



Sveučilište u Zagrebu
PRIRODOSLOVNO-MATEMATIČKI FAKULTET
Kemijski odsjek

Selektivna mehanokemijska sinteza

Lea Čolakić, mag. chem.

Izrađen prema:

J. G. Hernández, C. Bolm, *J. Org. Chem.* **82** (2017) 4007–4019.

Zagreb, 2025.



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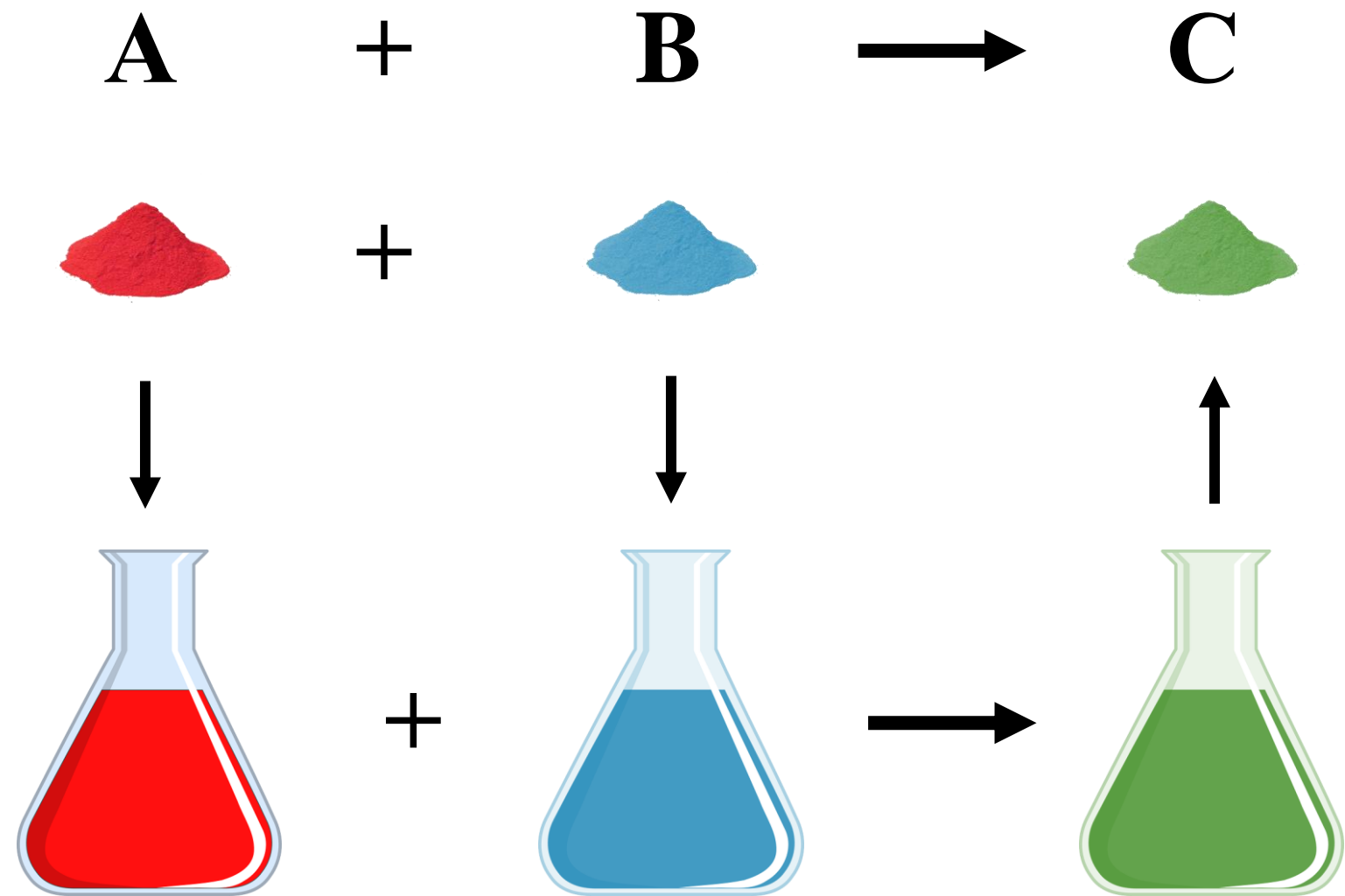
Selektivna mehanokemijska **sinteza**

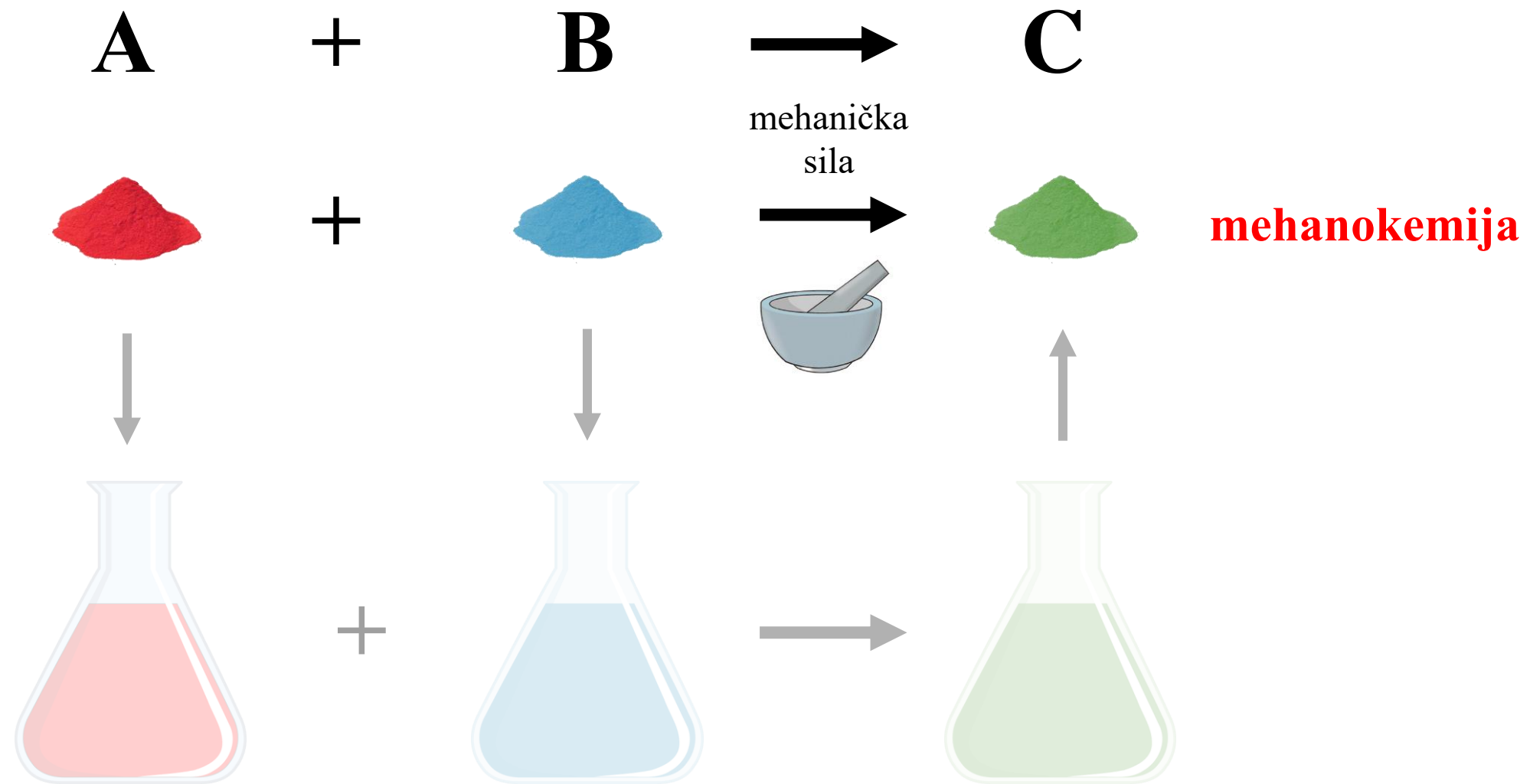
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mehanokemija = korištenje mehaničke sile za poticanje kemijskih reakcija

