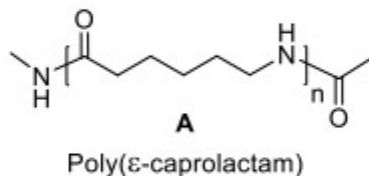


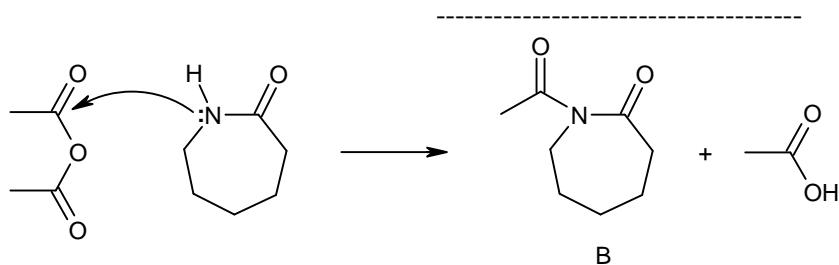
Problem 26. Ring opening polymerization (ROP)

Prof. Otto Wichterle was a famous Czech polymer chemist and inventor of soft contact lenses. He also contributed to the production of an industrially important polymer poly(ϵ -caprolactam) (silon, **A**) by ring opening polymerization of ϵ -caprolactam (hexano-6-lactam).



The polymerization reaction is usually carried out by a special type of anionic polymerization initiated by the addition of a small amount of acetic anhydride to an excess of ϵ -caprolactam. Compound **B** is formed which contains an imide bond that is more susceptible to nucleophilic attack than that of the amide bond in ϵ -caprolactam. The molar amount of **B** is the same as the molar amount of the subsequently formed polymer chains.

