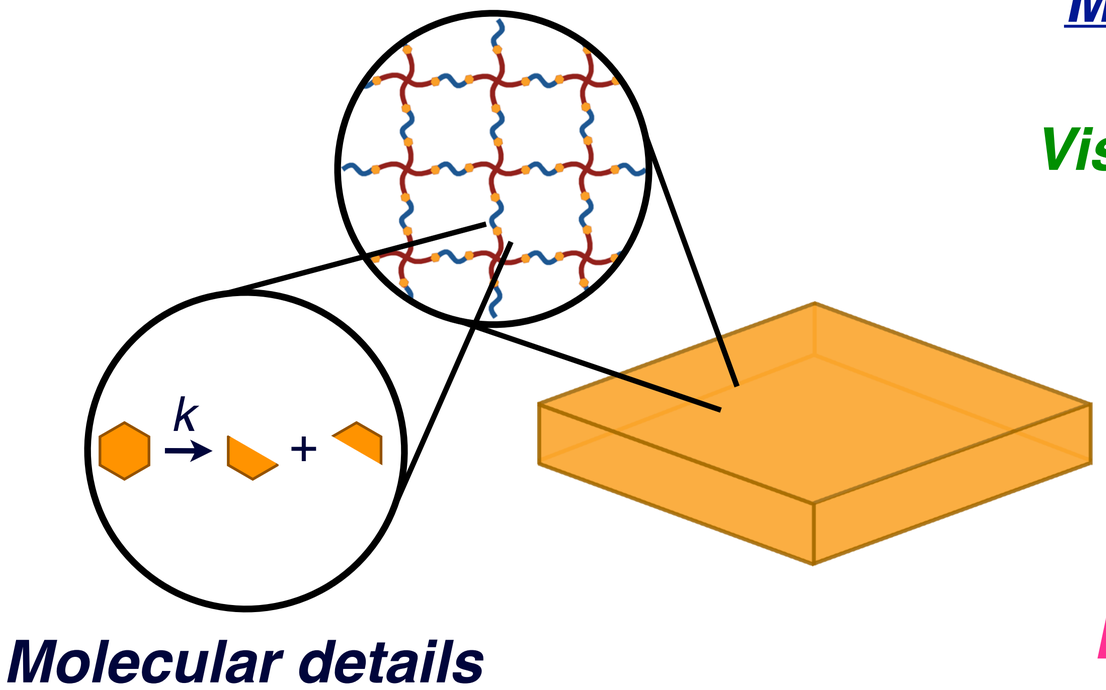
Polymer network or gel



10 nm scale

Viscoelastic insoluble network or gel

Macroscale properties are controlled by molecular details



Macroscale Properties

Viscoelasticity

Diffusivity

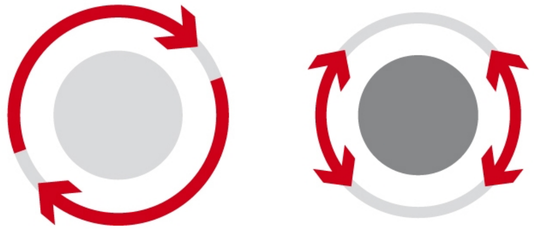
Surface chemistry

Swelling

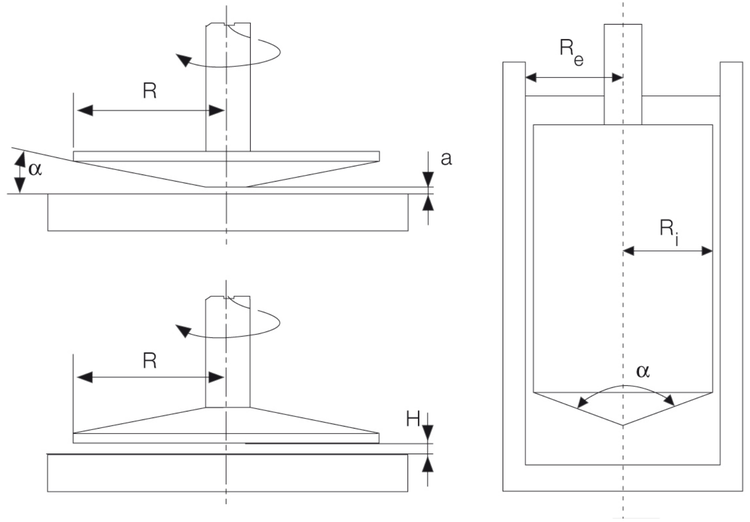
Degradation

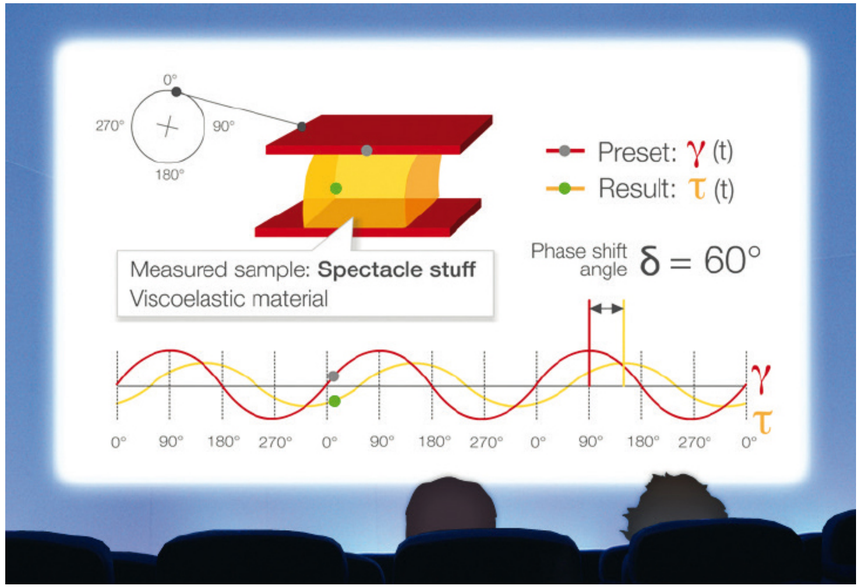
Macromolecular details inform material properties and provide a tunable handle in their design.