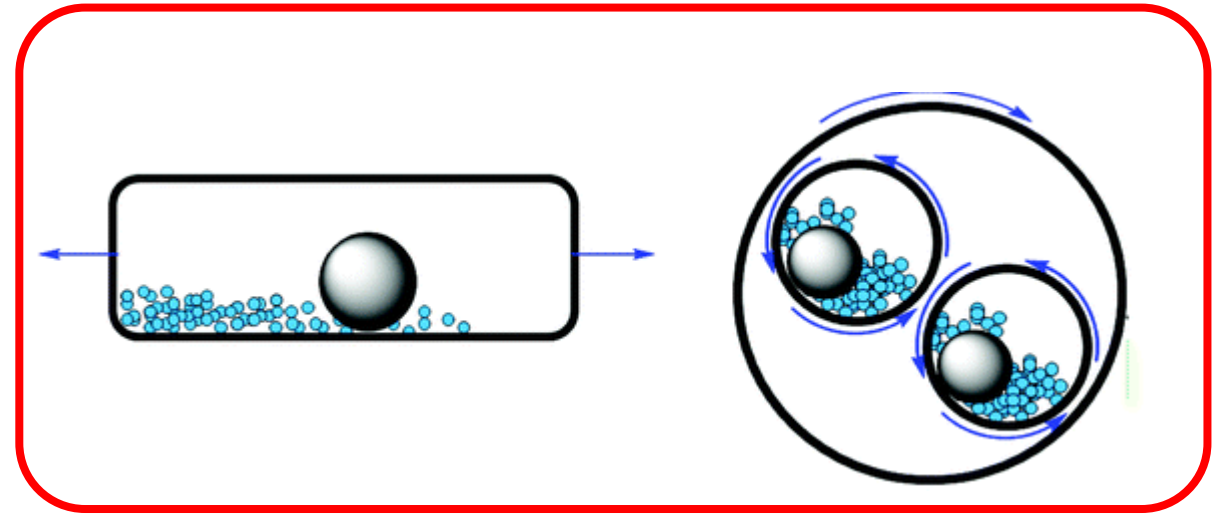
= kemijska sinteza bez otapala

= održiva i ekološki prihvatljiva metoda sinteze

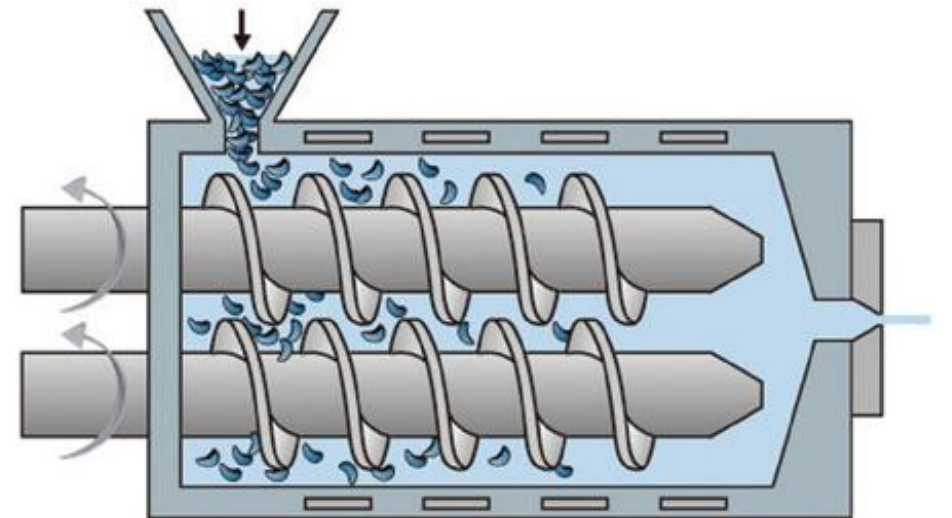


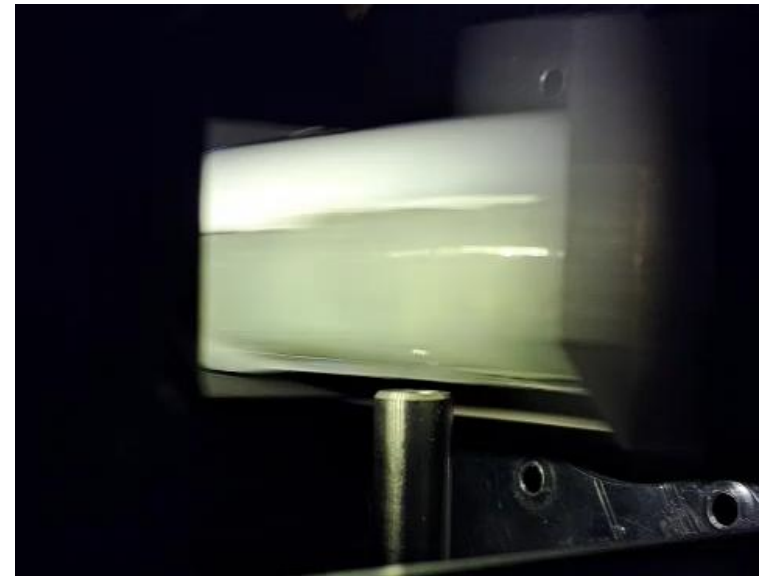
I U P A C

kemijska tehnologija koja bi mogla promijeniti svijet*



- **dugotrajno**
- **reproducibilnost**
- **kontrola**

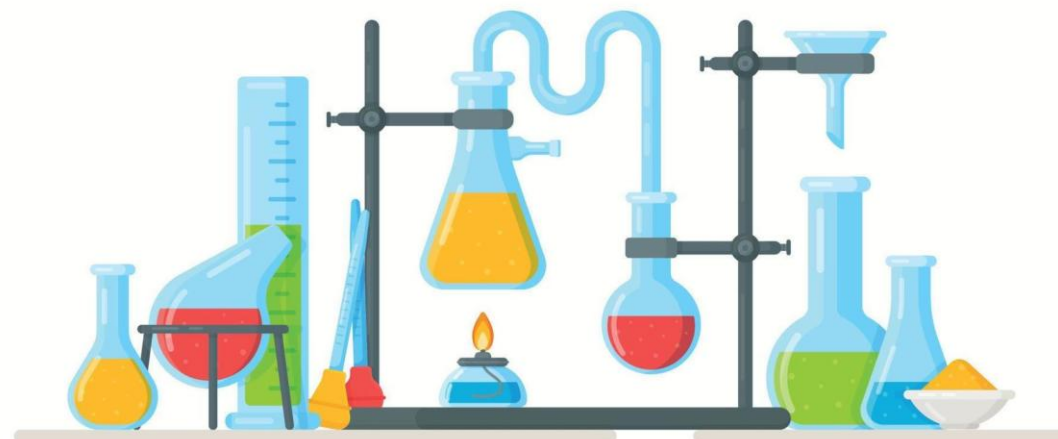




Mehanokemijska sinteza



VS

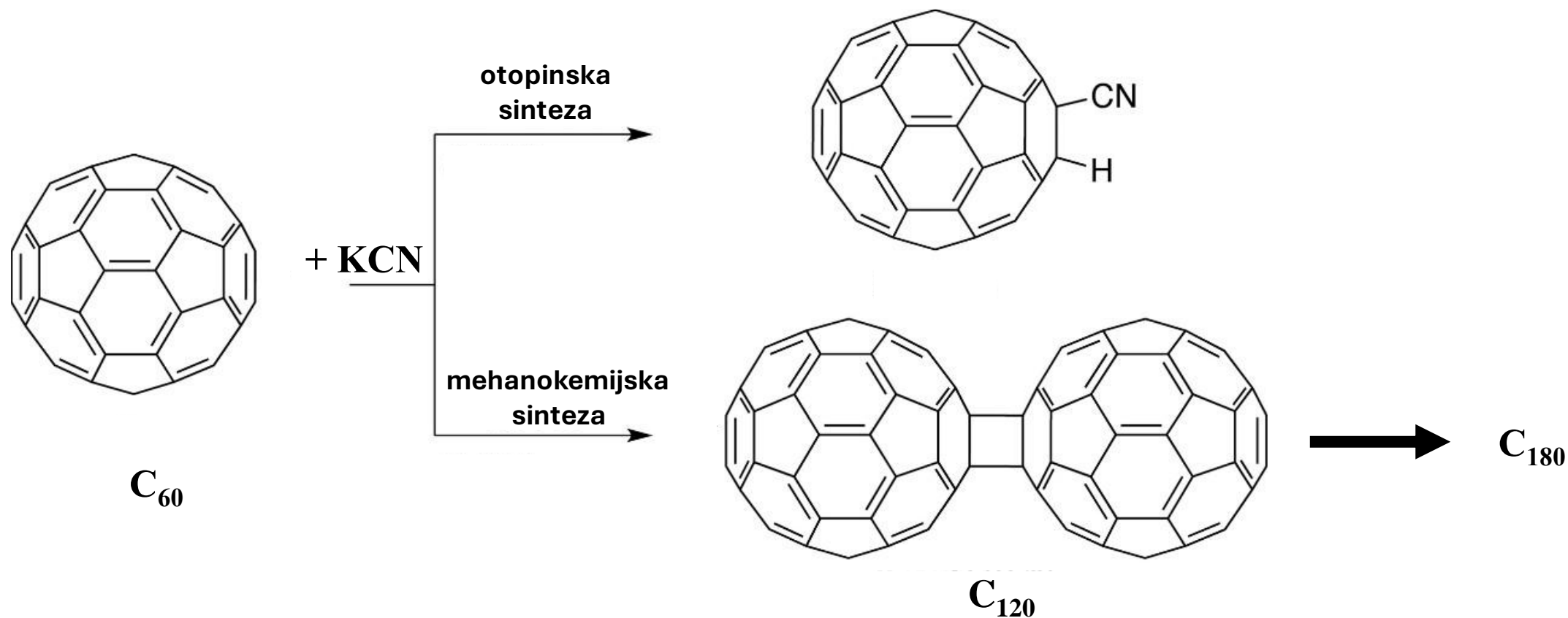


Otopinska sinteza

Mehanokemijska vs otopinska sinteza

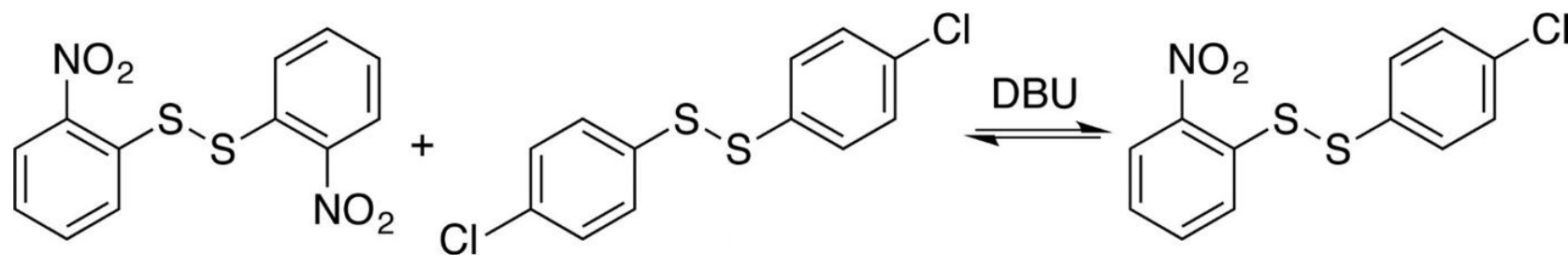
- 1996. – funkcionalizacija fulerena

– loša topljivost



Mehanokemijska vs otopinska sinteza

- ravnoteža u čvrstom stanju i otopini
 - reverzibilnost i termodinamička kontrola stvaranja disulfidnih veza



otopina

50%

50%

mljevenje

