Applications of hydrogels

Last Day: polyelectrolyte gels
Polyelectrolyte complexes and multilayers
Theory of ionic gel swelling

Today: hydrogels in biomedical/bioengineering applications
Linking gel mesh size to diffusivity of solutes

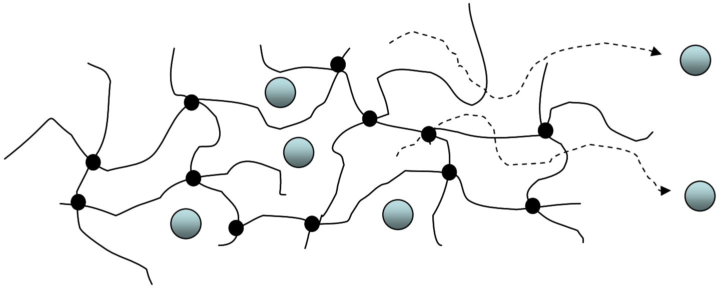
Reading: -

Supplementary Reading: S.R. Lustig and N.A. Peppas, 'Solute diffusion in swollen membranes. IX. Scaling laws for solute diffusion in gels,' *J. Appl. Polym. Sci*. **36**, 735-747 (1988)
T. Canal and N.A. Peppas, 'Correlation between mesh size and equilibrium degree of swelling of polymeric networks,' *J. Biomed. Mater. Res*. **23**, 1183-1193 (1989)

ANNOUNCEMENTS:

Last time

Applications of hydrogels in bioengineering



Hydrogels applied to drug delivery

On/off drug release using PE hydrogels

Two strategies:

Kinetics of drug release from hydrogels using swollen-on/collapsed-off mechanism

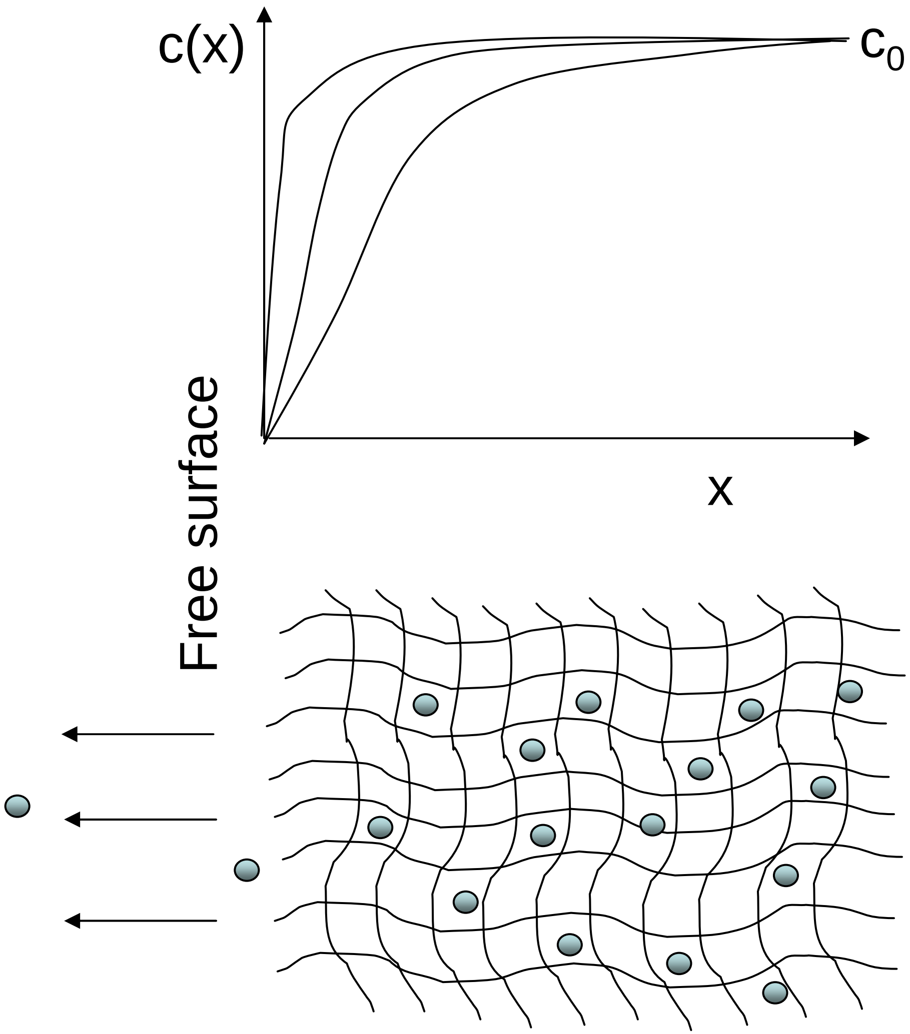
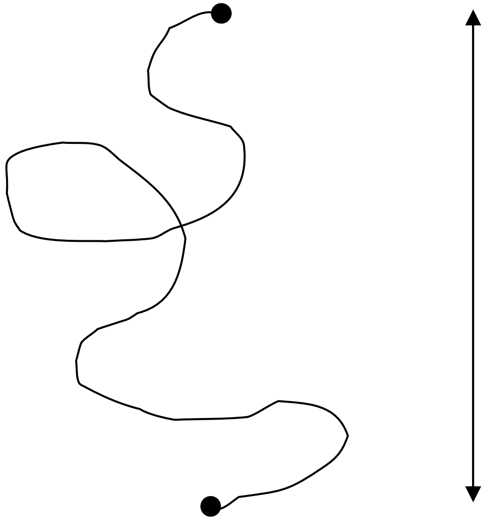