Data on viscoelasticity of ‘real’ materials

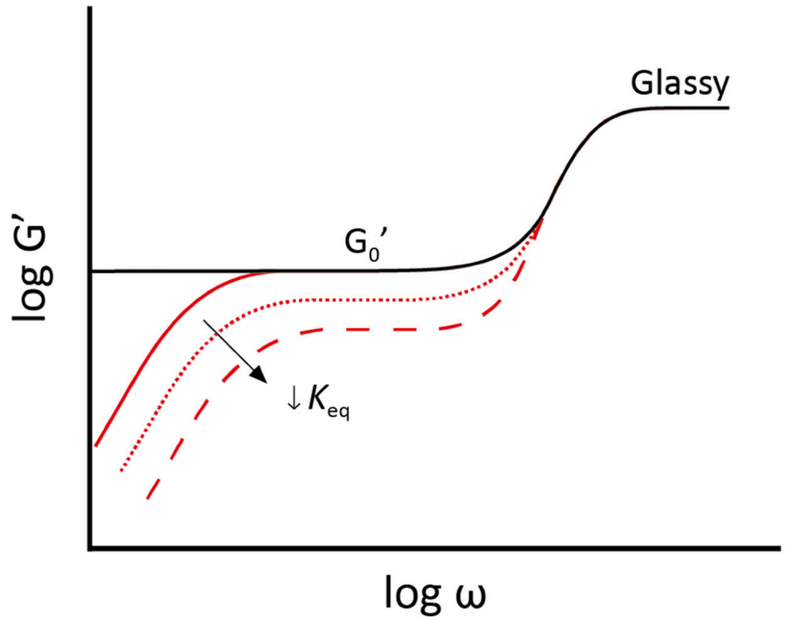


Anton-Paar

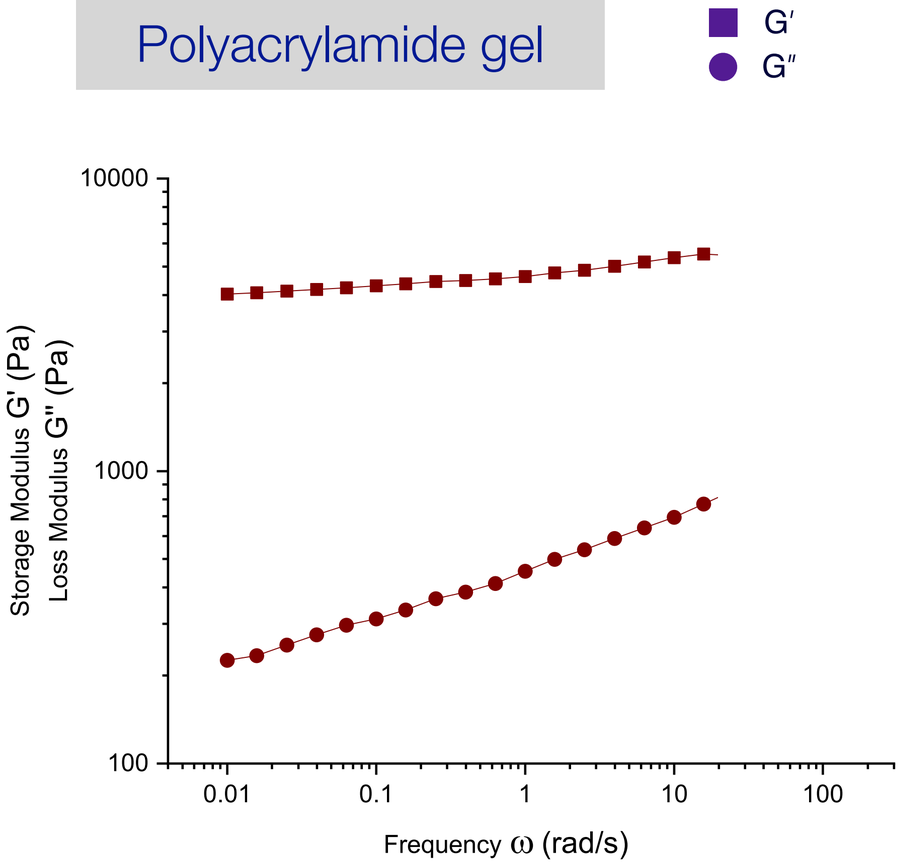




Chemically cross-linked hydrogel network



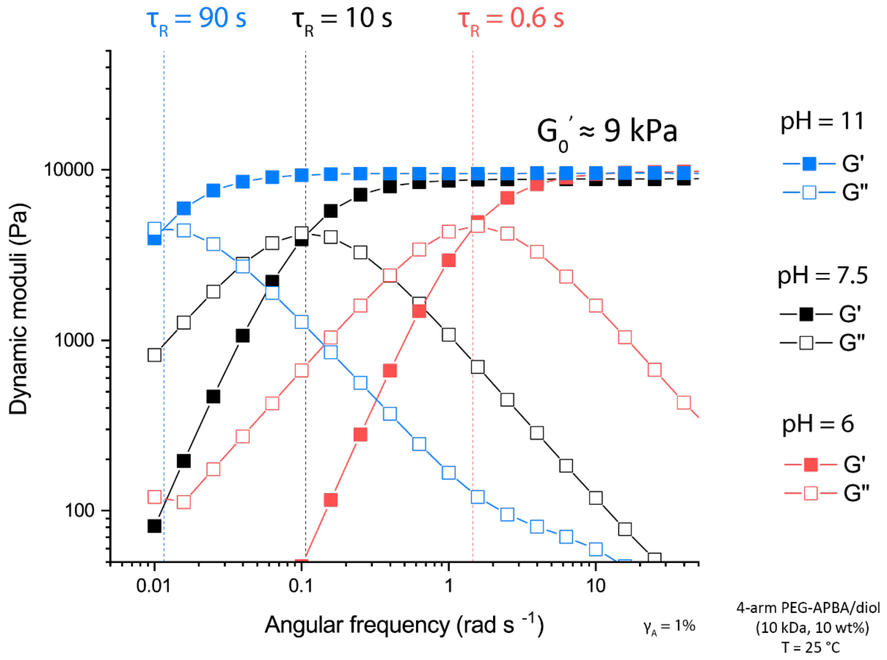
Polyacrylamide gel

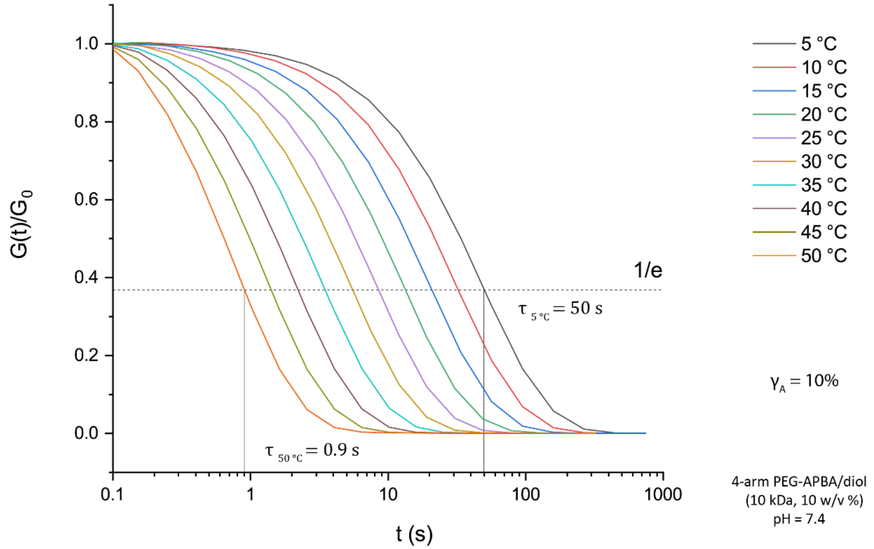


Wassim Dhaouadi & Bruno Marco-Dufort

Marco-Dufort and Tibbitt *Mater. Today Chem.* **2019**, *12*, 16–33.