2%

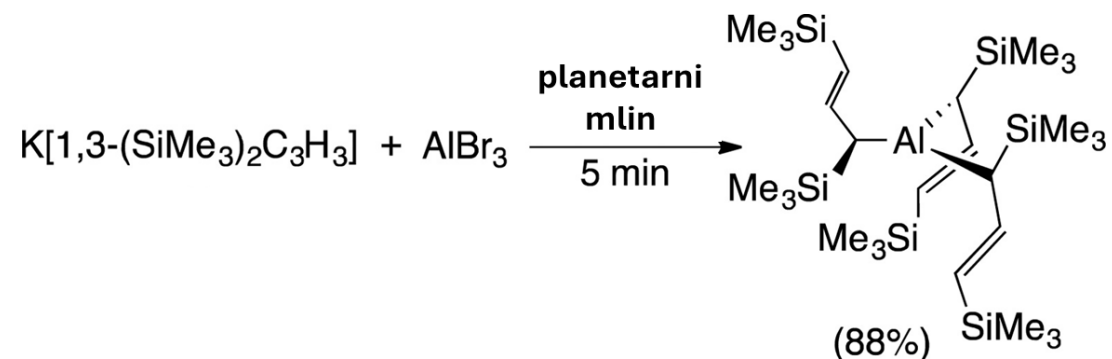
98%

veća stabilnost heterodimera u čvrstom stanju

Mehanokemijska vs otopinska sinteza

- organometalna sinteza

– sinteza nesolvatiranog tris(alil)aluminijevog kompleksa

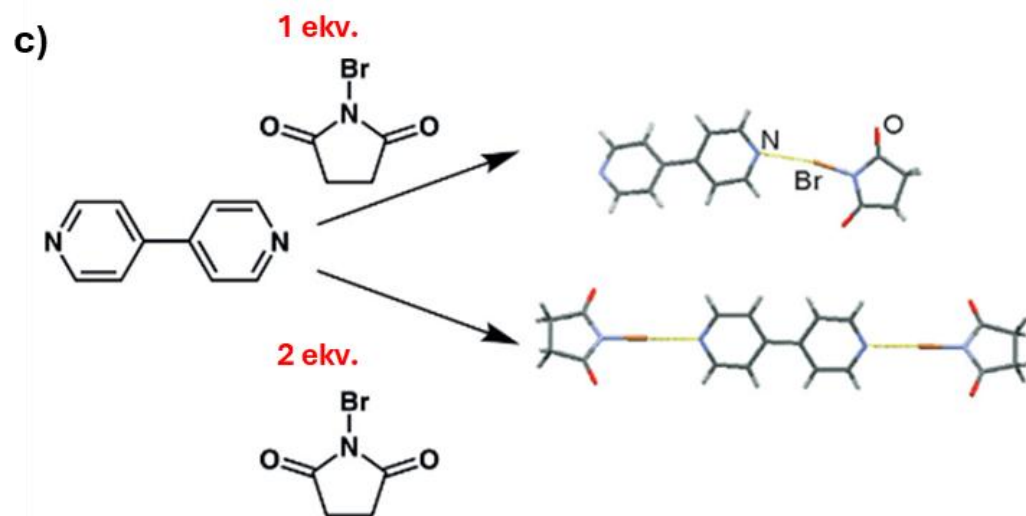


- vakuumska sinteza
- Schlenkova sinteza

Mehanokemijska vs otopinska sinteza

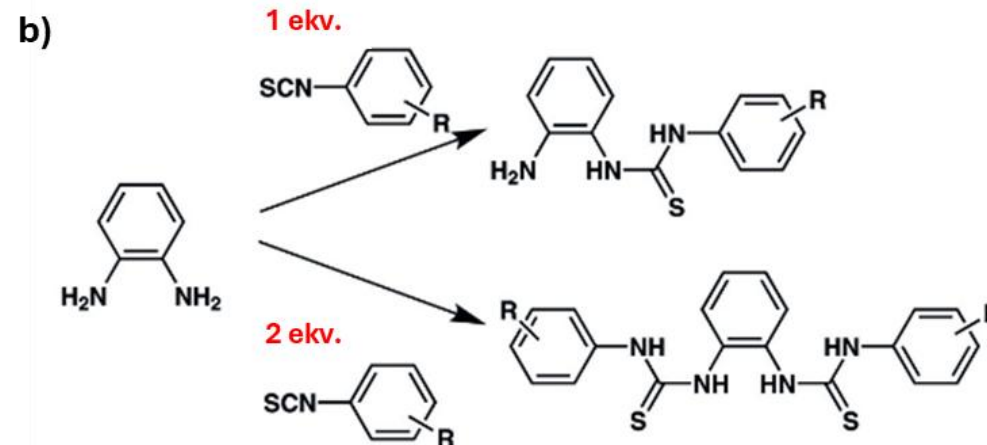
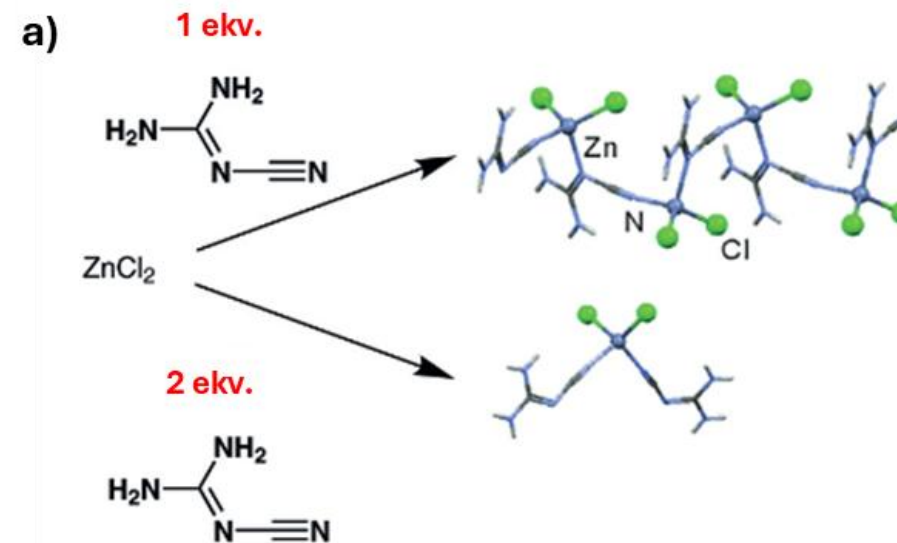
- stehiometrijska kontrola

– kokristali



d) nikotinamid (API) + dikarboksilne kiseline

– kontrola nad kristalnim oblikom djelatne
tvari ključna za učinkovitost lijekova



Stereoselektivna mehanokemijska sinteza

mehanokemija

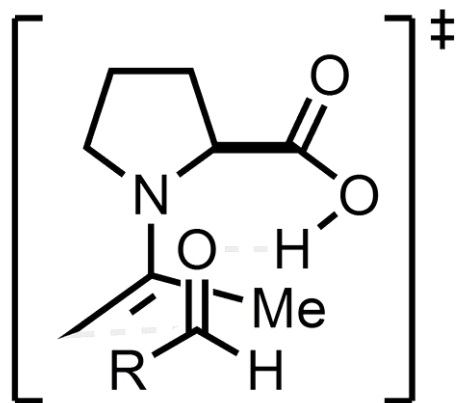
+

organokataliza

– bez otapala

– bez metala

stabilnost prijelaznog stanja?



