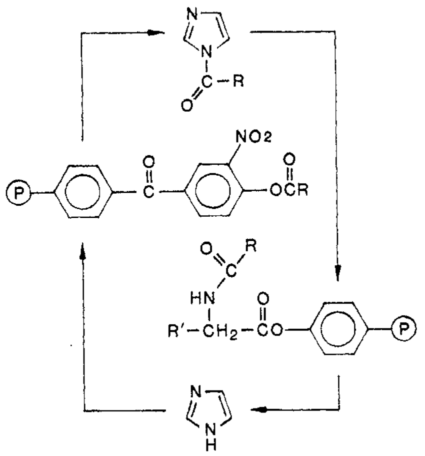
free imidazole is then recycled through the loop until the process is virtually 100 percent complete. The blocking agent of the amine group is then removed quantitatively with trifluoroacetic acid and the process repeated with the next amino acid desired. Using the shadchen techniques, Patchornik and Yechiel Shai synthesized the blocked form of the pentapeptide Leu-enkephalin with a purity of 99 percent. "With this synthesis," he says, "we proved two things: that it worked, and that it worked beautifully."



Shadchen chemistry can also be used to recharge the system. Polysulfonyl chloride, for example, can be used as polymer II to make anhydrides of the appropriate amino acids; the anhydrides then acylate polymer I. (The polysulfonyl chloride can be regenerated with chlorosulfonic acid.) Polysulfonyl chloride can be used in a similar fashion to convert phosphoric acid derivatives to phosphoric anhydrides for the synthesis of oligonucleotides. It can also be used to convert nitrates to their anhydrides, producing a useful nitrating agent.

The great potential utility of shadchen chemistry, Patchornik says, lies in the fact that more than 40 percent of all organic chemistry reactions can be written in the form

$$B + A{-}\alpha \rightarrow B{-}A + \alpha$$

which is the form of the shadchen reaction with α as the matchmaker molecule. Patchornik has patented the process and is now attempting to license it. The great specificity and high yields associated with each of the techniques he describes should make them very useful not only in industrial processes but also for the laboratory chemist.—THOMAS H. MAUGH II

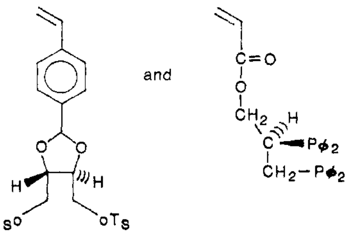
Additional Reading

1. B. J. Cohen, M. A. Kraus, A. Patchornik, *J. Am. Chem. Soc.* **103**, 7620 (1981).
2. A. Patchornik and B. J. Cohen, in *Perspectives in Peptide Chemistry*, A. Eberle, R. Geiger, T. Weiland, Eds. (Karger, Basel, 1981), pp. 118–128.

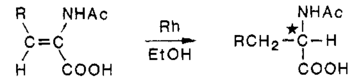
Stereoselective Synthesis of Amino Acids

New chiral monomers that can be used in the stereoselective synthesis of amino acids were described at the 28th Macromolecular Symposium of the International Union of Pure and Applied Chemistry* by John K. Stille of Colorado State University. L-Amino acids are very difficult to synthesize now and have generally been obtained from natural products or by cloning techniques. Stille's work could establish an industrial synthetic route to some that are in short supply.

Stille first synthesized monomers such as†:



These can be copolymerized with hydroxyethyl methacrylate and ethylene methacrylate to give polymers that swell in ethanol and that contain ligand sites onto which rhodium can be exchanged. With the use of the polymer-bound rhodium, amino acids of more than 90 percent optical purity can be synthesized by the hydrogenation of *Z*-acylaminocinnamic acid derivatives:



$$\underset{H}{\overset{R}{}}\!\!>C{=}C\!<\!\underset{COOH}{\overset{NHAc}{}} \xrightarrow[EtOH]{Rh} RCH_2{-}\overset{\overset{NHAc}{|}}{\underset{\underset{COOH}{|}}{\overset{\star}{C}}}{-}H$$

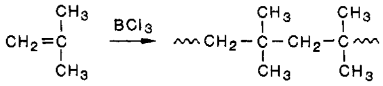
The polymeric catalyst can be recovered and used again. A polymer carrying the enantiomeric compounds can be used to produce D-amino acids in similar high yields.