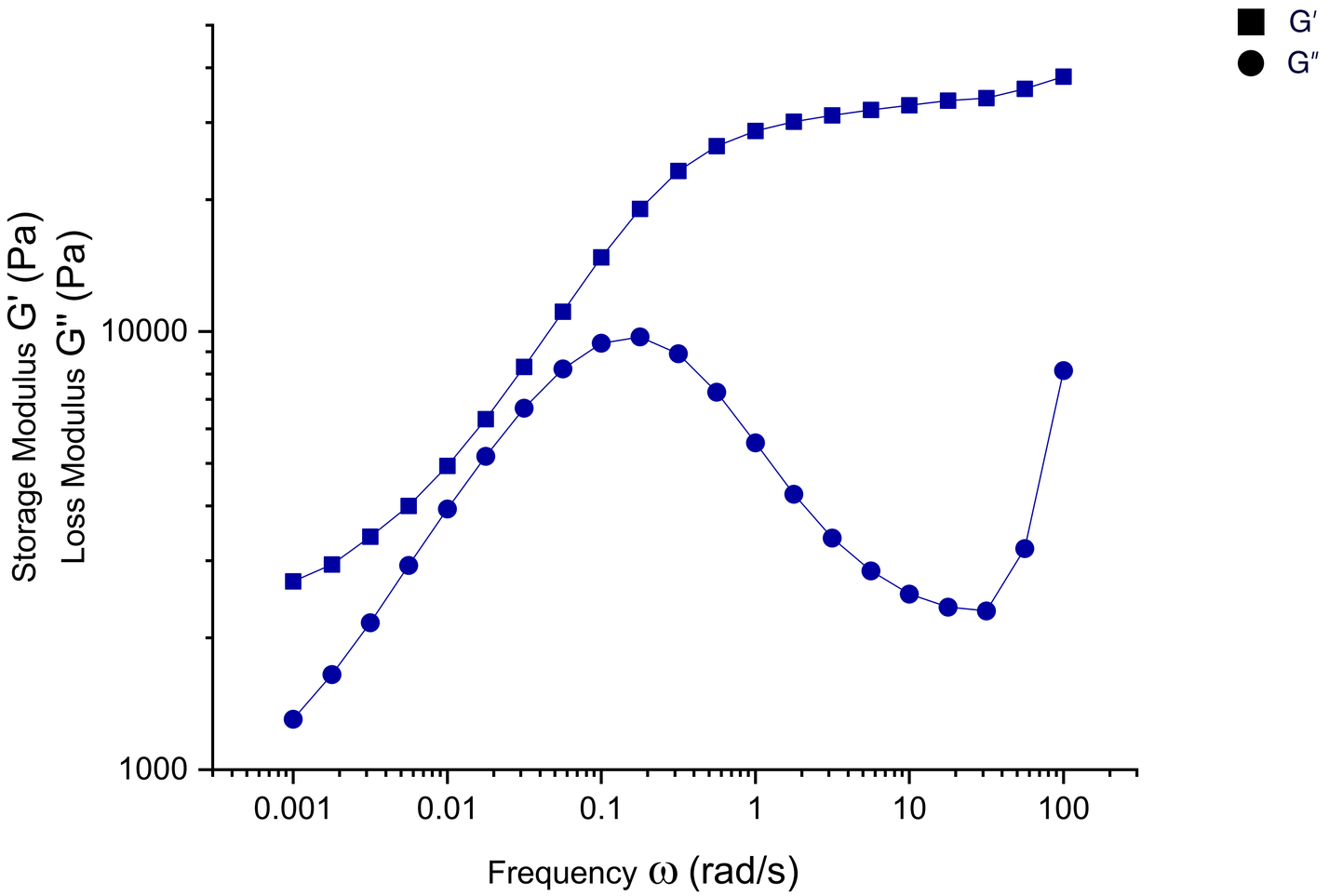
Dynamic covalent cross-linked hydrogel





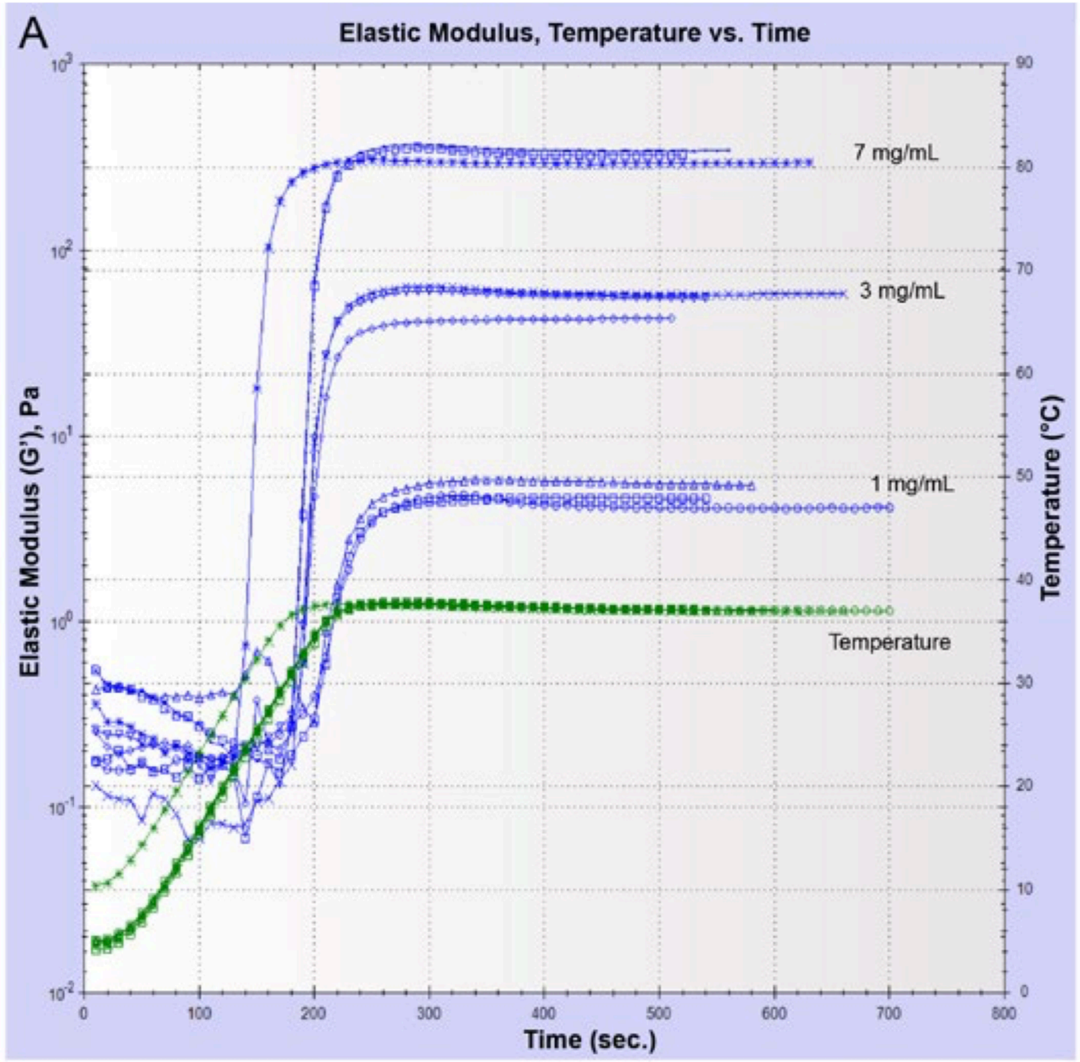
$$G(t) = G_0 \; e^{-\frac{t}{\tau_R}}$$

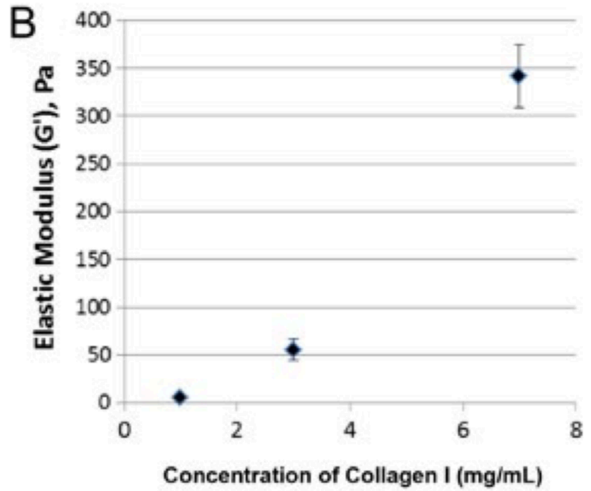
Double network hydrogel

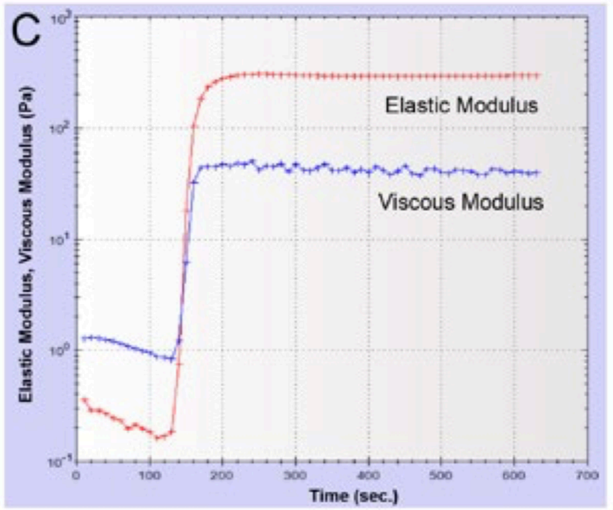


Wassim Dhaouadi & Bruno Marco-Dufort

Collagen hydrogels

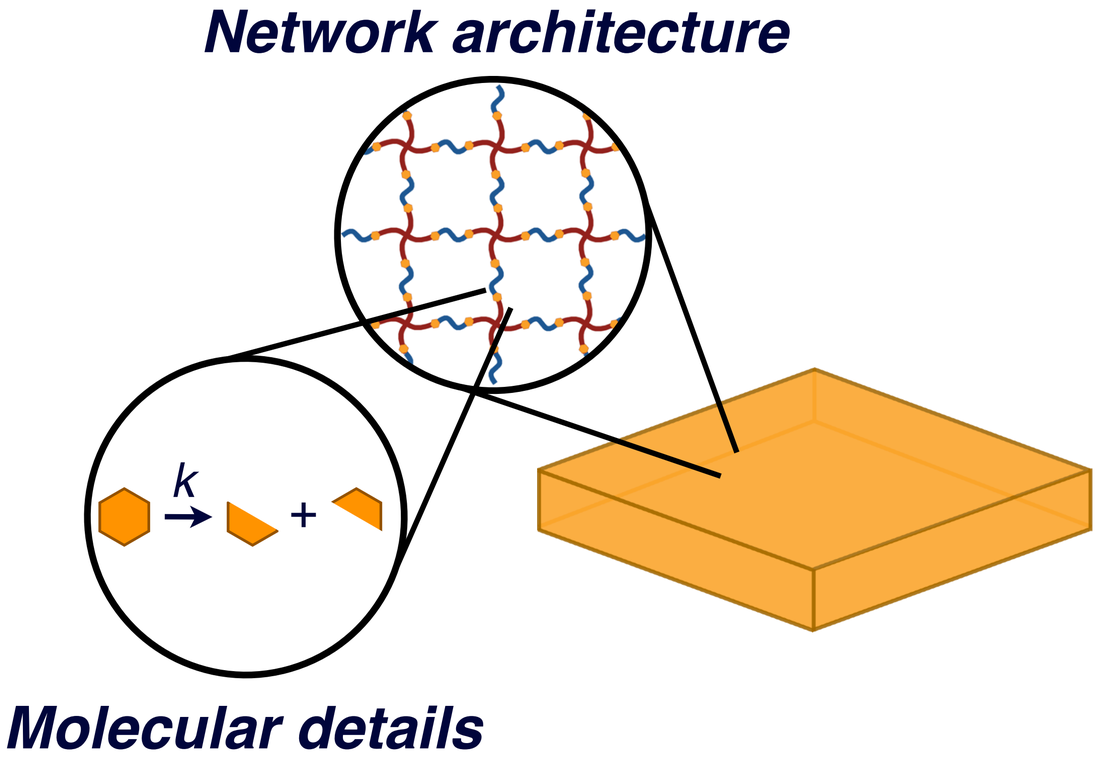






Corning, Inc.