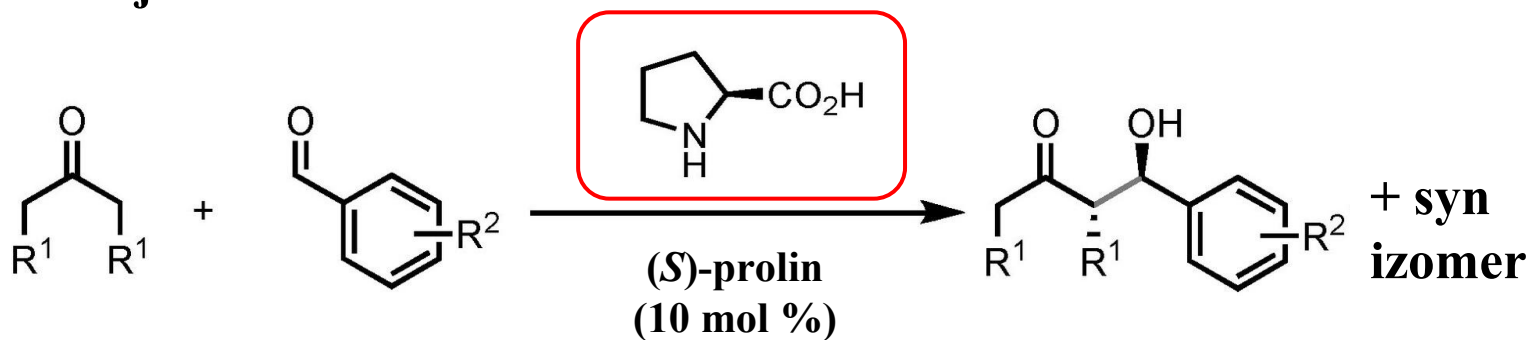
– prisutstvo otapala

– jaki udarci

Stereoselektivna mehanokemijska sinteza

- nastajanje C–C veze
– aldolna reakcija

modifikacija katalizatora

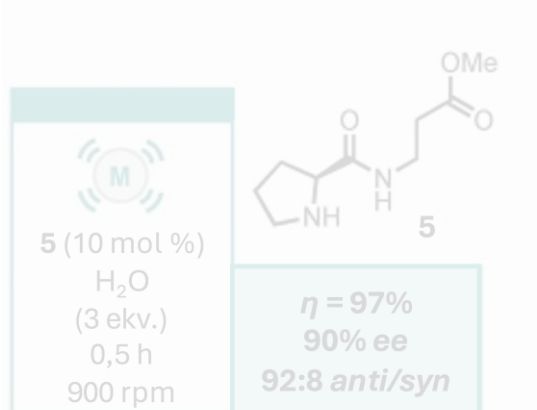
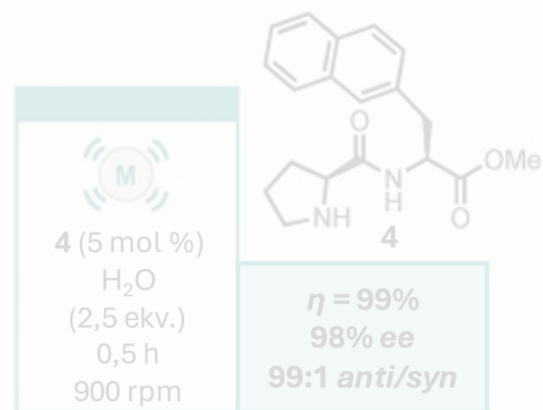
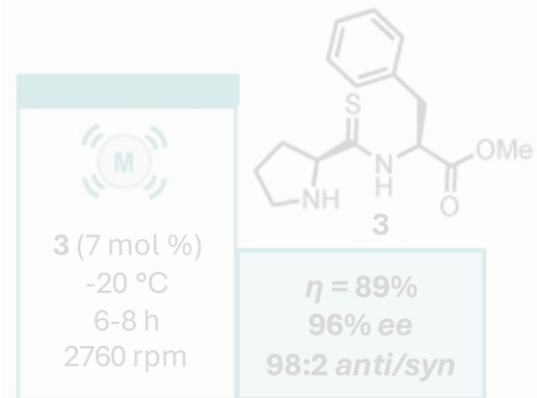
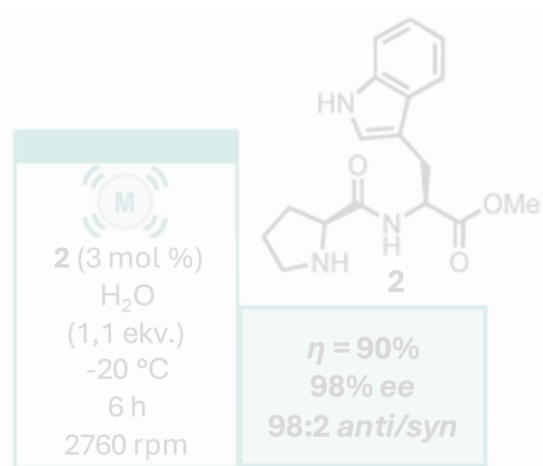
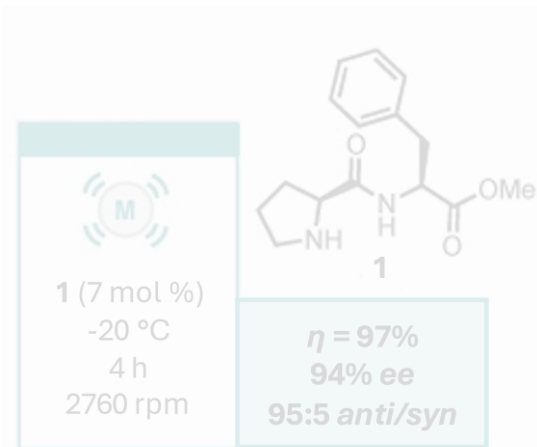
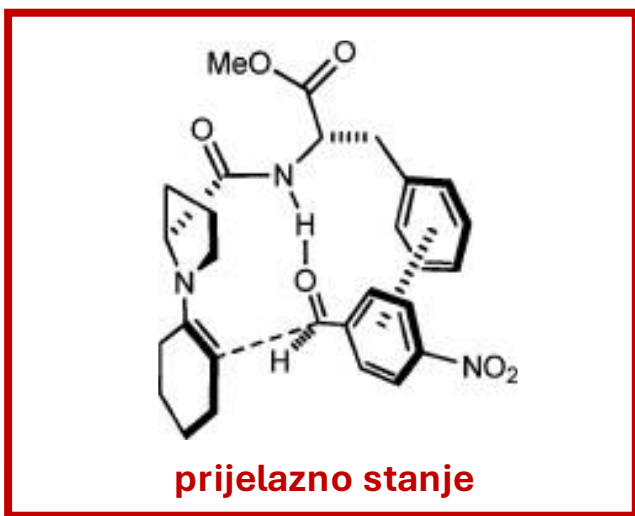
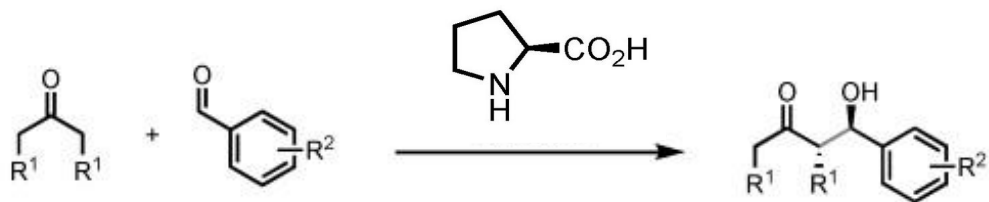