Image removed due to copyright reasons.
Please see:
Figure 3 in Canal, T., and N. A. Peppas. "Correlation Between Mesh Size and Equilibrium Degree of Swelling of Polymeric Networks." *Journal of Biomedical Materials Research* 23 (1989): 1183-1193.

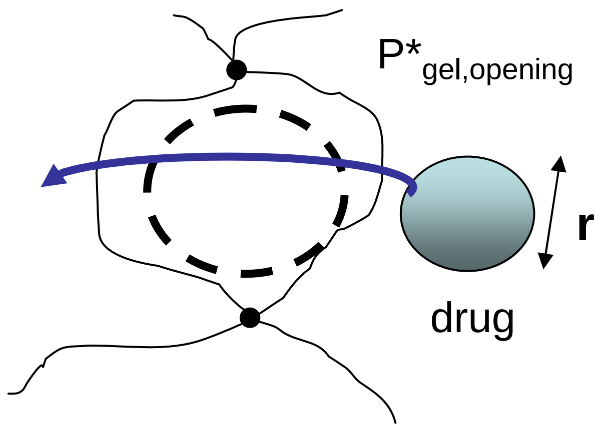
Mesh size of hydrogel networks

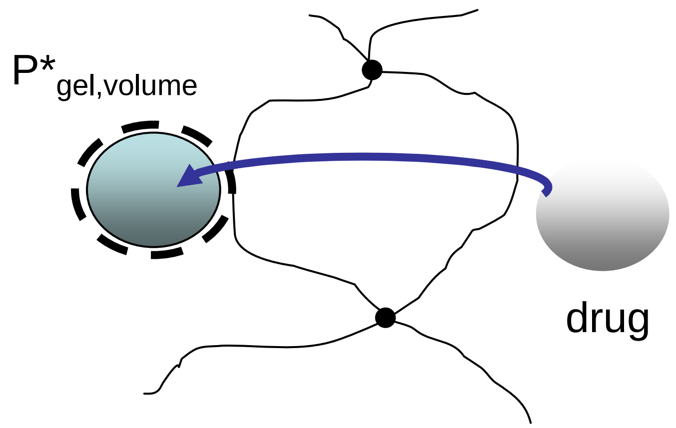


$$(\langle r_0^2 \rangle)^{1/2} = N_c^{1/2} a$$

statistical segment length

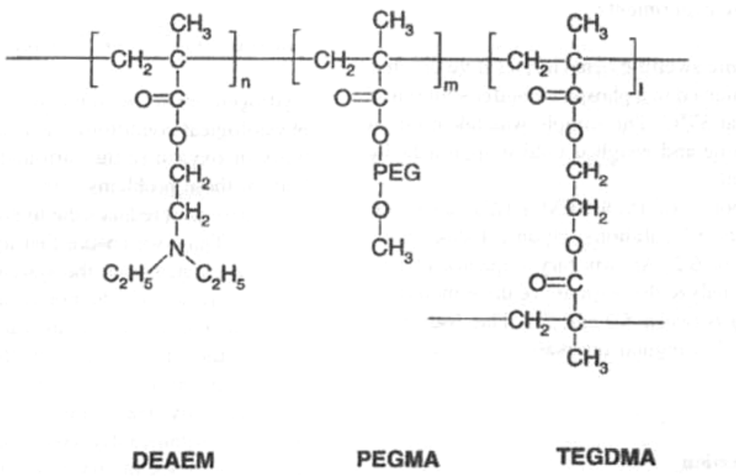
Number of segments
between cross-links



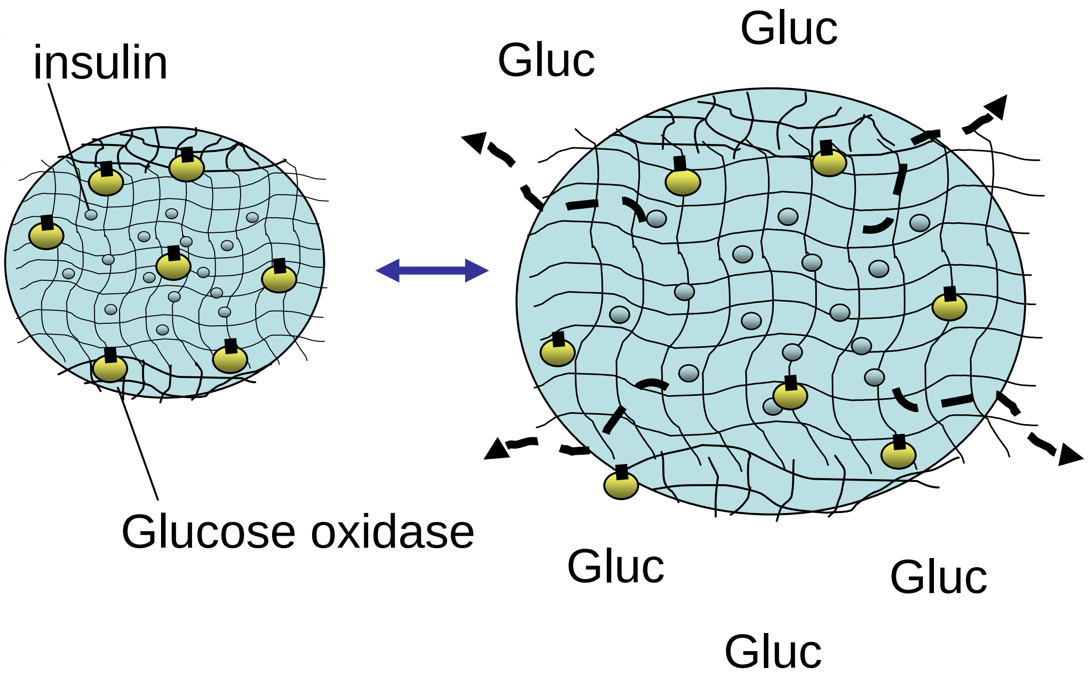


Connection between mesh size and diffusion coefficient of entrapped molecules

Controlling diffusivity for responsive drug delivery: treatment of diabetes



$$\text{Glucose} + O_2 \xrightarrow{\text{Glucose oxidase}} \text{Gluconic acid} + H_2O_2$$



Controlling diffusivity for responsive drug delivery: treatment of diabetes

Image removed due to copyright reasons.
Please see:
Figure 3 in Podual, K., F. J. Doyle, and N. A. Peppas. "Dynamic Behavior of Glucose Oxidase-containing Microparticles of Poly(ethylene glycol)-grafted Cationic Hydrogels in an Environment of Changing pH." *Biomaterials* 21 (2000): 1439-1450.

Response of gel microparticles

Graphs removed due to copyright reasons.
Please see:
Figures 8 and 9 in Podual, K., F. J. Doyle, and N. A. Peppas. "Dynamic Behavior of Glucose Oxidase-containing Microparticles of Poly(ethylene glycol)-grafted Cationic Hydrogels in an Environment of Changing pH." *Biomaterials* 21 (2000): 1439-1450.