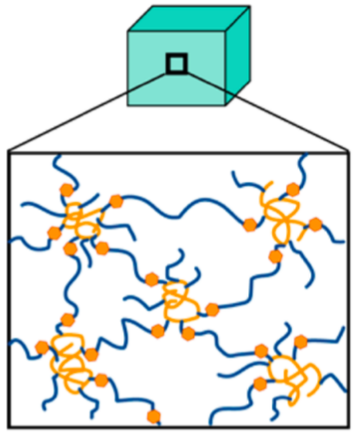
Cross-linking criteria



- Enable linking between polymer chains
- Sufficiently high reaction efficiency to generate network
- Ideally mild for biological use

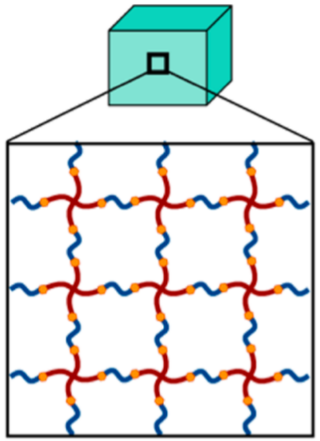
Chain and step-growth polymerization mechanisms

Chain polymerization



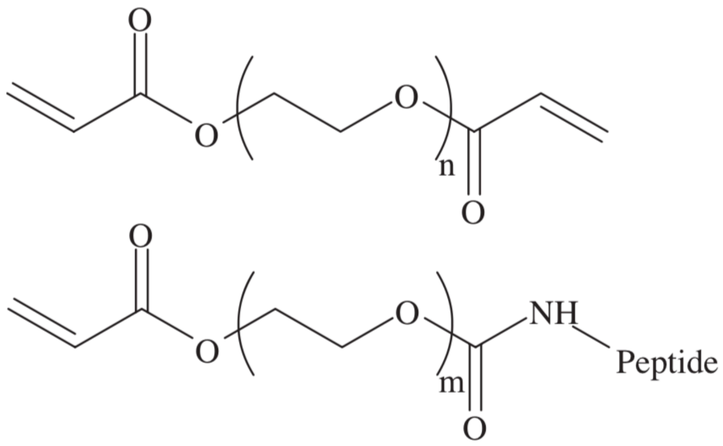
- Heterogeneous structure
- Kinetic chain length controls mechanical properties

Step-growth polymerization



- Homogeneous structure
- Polymer precursors controls mechanical properties

Chain polymerization of (meth)acrylates



Peptide = YRGDS or YRDGS

Fig. 1. Chemical structures of the multifunctional macromer PEGDA and monovinyl macromer acryloyl-PEG-Arg-Gly-Asp (Acr-PEG-RGD) used for hydrogel fabrication and osteoblast encapsulation.

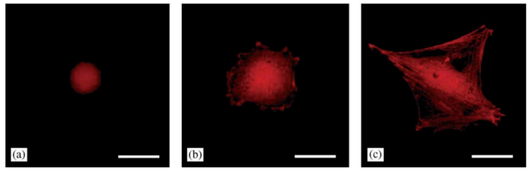


Fig. 5. Cytoskeleton organization observed with fluorescent confocal microscopy of actin-stained osteoblasts after 12 h on 10% PEGDA in PBS with no Acr-PEG-RGD (a), 0.5 mM Acr-PEG-RGD (b), and 5.0 mM Acr-PEG-RGD (c), bar = 20 μm.

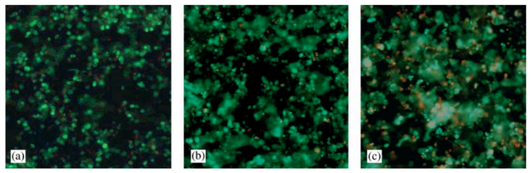
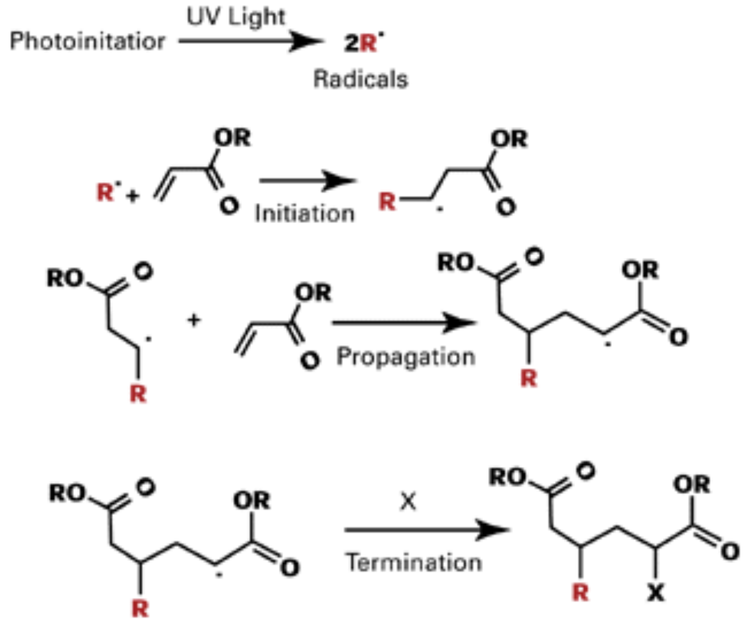


Fig. 6. Osteoblasts encapsulated in hydrogels formed from 10% PEGDA in PBS (a), 20% PEGDA in PBS (b), and 30% PEGDA in PBS (c) 24 h after encapsulation and stained with a LIVE/DEAD cell assay, where live cells fluoresce green and dead cells fluoresce red.

Figure 9 / Mechanism of Free Radical Polymerization



PCI magazine

Burdick and Anseth *Biomaterials* **2002**, *23*, 4315–4323.

Chain polymerization of degradable (meth)acrylates

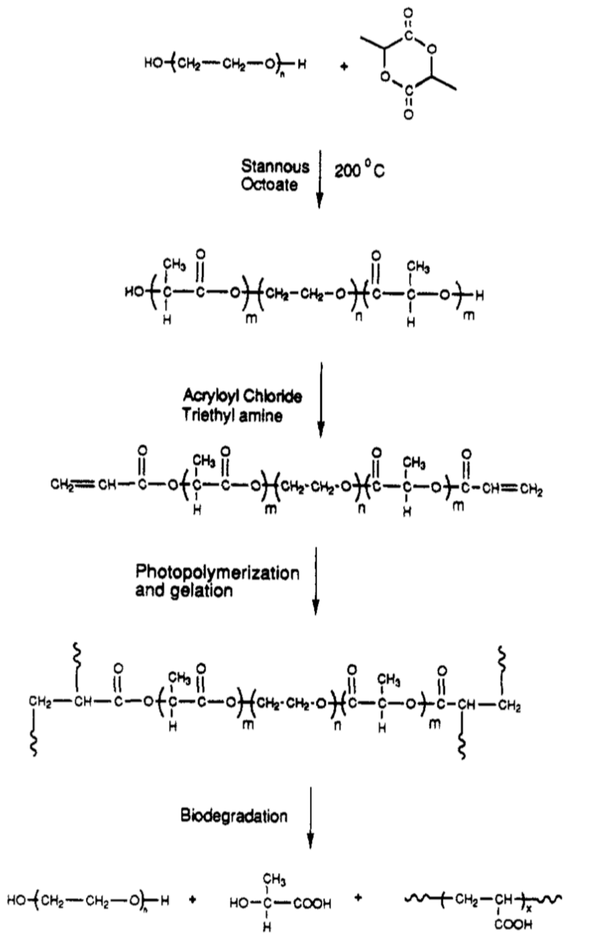
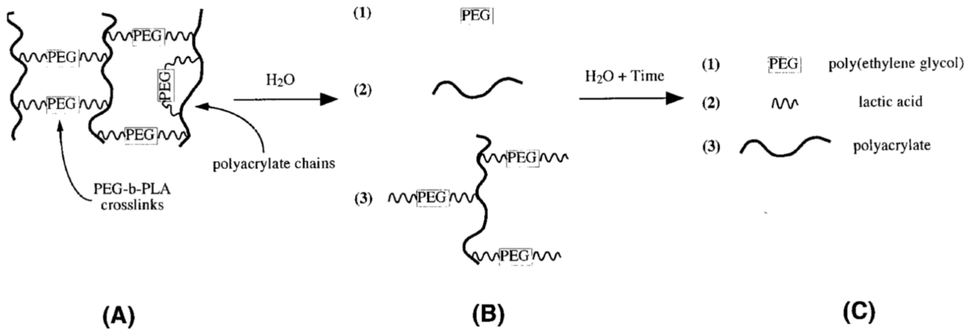


Figure 1. Reaction scheme for the synthesis of polymerizable PEG-*co*-poly(α-hydroxy acid) di- and tetraacrylates and hydrogels, as well as their degradation.

Sawhney et al. *Macromolecules* **1993**, *26*, 581–587.