otopina
anti/syn = 89:11

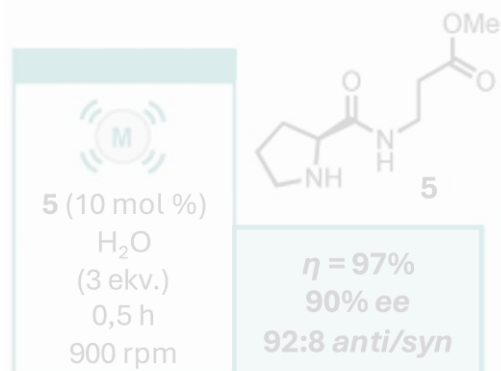
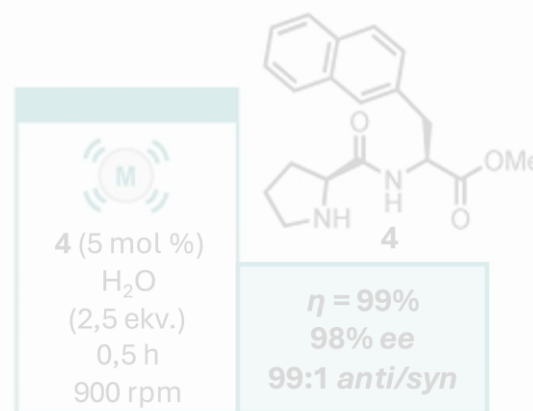
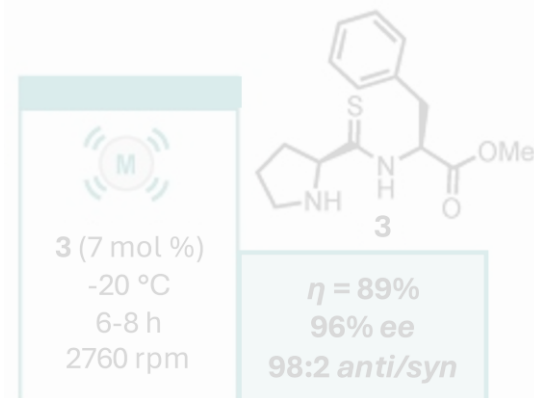
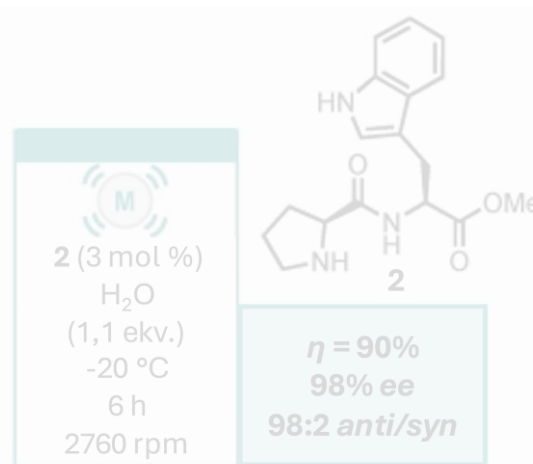
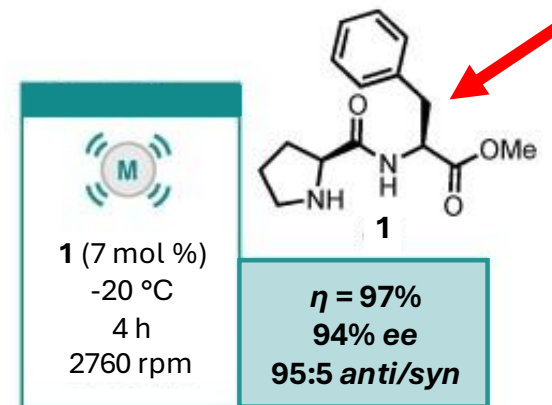
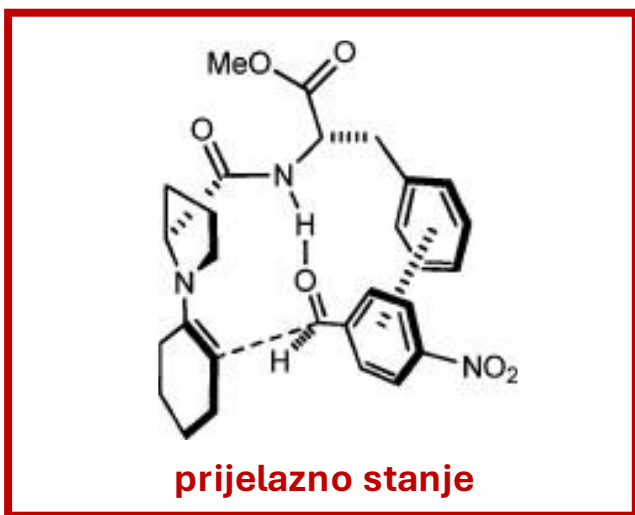
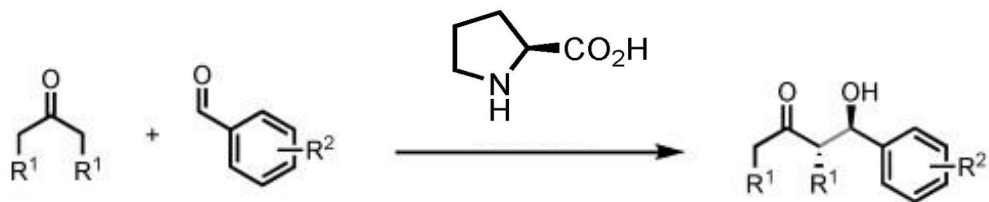
mljevenje
5.5 h
400 rpm
 $\eta = 99\%$
99% ee

mljevenje
anti/syn = 95:5

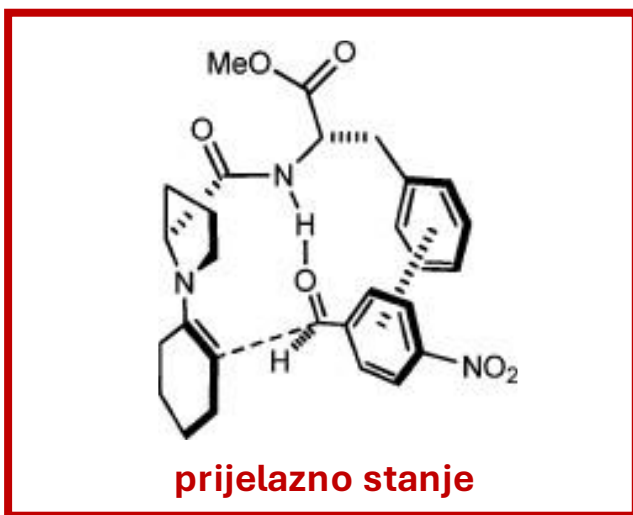
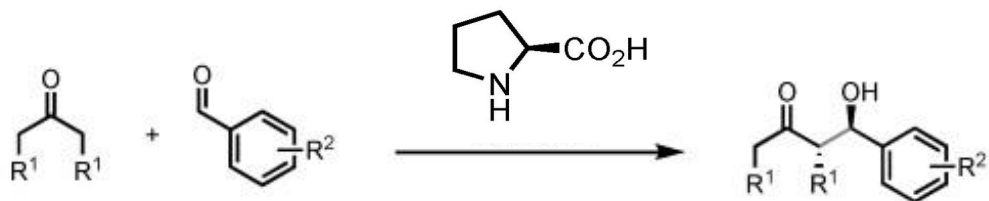
modifikacija katalizatora