The same polymers with rhodium replaced by platinum can also be used to perform chiral hydroformylations, a process that is useful in drug synthesis, among other things. In this case, the polymers produce an optical purity of 70 to 90 percent, compared to the 20 to 40 percent obtained by conventional techniques.

Novel Materials from Telechelic Prepolymers

Interesting new materials can be obtained by copolymerizing conventional monomers with telechelic prepolymers prepared by the inifer method, reported Joseph P. Kennedy of the University of Akron. Telechelic prepolymers (from the Greek for "far claws") are soluble polymers, with a mass of 500 to 20,000 daltons, that carry one or more functional end groups; they can be linear or branched. The term inifer (from *ini*tiator-trans*fer* agent) was coined by Kennedy to denote compounds capable both of initiating polymerization and terminating a growing polymer chain by transferring the active species to start a second chain.

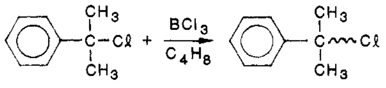
Most of Kennedy's studies have been performed with polyisobutylene (PIB), an inexpensive polymer that generally does not undergo side reactions during polymerization and that has good physical properties. It is readily formed by a carbocationic process with boron trichloride as a catalyst:



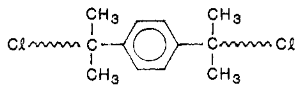
$$CH_2{=}\underset{\underset{CH_3}{|}}{\overset{\overset{CH_3}{|}}{C}} \xrightarrow{BCl_3} \sim CH_2{-}\underset{\underset{CH_3}{|}}{\overset{\overset{CH_3}{|}}{C}}{-}CH_2{-}\underset{\underset{CH_3}{|}}{\overset{\overset{CH_3}{|}}{C}}\sim$$

A short (or long) polymer formed in this manner has no reactive end groups.

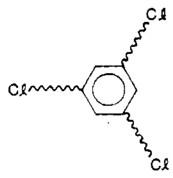
When cumyl chloride is used as a monofunctional inifer (minifer), however, it is possible to prepare PIB of controlled size with a functional end group:



With the corresponding binifer, it is possible to obtain two functional end groups:



Trinifers can also be used:



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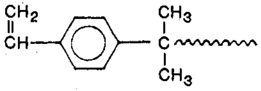
*Held at the University of Massachusetts, Amherst, 12 to 16 July 1982.

†Ts = tosylate; φ = phenyl; Ac = acyl; EtOH = ethanol; PVP = polyvinylpyrrolidone.

The reactive chlorines on the end of the PIB prepolymer can then be converted to other functional groups by more or less conventional chemistry.

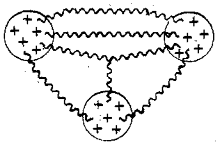
If a different minifer is used, it is possible to make PIB with one styryl head group:



A graft copolymer of this monomer with methyl methacrylate, for example, produces optically clear sheets that are flexible rather than rigid like pure polymethyl methacrylate.

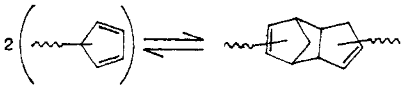
Kennedy has also synthesized telechelic prepolymers with two and three styryl head groups. These can be copolymerized with vinyl acetate or vinyl pyrrolidone, for example, to give amphiphilic networks in which the hydrophilic vinyl acetate or vinyl pyrrolidone chains are cross-linked by the hydrophobic PIB. These networks do not dissolve in water or organic solvents, but they do swell. The amount of swelling can be controlled by varying the ratio of the two components or the length of the PIB cross-link. The amphiphilic networks could prove useful as slow-release polymers for medical applications and perhaps also in water purification.