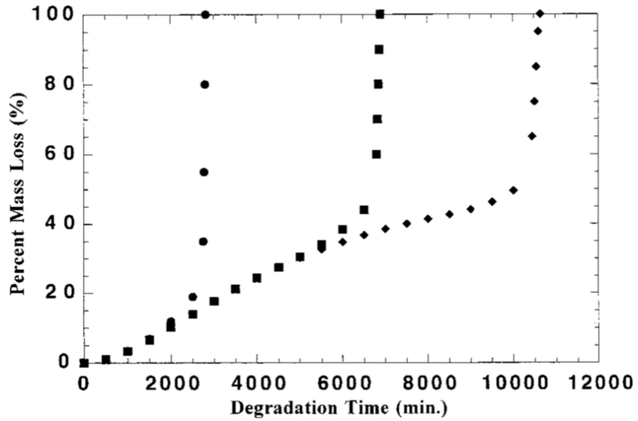
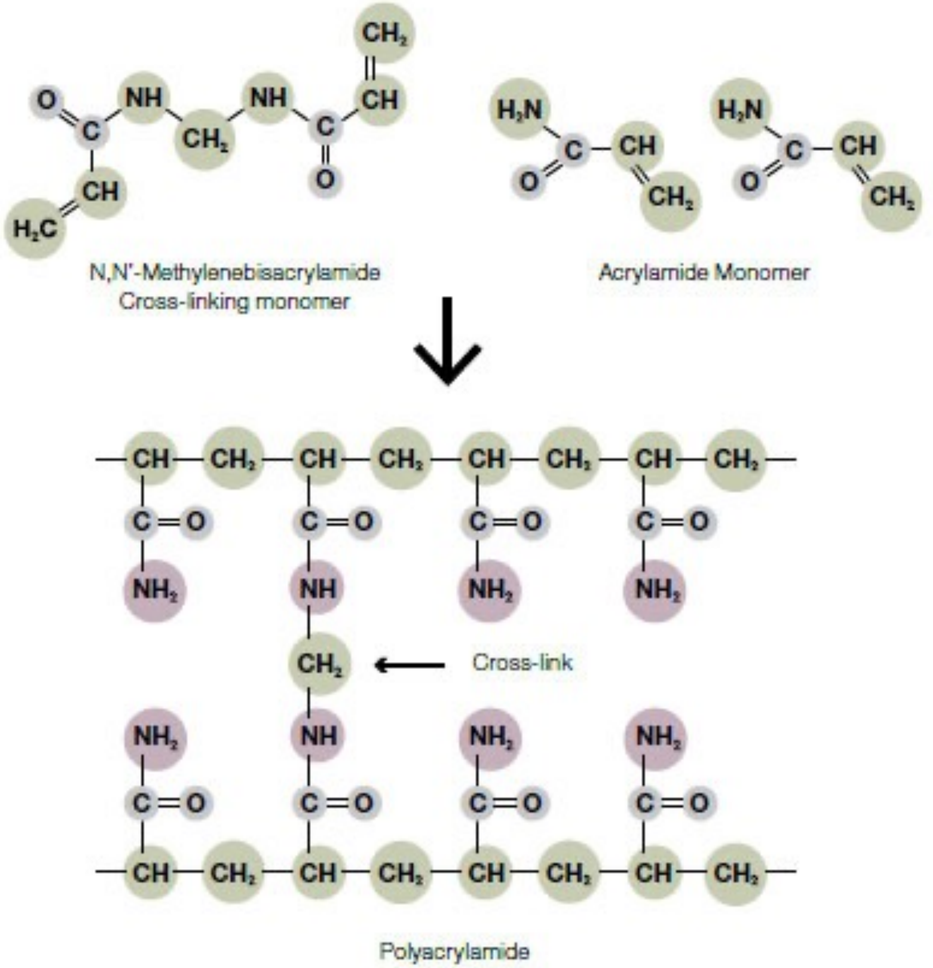
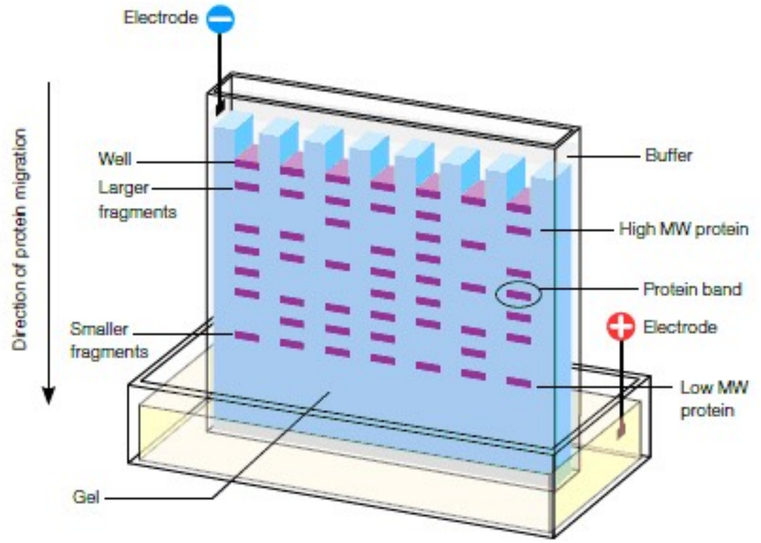


Figure 5. Percent mass loss as a function of degradation time for hydrogels with an increasing number of PLA-*b*-PEG-*b*-PLA cross-links per backbone chain: (●) $N = 10$; (■) $N = 100$; and (◆) $N = 1000$. Other model parameters for all curves: $W_{PA} = W_{PEG} = 50$ wt % and $k' = 0.0003$ min^{-1}.

Metters et al. *J. Phys. Chem. B* **2000**, *104*, 7043–7049.