modifikacija katalizatora



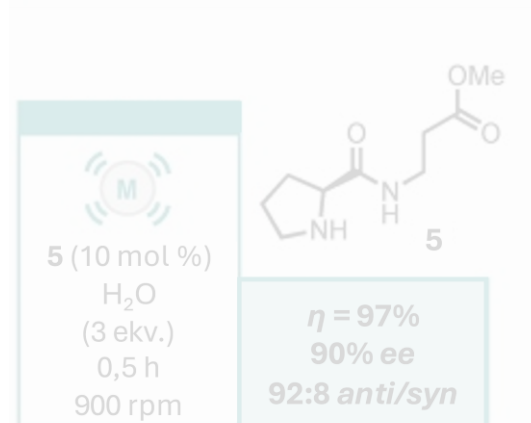
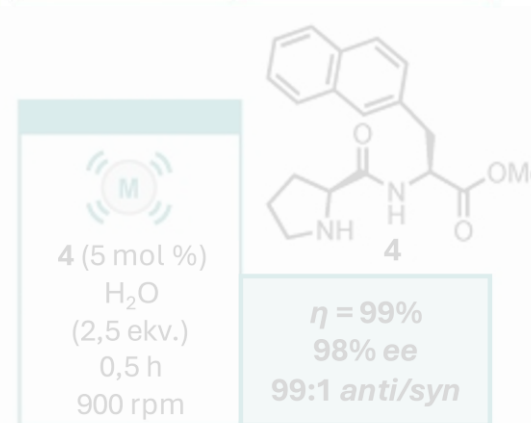
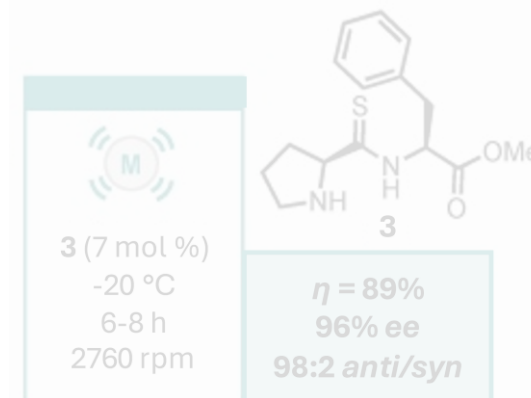
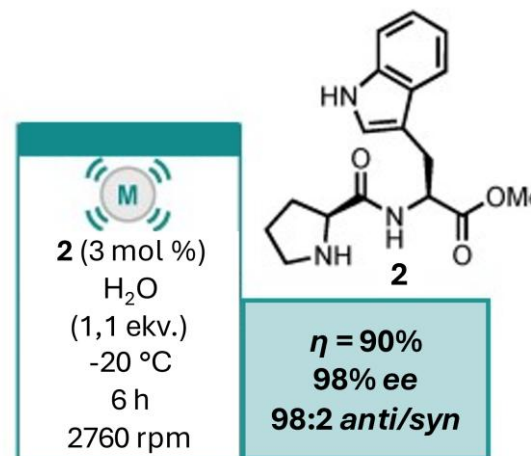
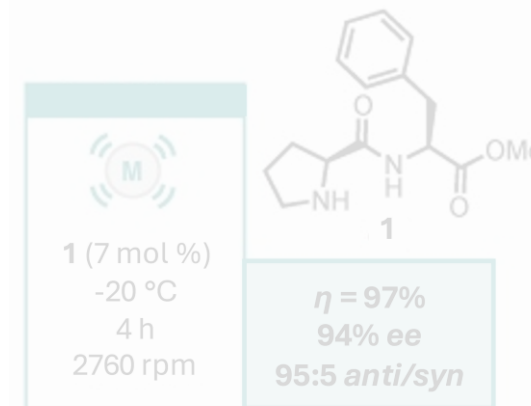
modifikacija katalizatora



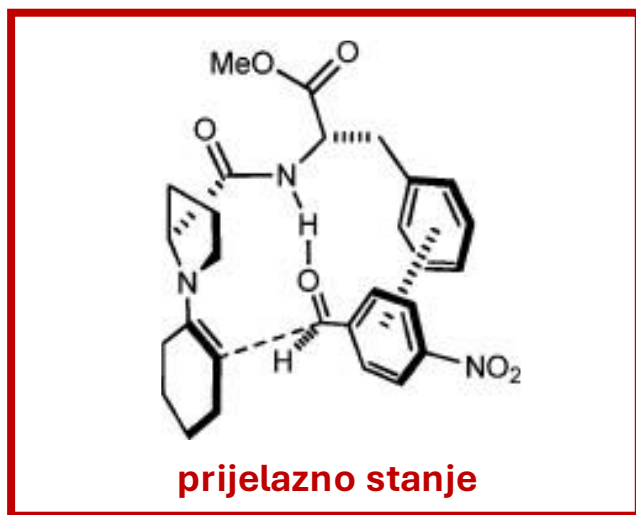
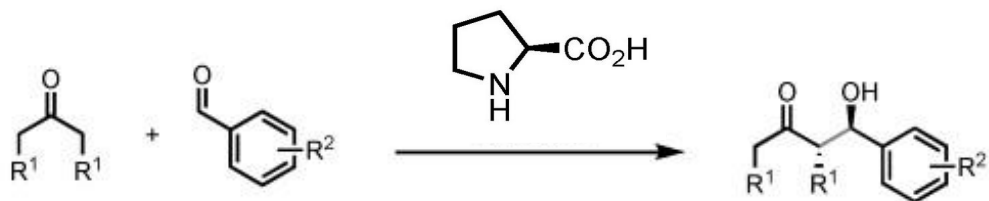
- poboljšanje lipofilnosti

odbijanje molekula vode

- reaktanti bliže



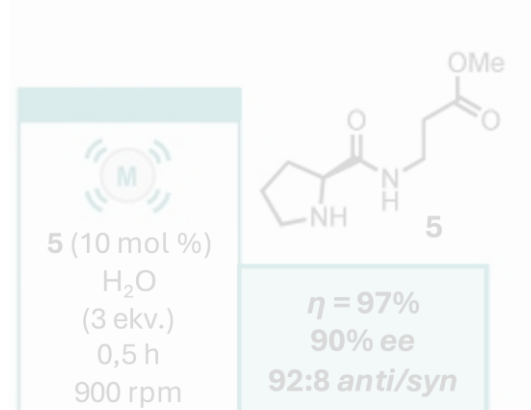
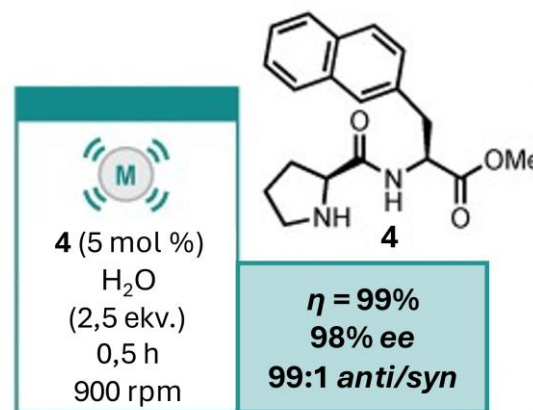
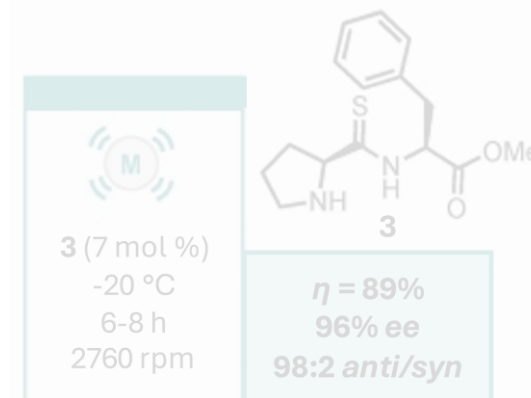
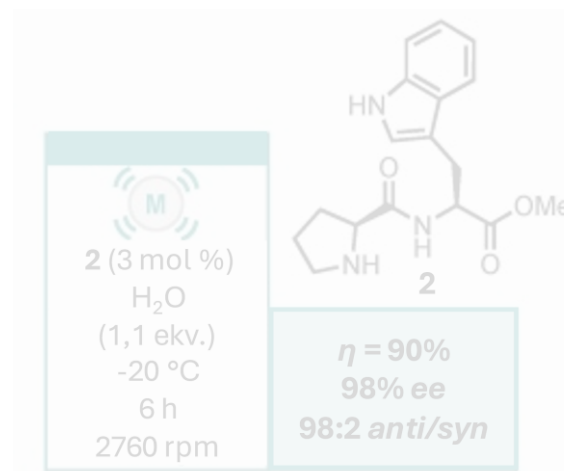
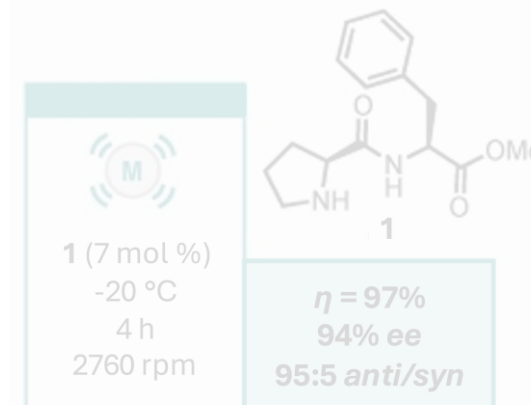
modifikacija katalizatora