26.1 Draw the structure of compound **B**.

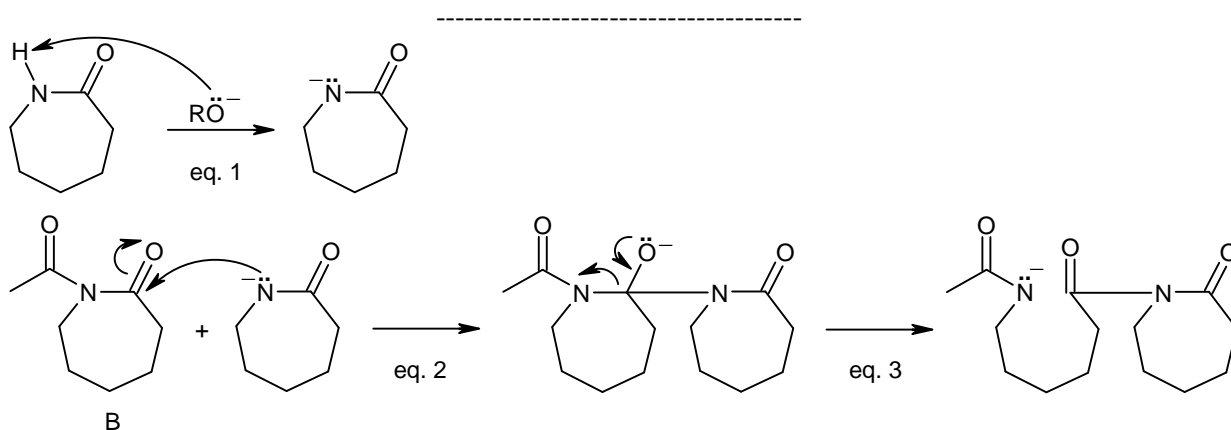


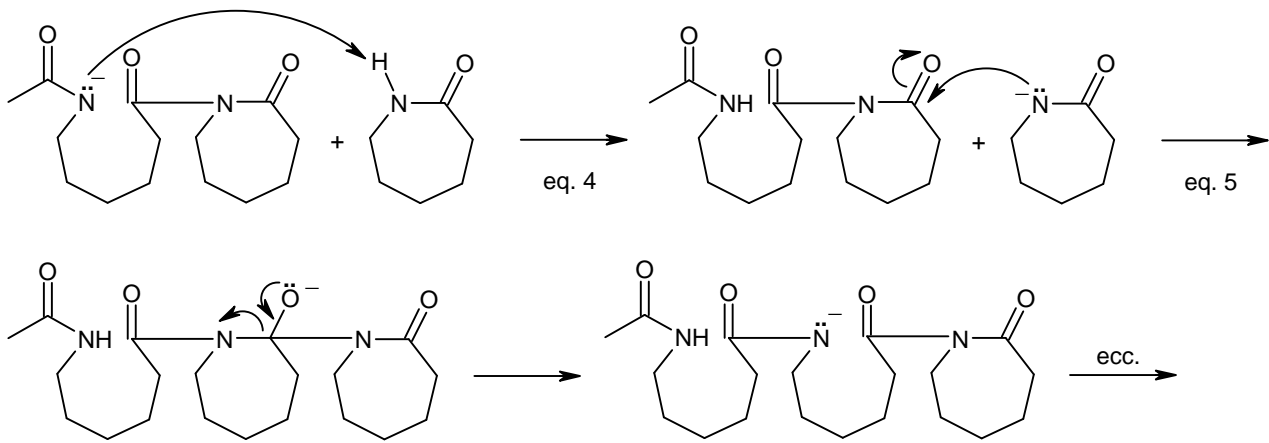
After the initial activation, a base is added to the mixture (usually an alkali metal hydride or an alkoxide) to deprotonate another ϵ -caprolactam molecule (equation 1). This initiates polymerization, which proceeds almost quantitatively typically within minutes. Propagation proceeds as follows:

- nucleophilic attack of ϵ -caprolactam anion on compound **B** (equation 2)
- ring-opening of compound **B** (equation 3)
- protonation of the product by another ϵ -caprolactam molecule, resulting in a further unreactive *N*-alkyl acetamide end (equation 4).

The other end of the molecule contains the same type of activated imide as compound **B** and is susceptible to ring opening by another ϵ -caprolactam anion, which is formed from ϵ -caprolactam during the proton transfer step (equation 5).

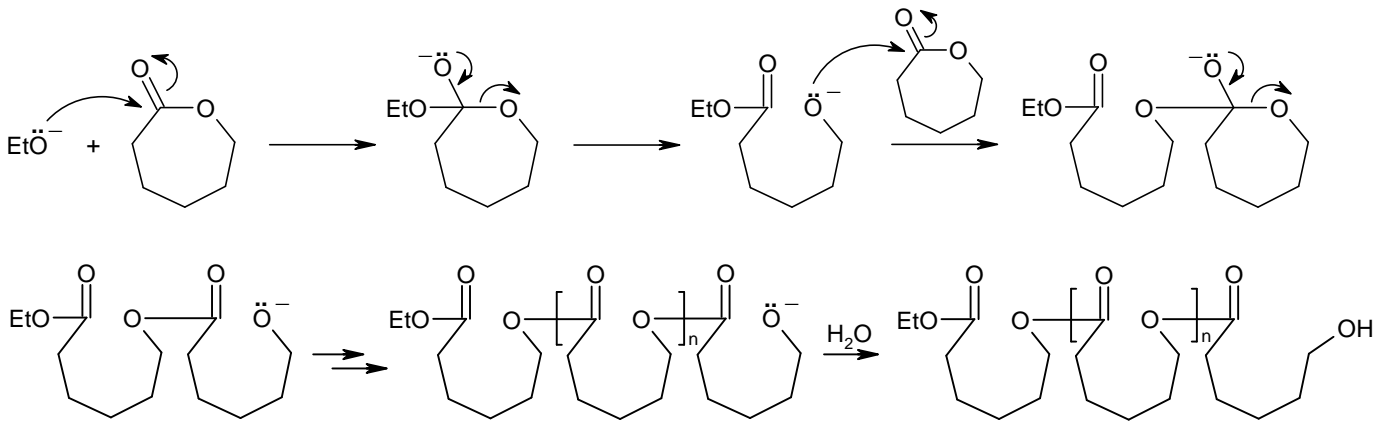
26.2 Write an arrow-pushing mechanism of the described initiation and propagation steps.





Poly(ϵ -caprolactone) is structurally similar to poly(ϵ -caprolactam), being a polyester instead of polyamide. The ring opening ϵ -caprolactone (hexano-6-lactone) polymerization can proceed by cationic, anionic or coordination mechanisms.

26.3 Draw the structure of poly(ϵ -caprolactone) prepared with sodium ethoxide as the initiator and water as the terminator.



26.4 Two kilograms of ϵ -caprolactone were polymerized with 10 g sodium ethoxide with 83% conversion. Calculate the number-average molecular weight of the obtained polymer (use atomic masses of elements rounded to whole numbers). Neglect the weight contribution of the initiator residue to the molecular weight of the polymer.

L'83% di conversione significa che l'83% di 2000 g di monomero vengono trasformati in polimero, quindi solo 1660 g di monomero reagiscono.