Glucose sensitivity

Graph removed due to copyright reasons.
Please see:
Figure 3 in Podual, K., F. J. Doyle, and N. A. Peppas. "Glucose-sensitivity of Glucose Oxidase-containing Cationic Copolymer Hydrogels Having Poly(ethylene glycol) Grafts." *Journal of Controlled Release* 67 (2000): 9-17.

Graph removed due to copyright reasons.
Please see:
Figure 6 in Podual, K., F. J. Doyle, and N. A. Peppas. "Glucose-sensitivity of Glucose Oxidase-containing Cationic Copolymer Hydrogels Having Poly(ethylene glycol) Grafts." *Journal of Controlled Release* 67 (2000): 9-17.

Diffusion rate changes in responsive microgels

Graphs removed for copyright reasons.
Please see:
Figures 5 and11 in Podual, K., F. J. Doyle, and N. A. Peppas. “Dynamic Behavior of Glucose Oxidase-containing Microparticles of Poly(ethylene glycol)-grafted Cationic Hydrogels in an Environment of Changing pH.” *Biomaterials* 21 (2000): 1439-1450.

Chemical functionality in hydrogels can be utilized for responsive hydrogels

Mechanisms of environmental responsiveness in hydrogels:

Chemical functionality in hydrogels can be utilized for responsive hydrogels

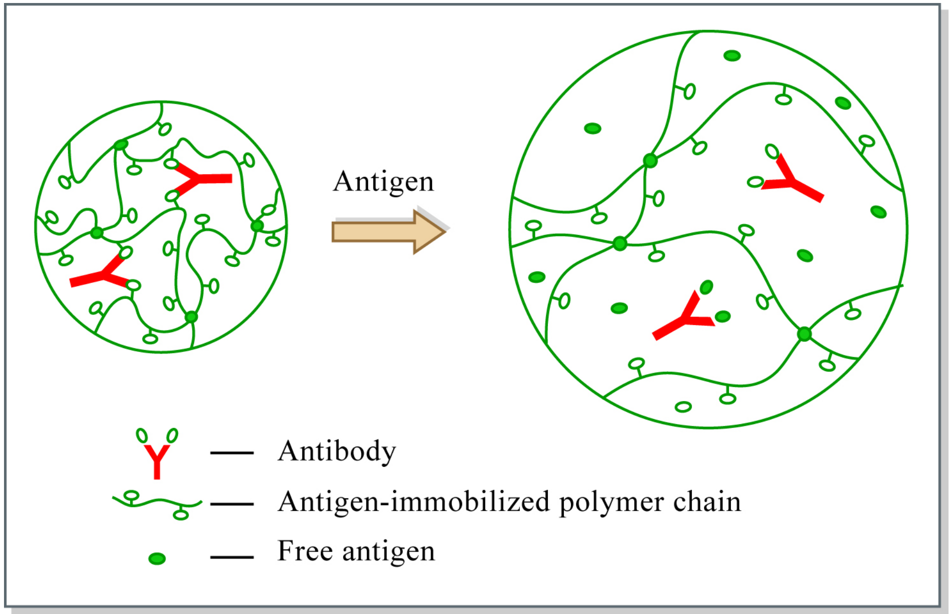


Figure by MIT OCW.