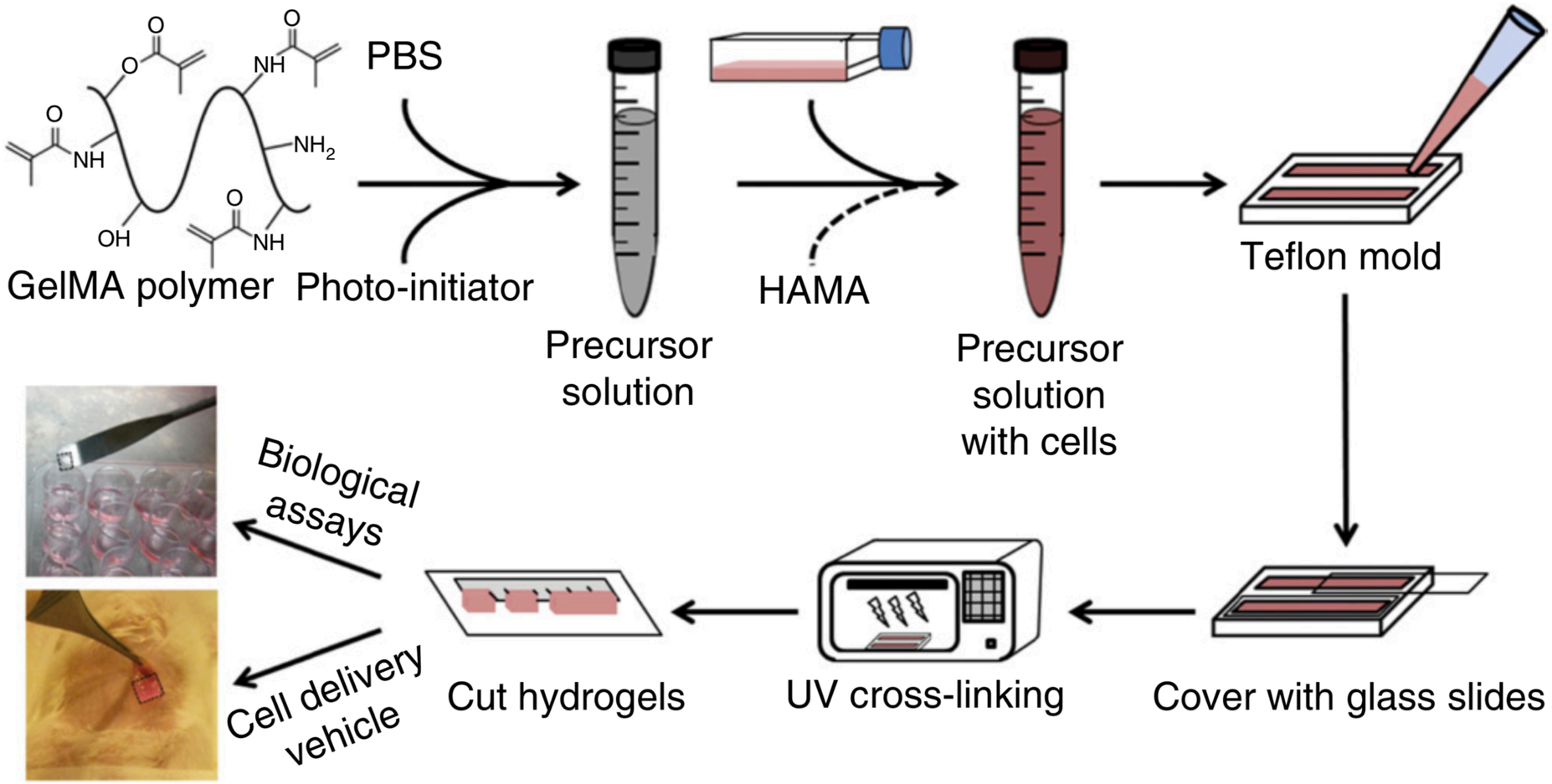
Polyacrylamide hydrogels





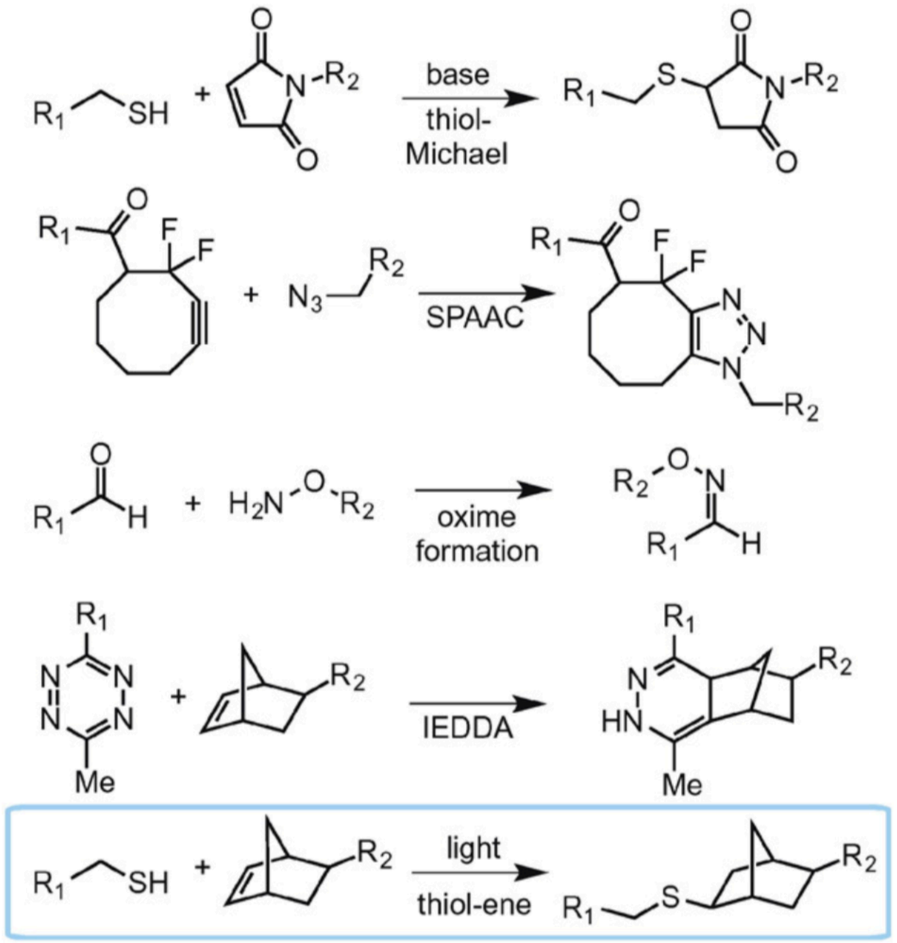
bio-rad.com

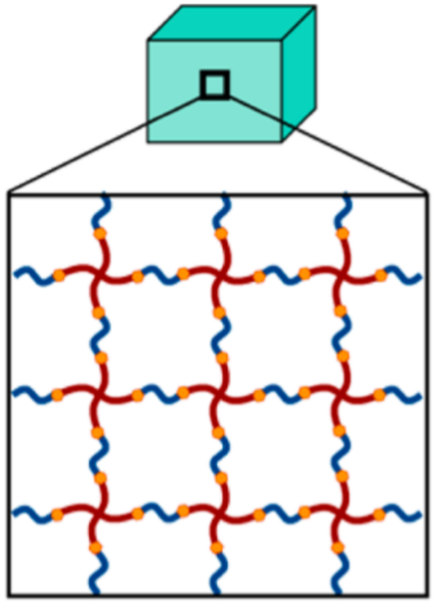
Methacryloyl gelatin



Loessner et al. *Nat. Protoc.* **2016**, *11*, 727–746.

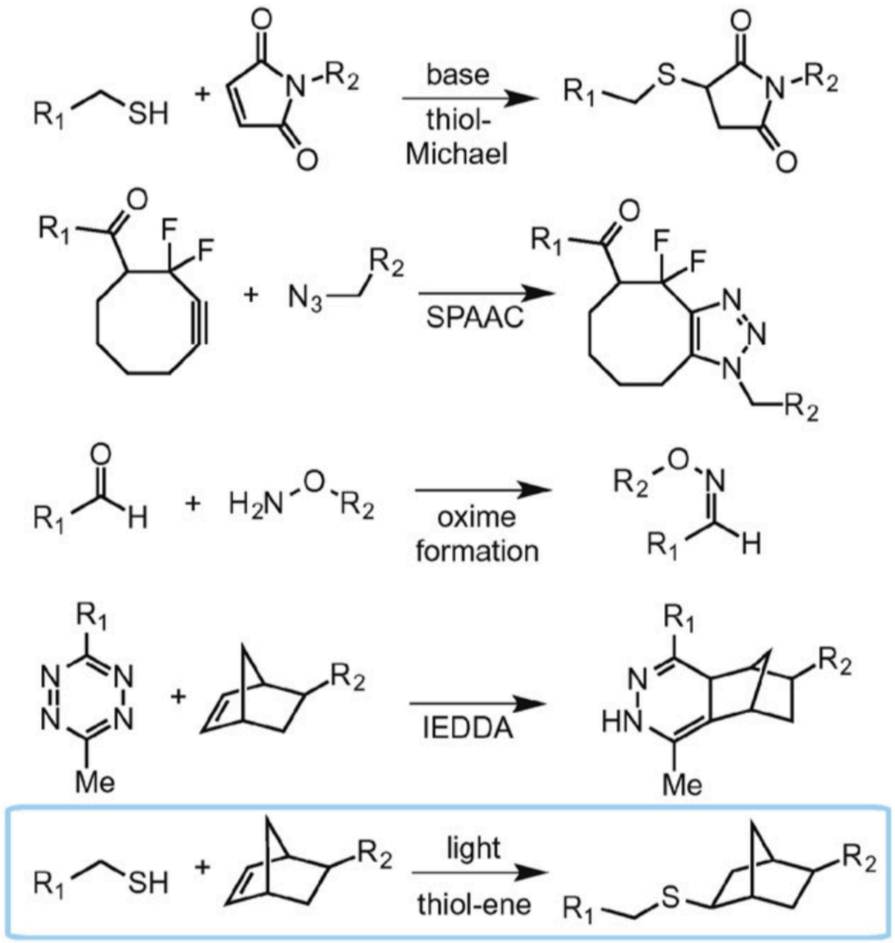
Step-growth polymerization (polycondensation) mechanisms

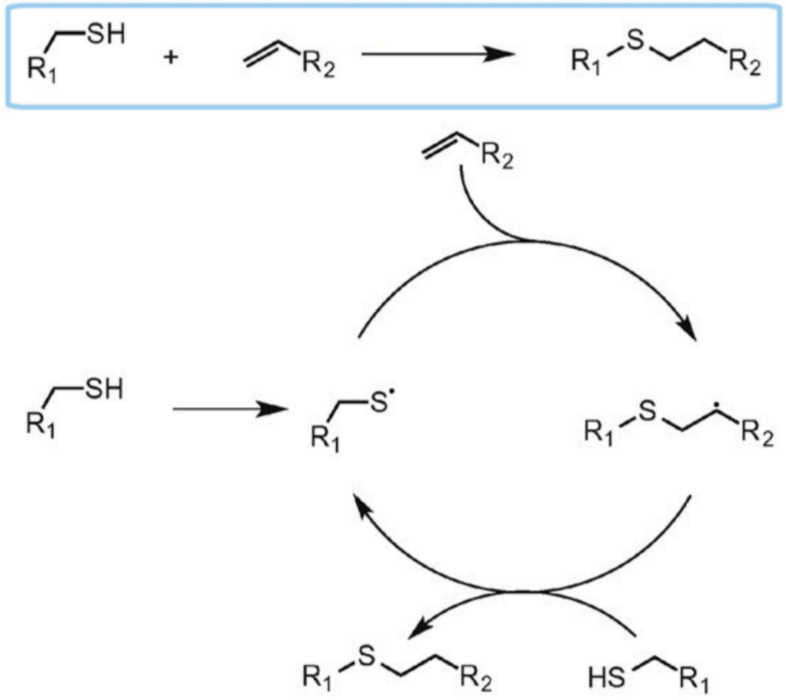




Grim et al. *J. Controlled Release* **2015**, *219*, 95–106.

Thiol-ene cross-linking





Scheme 1. Mechanism for the photo-click thiol-ene reaction.

Grim et al. *J. Controlled Release* **2015**, *219*, 95–106.