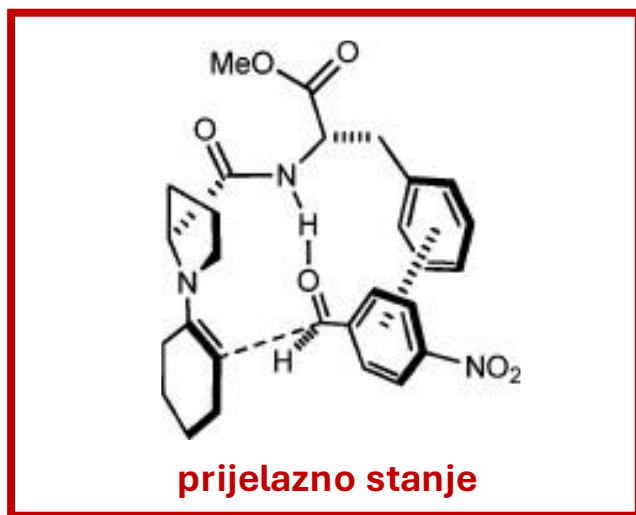
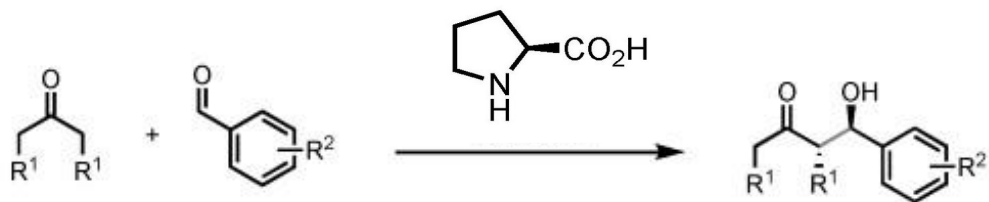
- naftalen = bolje π - π interakcije

krutost supstituenta

- bolja stereoselektivnost

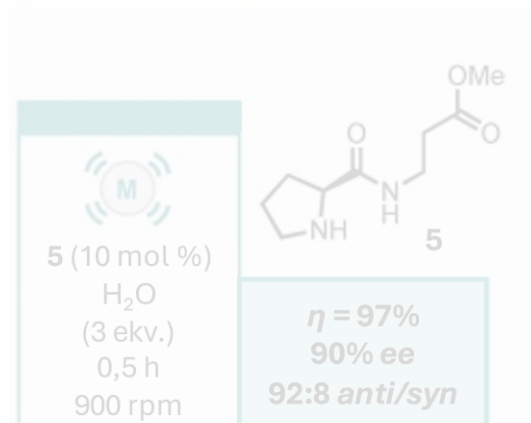
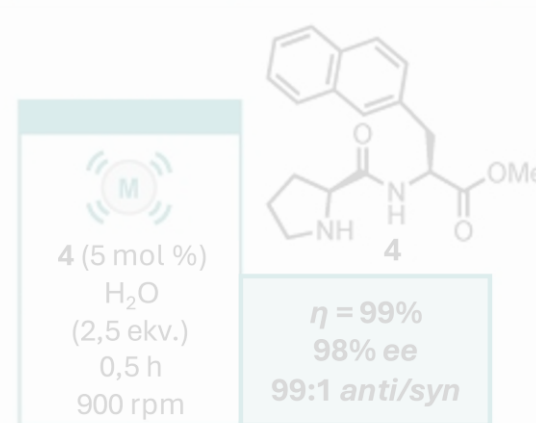
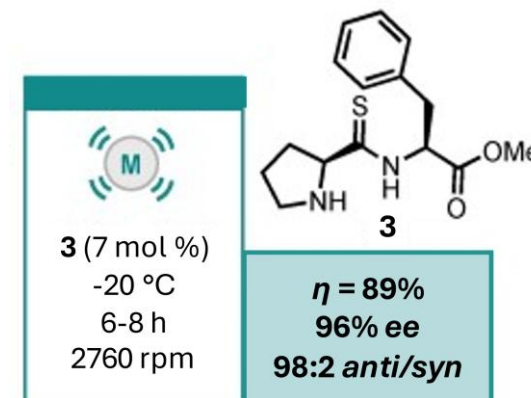
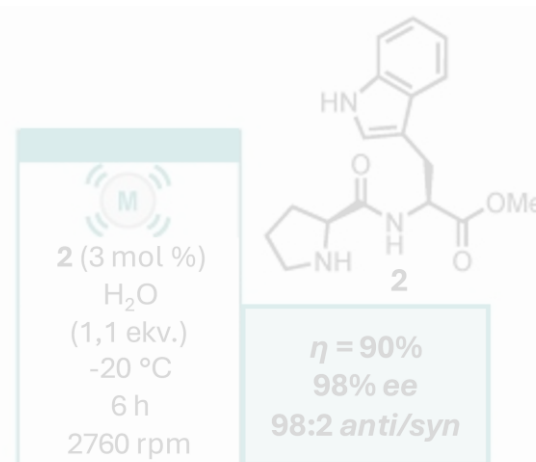
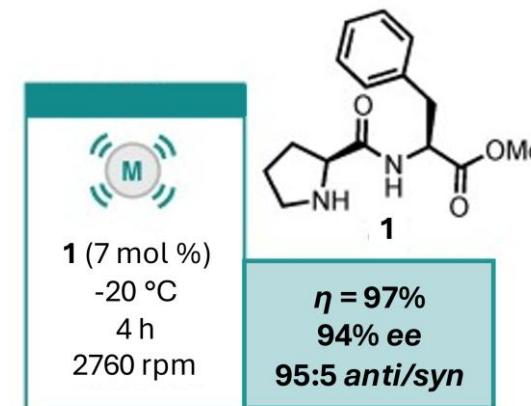


modifikacija katalizatora

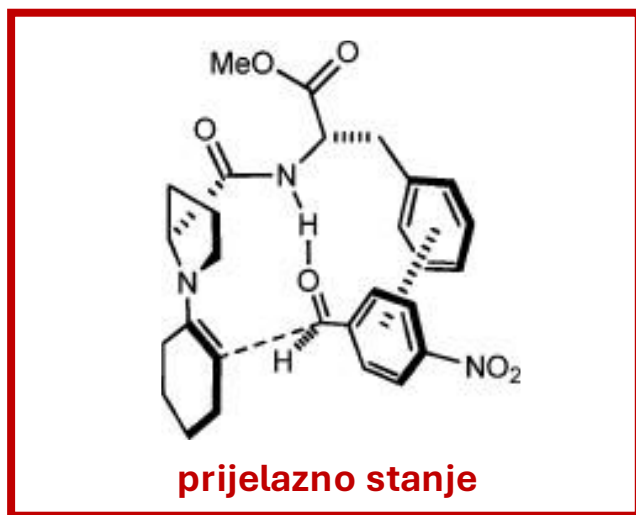
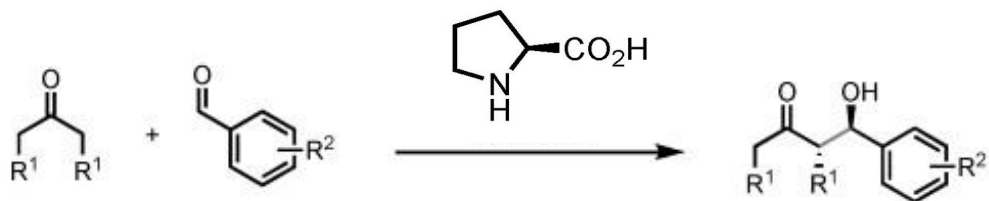


- **tioamidna veza = bolja nukleofilnost**

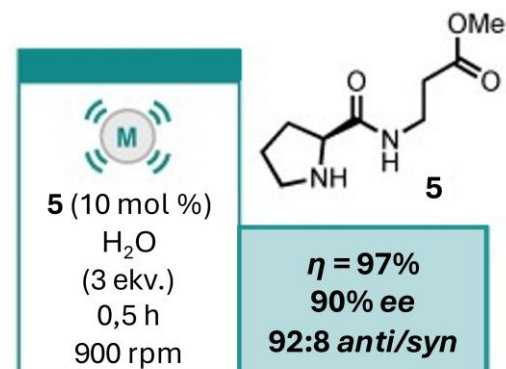
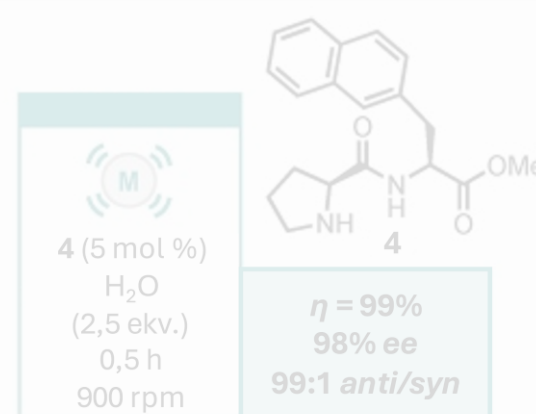
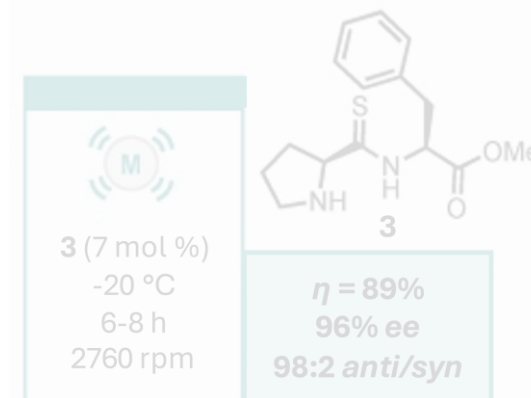
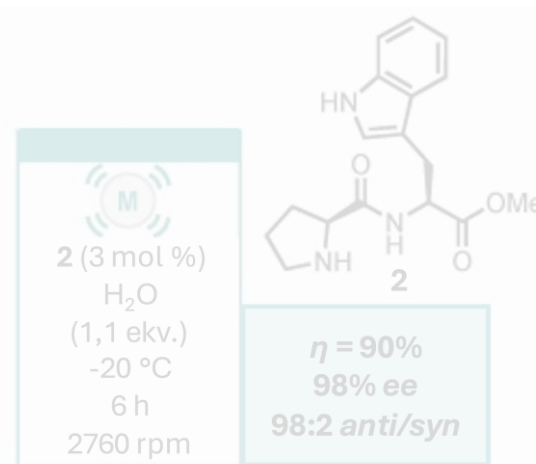
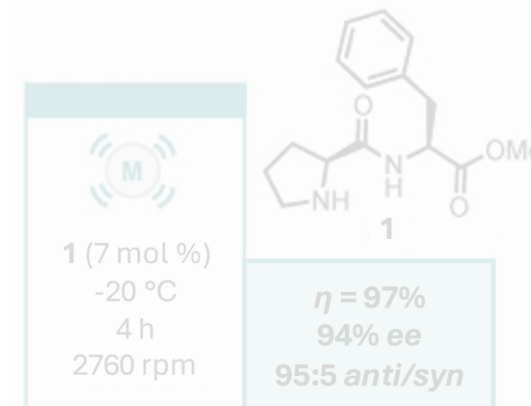
- **bolja stereoselektivnost**