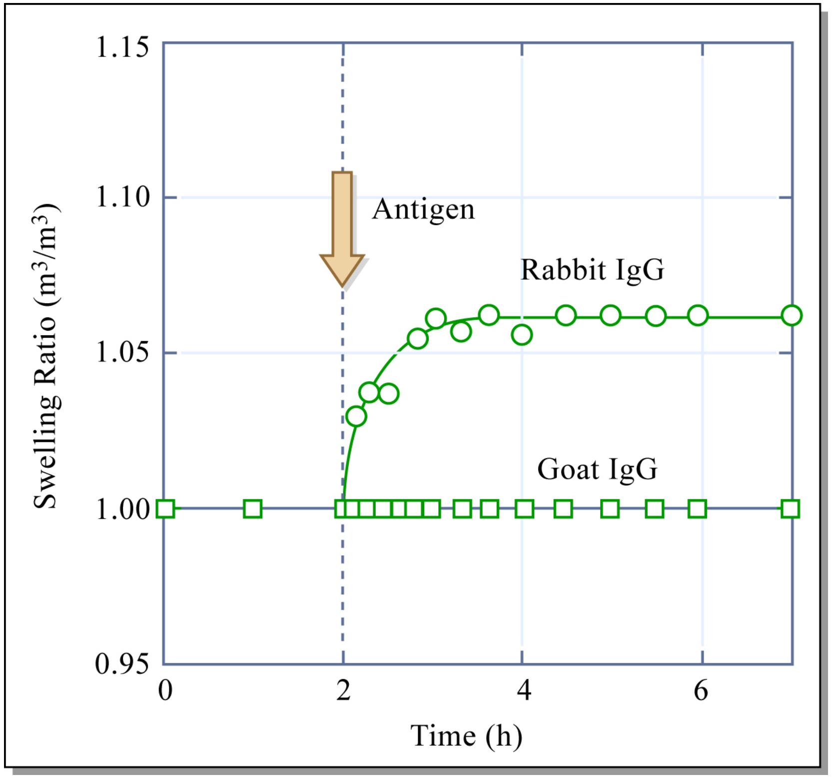


Figure by MIT OCW.

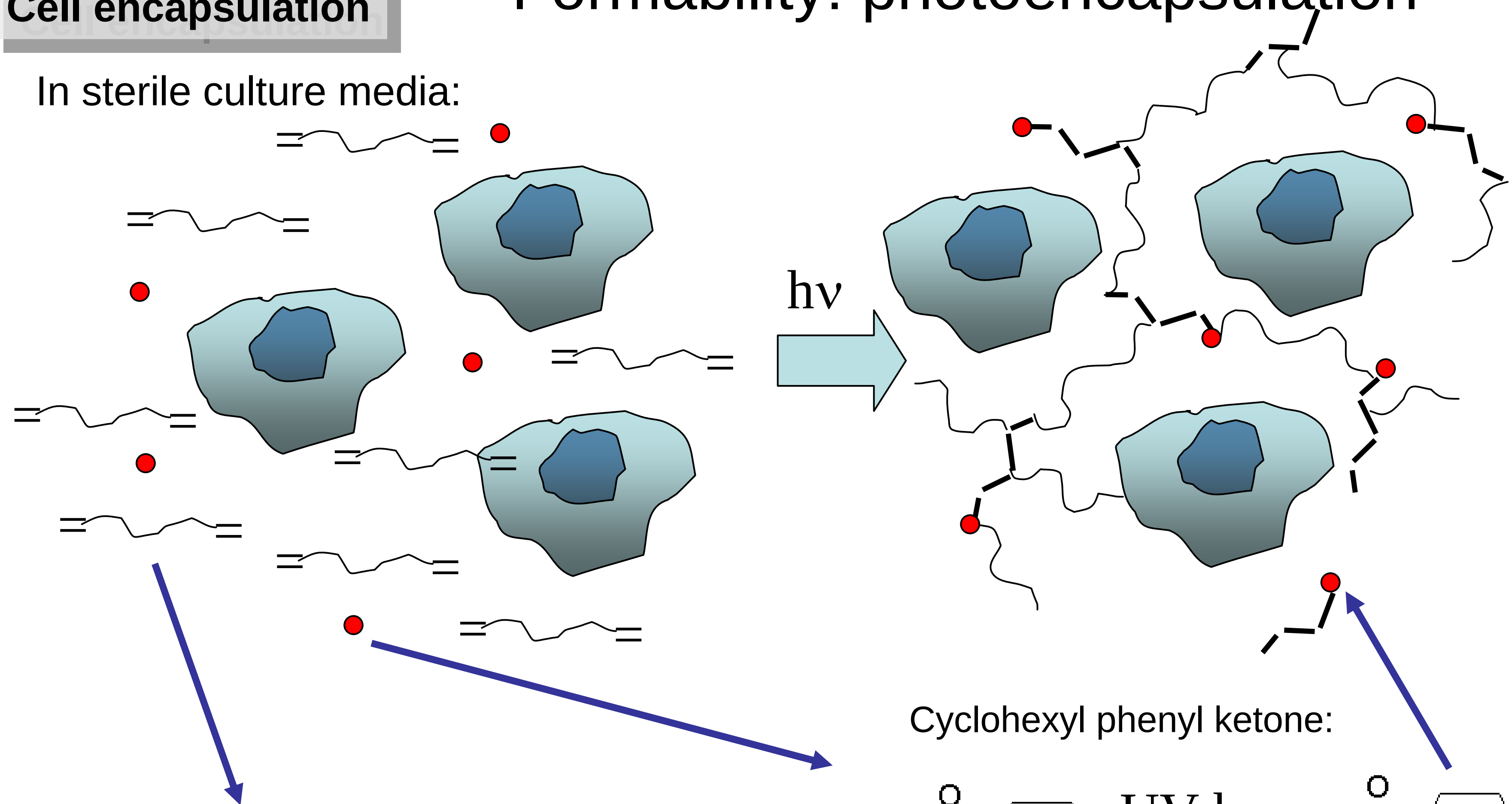
(Takahashi et al. *Macromol* **32**, 2082-2084 (1999))