Thiol-vinyl sulfone cross-linking

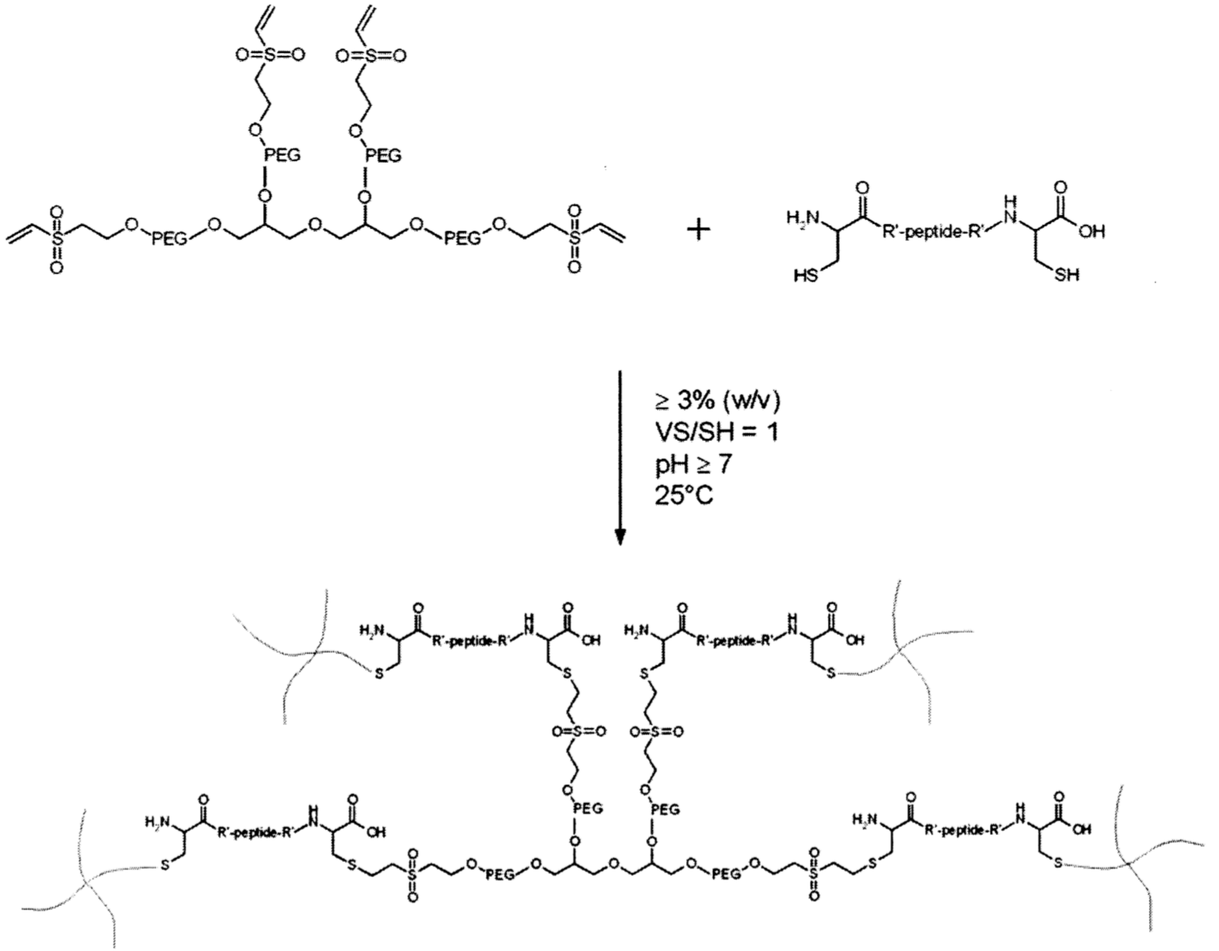
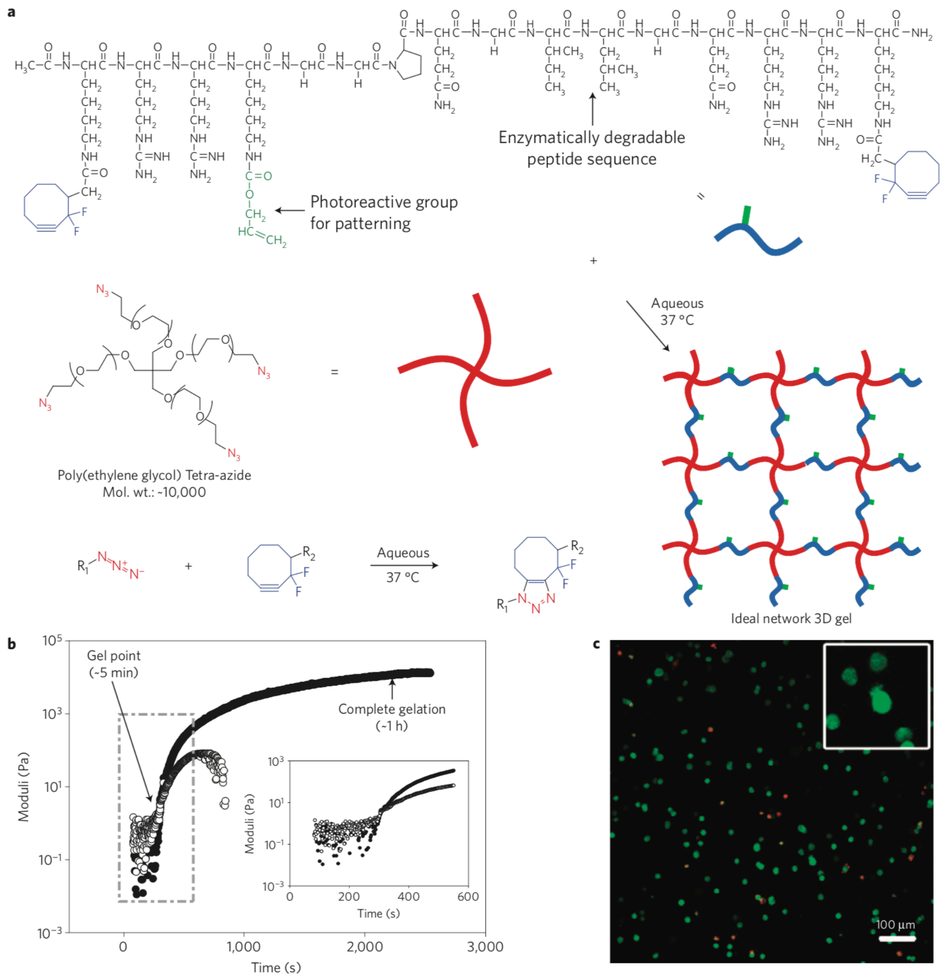


Figure 1. Synthesis scheme for the stepwise copolymerization of biomolecules containing free thiols on Cys residues with end-functionalized PEG macromers bearing conjugated unsaturated moieties.

Lutolf and Hubbell *Biomacromolecules* **2003**, *4*, 713–722.

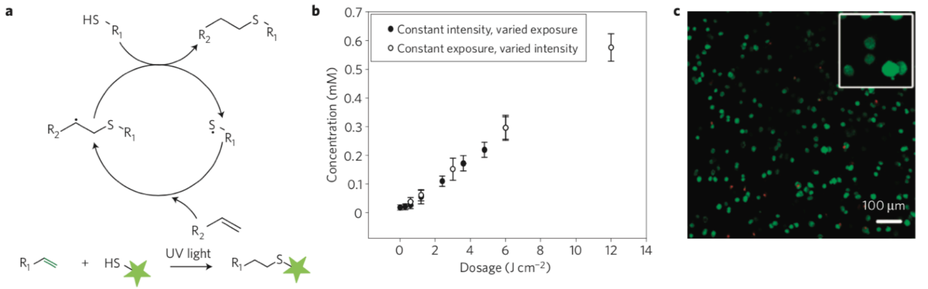
SPAAC cross-linking

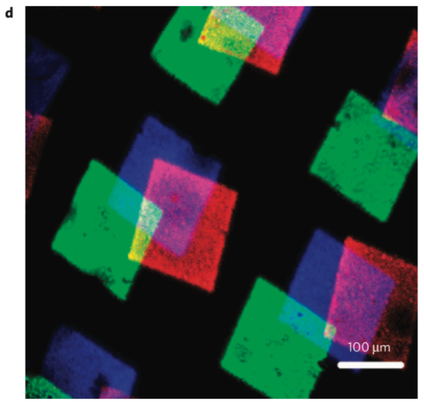


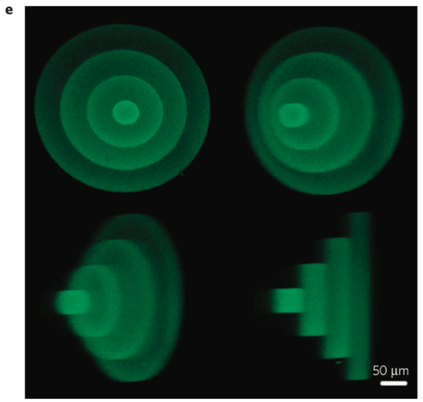
nature materials
LETTERS
PUBLISHED ONLINE: 21 JUNE 2009 | DOI: 10.1038/NMAT2473