Kennedy and his associates have also prepared a bisphenol-PIB that can be reacted with epichlorohydrin to give epoxy resins with built in elastomeric segments that make them highly flexible. The bisphenols can also be converted to polycarbonates for the same purpose. Another useful liquid prepolymer has an olefin on each end of the PIB chain. Not only can the olefin itself be copolymerized but it can also be epoxidized, hydroborated to an alcohol, hydrosilylated, reacted with thioacids to form free carboxylic acids, and sulfonylated. The sulfonylated PIB's are very interesting, says Kennedy, because they produce "endless ionomers," polymeric networks connected by ionic domains:



By themselves, these produce optically clear rubbers that give an elongation of more than 1000 percent—a remarkable stretchability for an elastomer based on chains with a mass of only 9100 daltons.

A final, rather unusual telechelic prepolymer involves PIB's with cyclopentadienyl functional groups. The prepolymers themselves can be polymerized or extended by the reversible joining of the functional group:

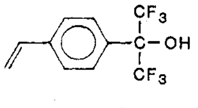


If the cyclopentadiene groups are randomly distributed along another polymer chain, thermally reversible cross-links appear. If butyl and other rubbers cross-linked in this manner are heated above 150°C, rubbery networks form; if they are heated above 180°C, the cross-links are broken so that the rubbers can be remolded.

New Polymers by Blending

When new properties are required in a polymer, it may be necessary to synthesize new materials as Kennedy has done. It is cheaper, however, if new properties can be obtained by blending polymers produced in existing facilities. Unfortunately, large molecules such as polymers are not normally miscible unless there is some form of active interaction, such as hydrogen bonding, between the two types. It is thus difficult, for example, to blend rigid polystyrene with more flexible polymers.

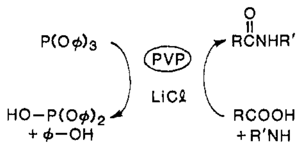
T. K. Kwei of the Industrial Technology Research Institute in Taiwan reported that styrene can be modified easily to produce exothermic interactions that promote miscibility. Kwei and Eli M. Pearce and B. Y. Min of the Polytechnic Institute of New York synthesized a styrene monomer containing the strong hydrogen-bonding agent hexafluoroisopropanol:



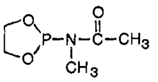
When this monomer is copolymerized with styrene monomer at a concentration of 1 to 2 mole percent, the polystyrene becomes compatible with more than 20 other polymers, Kwei says. It combines with polybutyl methacrylate, for example, to form a transparent film whose properties are intermediate between the rigid polystyrene and the softer polybutyl methacrylate. Compatibility is shown by the observation of one glass transition temperature rather than the two characteristic of an immiscible system.

Biomimetic Phosphorus Condensing Agents

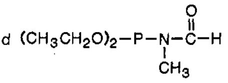
High-energy phosphorus compounds can simulate the activity of biological systems, according to Noboru Yamazaki of the Tokyo Institute of Technology. These biomimetic reactions can be used to produce many polymers. *N*-Phosphonium salts of triphenyl phosphite and pyridine, for example, can catalyze the condensation of *p*-aminobenzoic acid, isophthalic acid, and diamines to give polymers of high molecular weight. Similarly, triphenyl phosphite and lithium chloride embedded in a matrix of polyvinylpyrrolidone can catalyze the formation of polyamides of defined molecular weight, mimicking enzyme systems:



New reagents that may be very useful for synthetic purposes are phosphoramidates such as:



and



$(CH_3CH_2O)_2{-}P{-}\underset{CH_3}{N}{-}\overset{O}{\overset{\|}{C}}{-}H$

These can be used directly for polycondensation of diamines and dicarboxylic acids under relatively mild conditions. They can also be used for synthesis of oligopeptides.

Yamazaki used them, for example, to synthesize melanocyte-stimulating hormone-release-inhibiting factor (MSH-RIF), L-prolyl-L-leucylglycinamide. The tripeptide was obtained in good yield when synthesis was begun at the carboxyl terminal residue, the approach normally used in peptide synthesis to avoid racemization of the amino acids. The tripeptide was obtained in greater yield, however, and in an optically pure form, when synthesis was initiated at the amino terminal. This suggests, says Yamazaki, that the phosphoramidates do not promote racemization and can be used to elongate a peptide from either end.

Thomas H. Maugh II