Il caprolattone ha formula $C_6H_{10}O_2$ e ha $PM = 114 \text{ g/mol}$, quindi le moli di monomero che reagiscono sono $1660 \text{ g} / 114 \text{ g mol}^{-1} = 14,56 \text{ mol}$

L'etossido di sodio ha formula C_2H_5ONa e ha $PM = 68 \text{ g/mol}$.

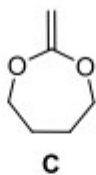
Le moli di polimero coincidono con le moli di etossido aggiunte, quindi $10 \text{ g} / 68 \text{ g mol}^{-1} = 0,1471 \text{ mol}$.

Le molecole medie di monomero per catena di polimero sono quindi $14,56 \text{ mol} / 0,1471 \text{ mol} = 99,02$.

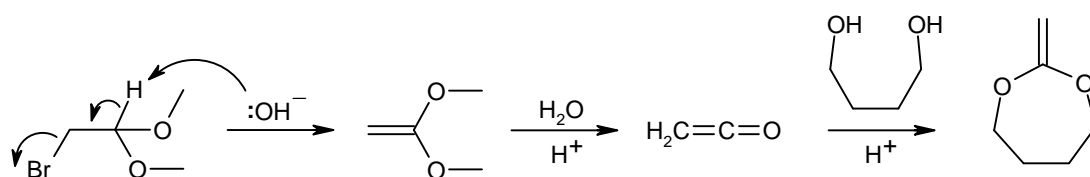
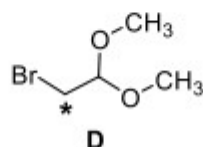
L'unità ripetente del polimero ha la stessa formula del monomero quindi ha $PM = 114 \text{ g/mol}$.

Il peso molecolare medio del polimero è quindi $99,02 \cdot 114 \text{ g/mol} = 11288 \text{ g/mol}$

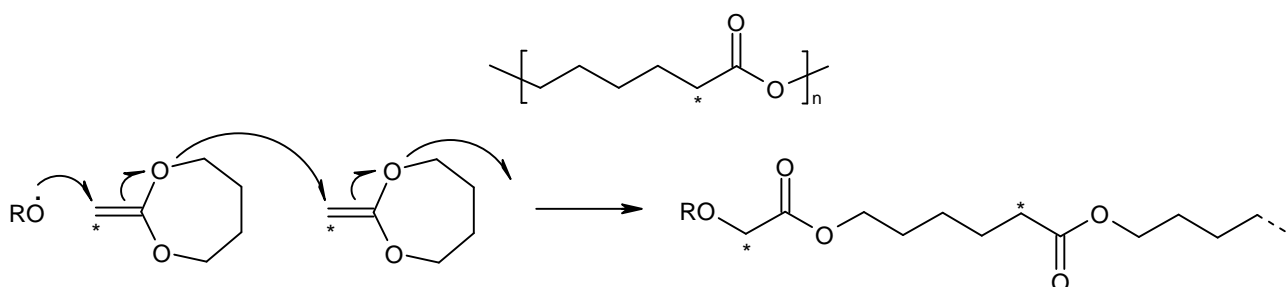
Poly(ϵ -caprolactone) can also be prepared by radical ring opening polymerization of 2-methylidene-1,3-dioxepane (**C**).



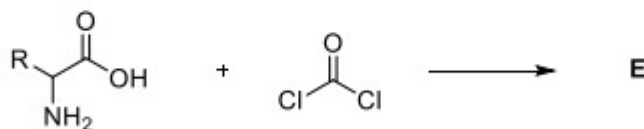
26.5 How would you synthesize precursor **C** starting from butane-1,4-diol and bromoacetaldehyde dimethyl acetal (**D**)? Write the synthetic scheme.



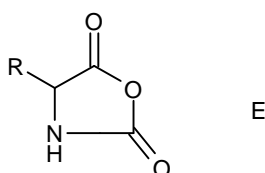
26.6 Imagine dioxepane **C** was prepared from a ^{14}C -labeled compound **D** (the labelled carbon is marked with an asterisk) and subjected to the radical polymerization reaction. Write the structure of poly(ϵ -caprolactone) and mark the radiolabelled carbon(s) with an asterisk.