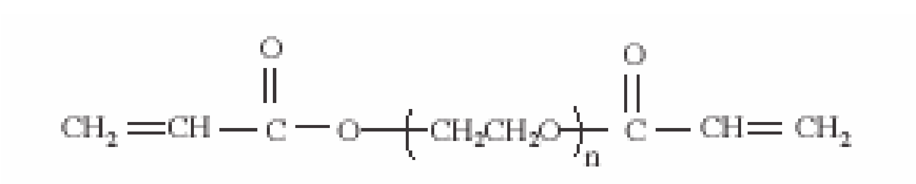
Immunoisolation/encapsulation of living cells

Immunoisolation/ Cell encapsulation

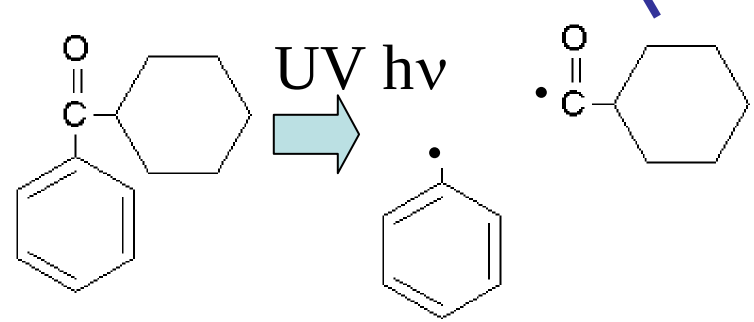
Formability: photoencapsulation

In sterile culture media:

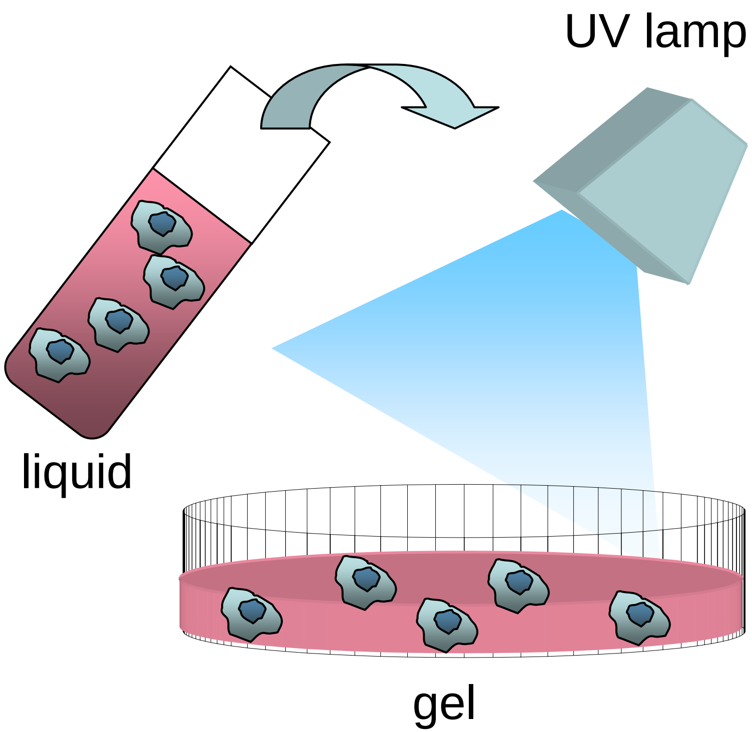




Cyclohexyl phenyl ketone:



Formability: photoencapsulation



Graph of Biochemical Analysis removed due to copyright restrictions.