Sequential click reactions for synthesizing and patterning three-dimensional cell microenvironments

Cole A. DeForest[1], Brian D. Polizzotti[1,2] and Kristi S. Anseth[1,2]*

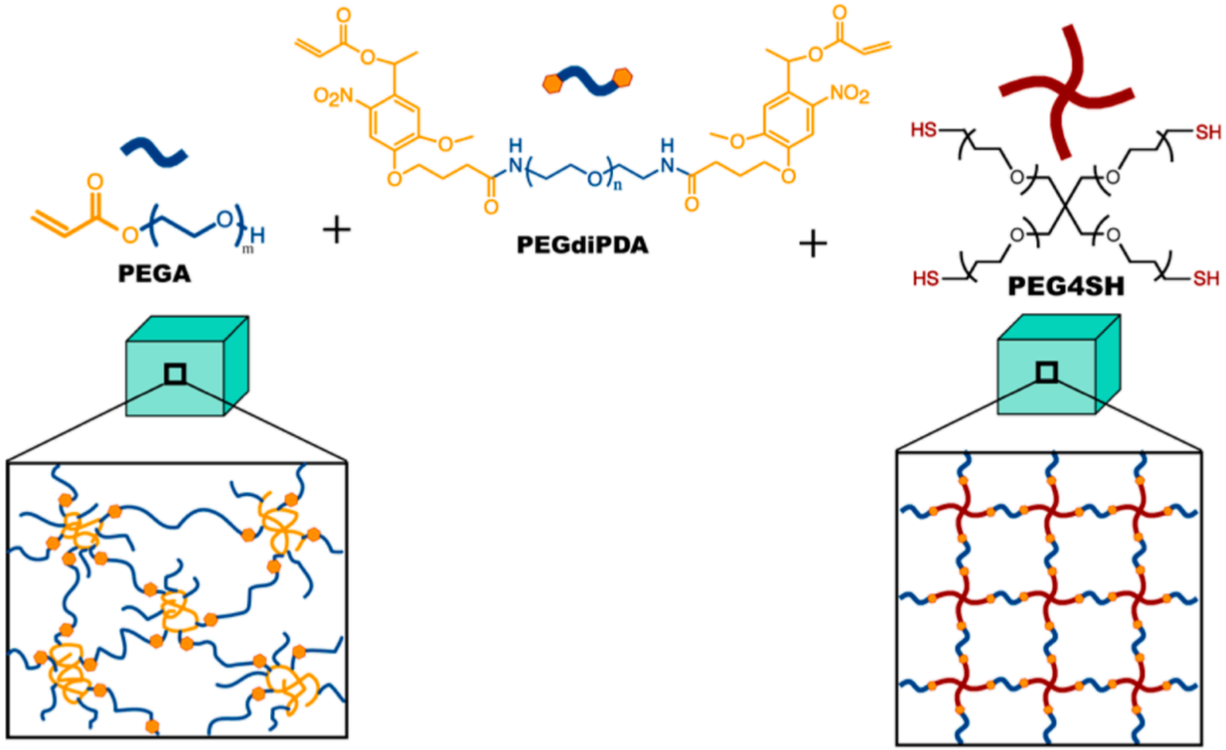






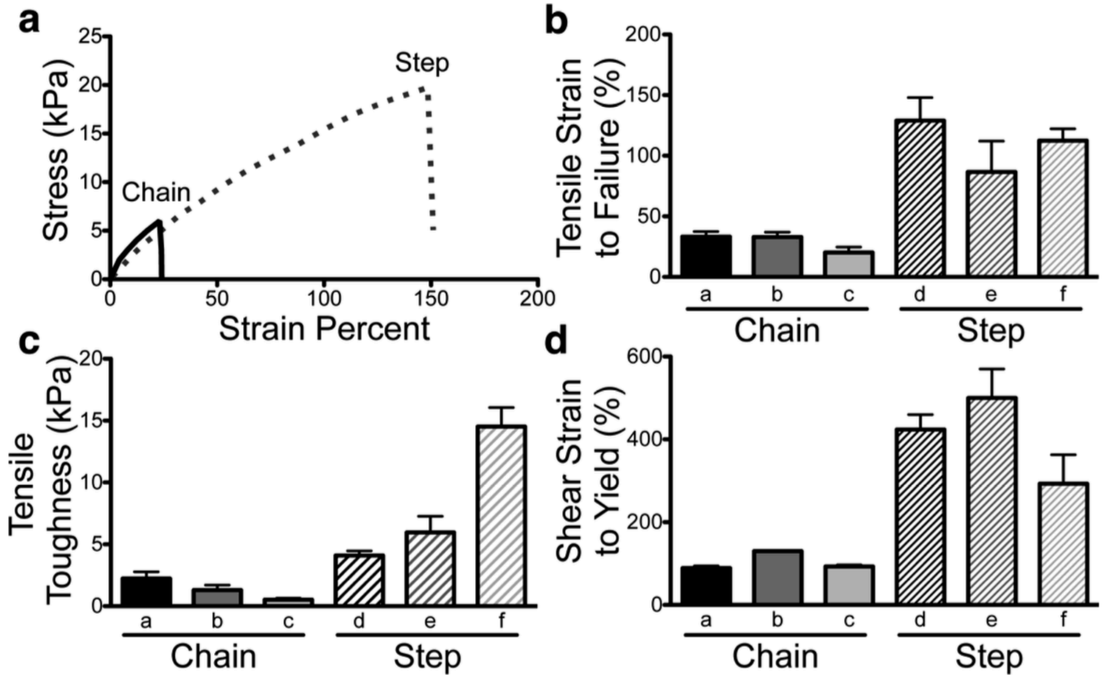
DeForest et al. *Nat. Mater.* **2009**, *8*, 659–664.

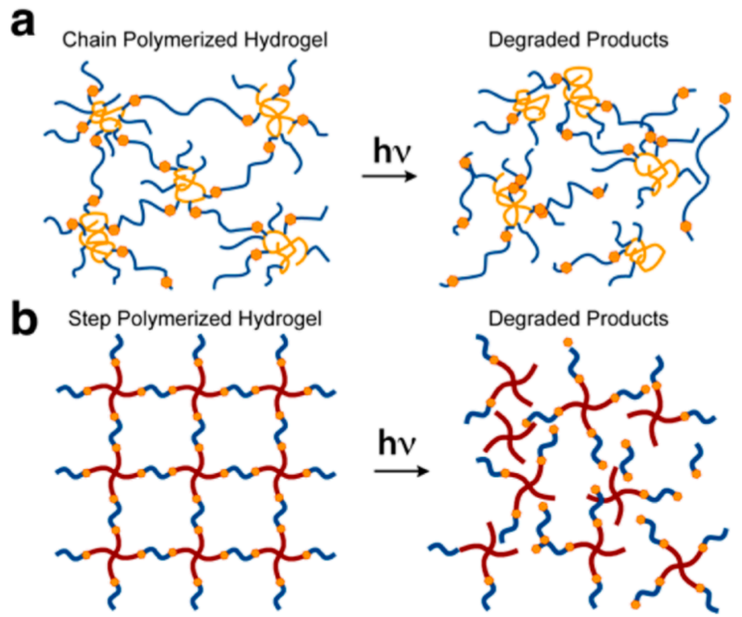
Comparison of chain and step growth networks

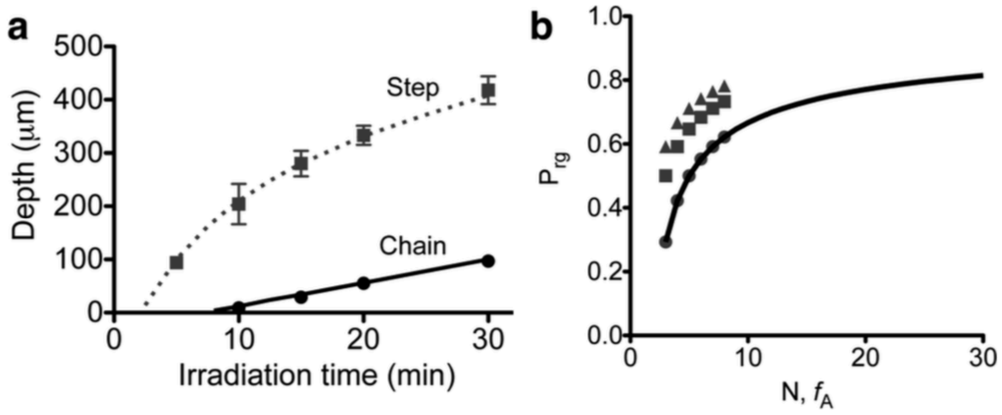


Tibbitt et al. *Macromolecules* **2013**, *46*, 2785–2792.

Comparison of chain and step growth networks







Tibbitt et al. *Macromolecules* **2013**, *46*, 2785–2792.