Proteins are natural polyamides based on α -amino acids. In living organisms, they are synthesized by translation based on genetic information, but they can also be prepared synthetically by a nucleophile-initiated ring opening polymerization. In this case, the activated cyclic monomers, *N*-carboxyanhydrides **E** (also called Leuchs' anhydrides) are used. They can be prepared by the reaction of an α -amino acid with phosgene:

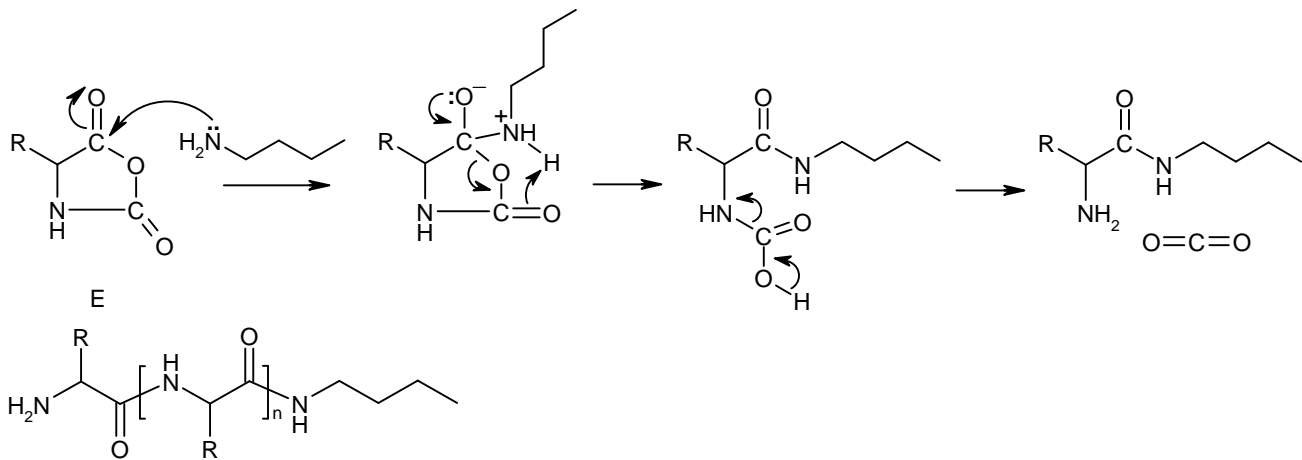


26.7 Draw the structure of the activated monomer **E** formed from α -alanine (2-aminopropanoic acid).



During polymerization, a gas is evolved and a polypeptide is formed.

26.8 Write the formula of the gas and the structure of the polymer formed from monomer **E** with butane-1-amine as initiator.



Natural proteins are formed exclusively from homochiral amino acids, i.e., only one enantiomer is present in the protein. This is vital for its 3D structure and function. Theoretically, if only a single amino acid in an enzyme is exchanged for its enantiomer, the chain changes its conformation, resulting in compromised catalytic efficiency.

Let us investigate lysozyme, a bacterial cell wall-lysing enzyme present in egg whites and tears. It contains 129 amino acid residues, 12 of which are glycines.

26.9 What would be the % yield of functional lysozyme if the proteosynthetic apparatus of the cell did not distinguish between enantiomers of the amino acids and had both enantiomers of amino acids available in equal quantities? Consider only the chirality on the α -carbon of all amino acids as the configuration on other chiral centres (in threonine and isoleucine) has only marginal effect on overall protein 3D structure. Note that only the enzyme digesting bacterial cell walls is claimed as functional.

Se 12 amminoacidi sono glicine, cioè non sono chirali, restano 117 amminoacidi chirali. Si possono formare 2^{117} diversi isomeri, ma solo uno di questi ha la configurazione S identica su tutti gli amminoacidi. La sua abbondanza percentuale è quindi $(1 / 2^{117}) \cdot 100 = (1 / 1,66 \cdot 10^{35}) \cdot 100 = 6,0 \cdot 10^{-34} \%$

26.10 In one egg there is ca 120 mg of lysozyme. How much protein (in kg) would you have to synthesize under the conditions described in 26.9 to produce enough functional lysozyme for one egg? Compare your result with the mass of the planet Earth (5.972×10^{24} kg).

E' necessario sintetizzare una quantità di lisozima $1,66 \cdot 10^{35}$ volte maggiore, quindi $120 \cdot 10^{-6} \text{ kg} \cdot 1,66 \cdot 10^{35} = 1,99 \cdot 10^{31} \text{ kg}$ di lisozima. Questa quantità è molto maggiore della massa del pianeta terra: $1,99 \cdot 10^{31} \text{ kg} / 5,972 \cdot 10^{24} \text{ kg} = 3,33 \cdot 10^6$ volte maggiore della massa della Terra. (Dato che il sole ha una massa di $1,99 \cdot 10^{30} \text{ kg}$, la massa di lisozima equivale a 10 masse solari.)

Soluzione proposta da Mauro Tonellato - Padova