immunoisolation

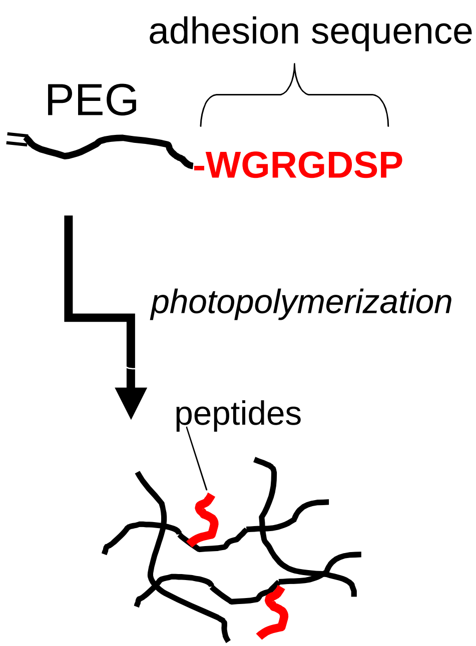
Images removed due to copyright restrictions,
Please see:
Lee, et al. *Adv. Drug Deliv Rev* 42 (2000): 103-120.

Hydrogels for tissue engineering

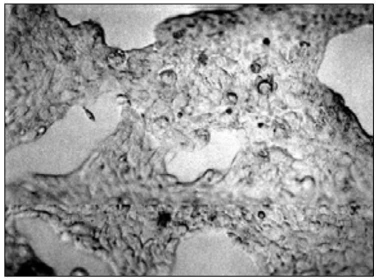
Motivation for hydrogels as tissue scaffolds:

Hydrogels are readily modified with biological recognition sites

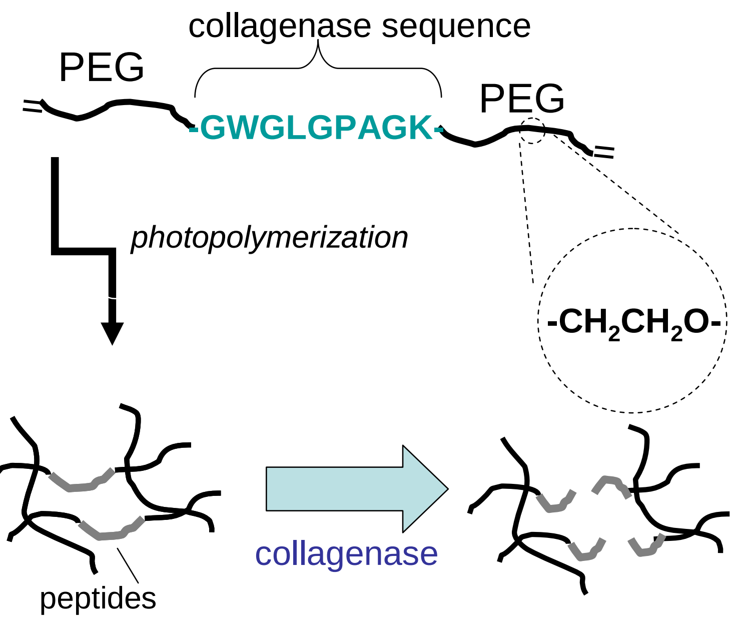
Incorporating biological recognition:



NR6 fibroblast adhesion on PEG-RGD hydrogel



(no cell adhesion on ligand-free hydrogels)



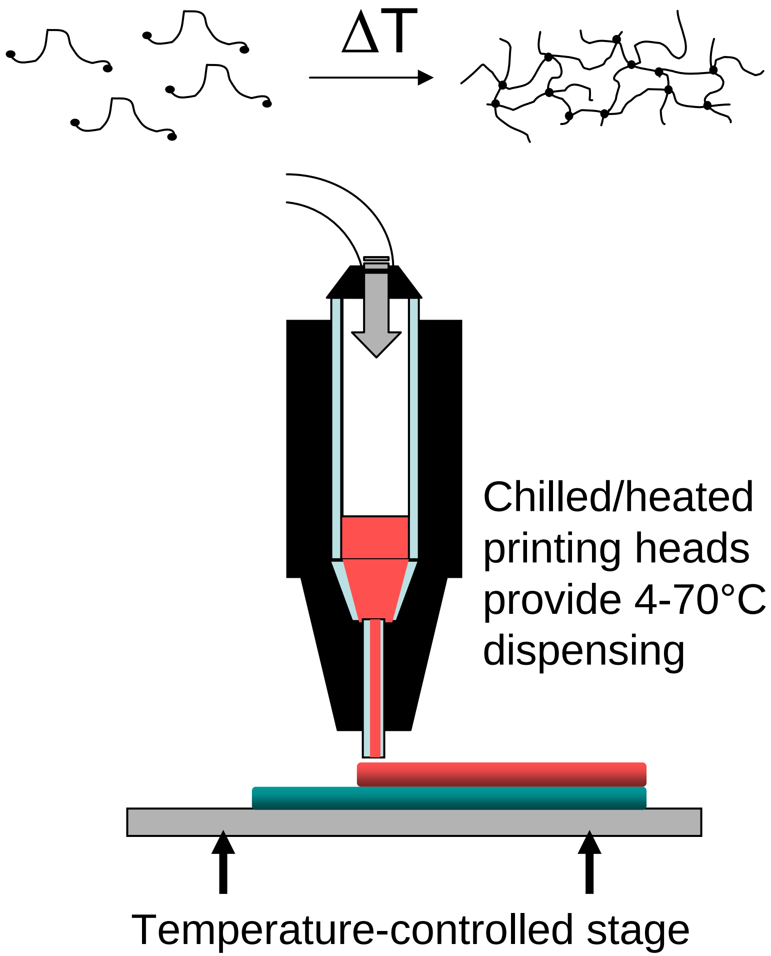
B.K. Mann, A.S. Gobin, A.T. Tsai, R.H. Schmedlen, J.L. West, *Biomaterials* **22**, 3045 (2001)

In situ formability: strategies for macroporous structures

Images removed for copyright reasons.
Please see:
Ford, Lavik, et al. *PNAS* 103 no. 8 (2006): 2512-2517.

Tissue engineering

In situ formability: example: ‘printable’ gels



Images removed for copyright reasons.
Please see:
Landers, et al. 2002.

Further Reading

1. Byrne, M. E., Oral, E., Hilt, J. Z. & Peppas, N. A. Networks for recognition of biomolecules: Molecular imprinting and micropatterning poly(ethylene glycol)-containing films. *Polymers for Advanced Technologies* **13**, 798-816 (2002).
2. Hart, B. R. & Shea, K. J. Molecular imprinting for the recognition of N-terminal histidine peptides in aqueous solution. *Macromolecules* **35**, 6192-6201 (2002).
3. Tan, Y. Y. & Vanekenstein, G. O. R. A. A Generalized Kinetic-Model for Radical-Initiated Template Polymerizations in Dilute Template Systems. *Macromolecules* **24**, 1641-1647 (1991).
4. Shi, H. Q., Tsai, W. B., Garrison, M. D., Ferrari, S. & Ratner, B. D. Template-imprinted nanostructured surfaces for protein recognition. *Nature* **398**, 593-597 (1999).
5. Shi, H. Q. & Ratner, B. D. Template recognition of protein-imprinted polymer surfaces. *Journal of Biomedical Materials Research* **49**, 1-11 (2000).
6. Lustig, S. R. & Peppas, N. A. Solute Diffusion in Swollen Membranes .9. Scaling Laws for Solute Diffusion in Gels. *Journal of Applied Polymer Science* **36**, 735-747 (1988).
7. Canal, T. & Peppas, N. A. Correlation between Mesh Size and Equilibrium Degree of Swelling of Polymeric Networks. *Journal of Biomedical Materials Research* **23**, 1183-1193 (1989).
8. Podual, K., Doyle, F. J. & Peppas, N. A. Dynamic behavior of glucose oxidase-containing microparticles of poly(ethylene glycol)-grafted cationic hydrogels in an environment of changing pH. *Biomaterials* **21**, 1439-1450 (2000).
9. Podual, K., Doyle, F. J. & Peppas, N. A. Preparation and dynamic response of cationic copolymer hydrogels containing glucose oxidase. *Polymer* **41**, 3975-3983 (2000).
10. Podual, K., Doyle, F. J. & Peppas, N. A. Glucose-sensitivity of glucose oxidase-containing cationic copolymer hydrogels having poly(ethylene glycol) grafts. *Journal of Controlled Release* **67**, 9-17 (2000).