modifikacija katalizatora



- α,β -dipeptid
- drugo stereogeno središte nužno

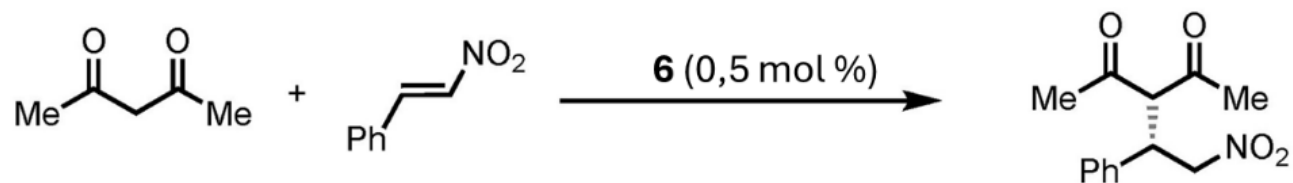


Stereoselektivna mehanokemijska sinteza

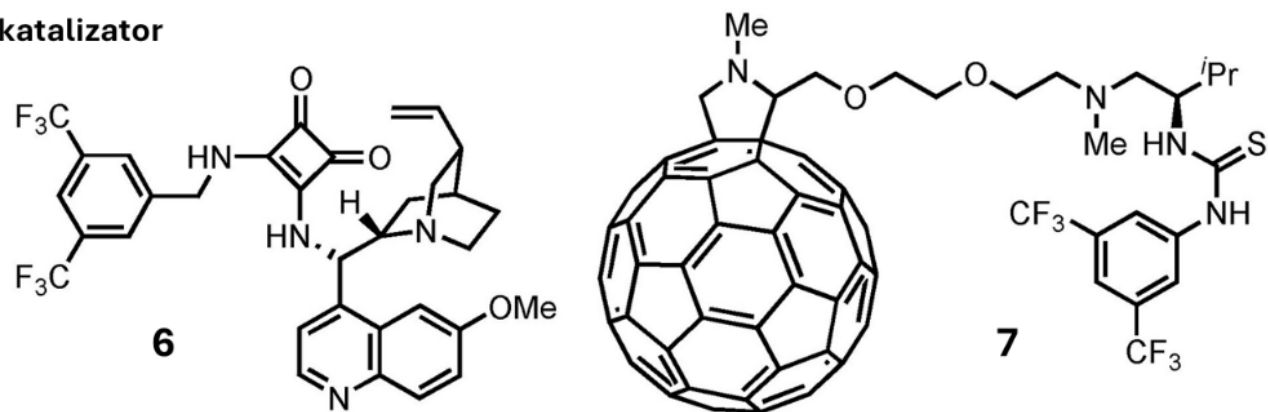
- nastajanje C–C veze

– Michaelova adicija

- kataliza pomoću supramolekulske mreže vodikovih veza
- ekstremno brzo



katalizator



otopina
otapalo: DCM
8h
RT
$\eta = 95\%$
98% ee

suho miješanje
7 (2 mol %)
8h
RT
$\eta = 87\%$
84% ee

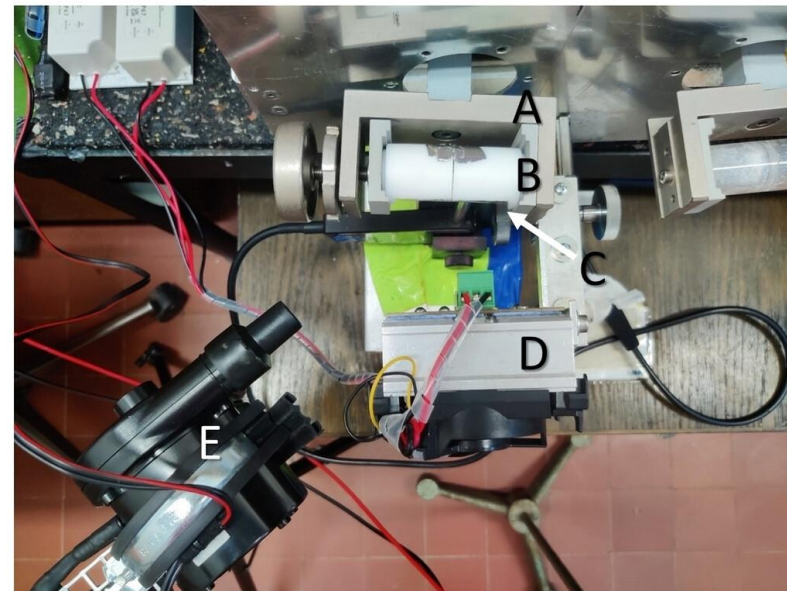
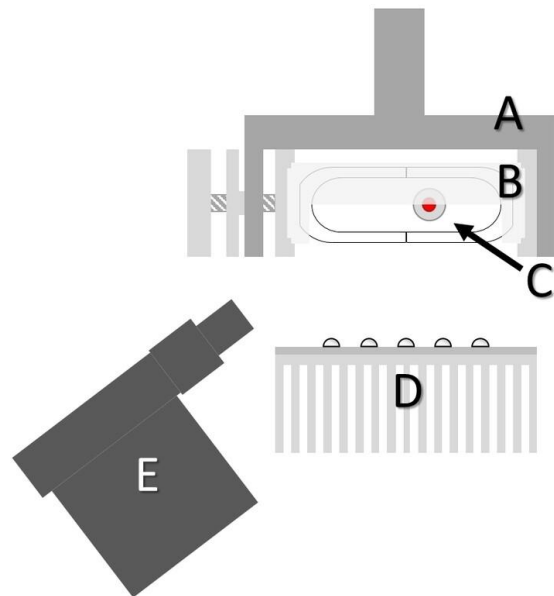
mljevenje
10 min
400 rpm
$\eta = 91\%$
97% ee

Stereoselektivna mehanokemijska sinteza

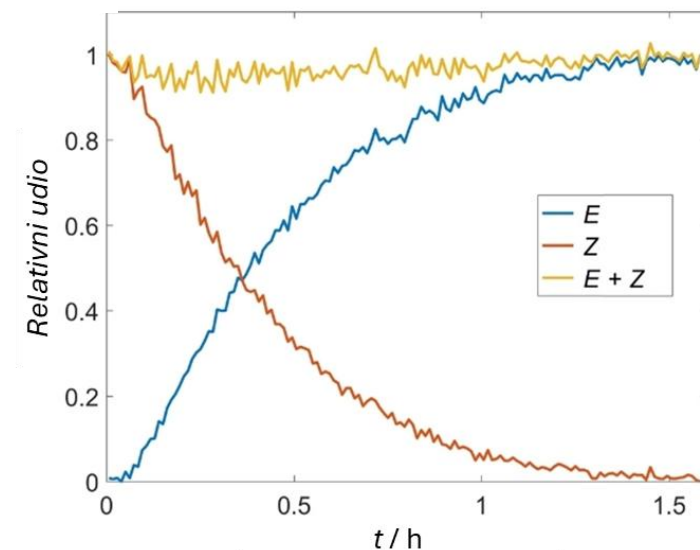
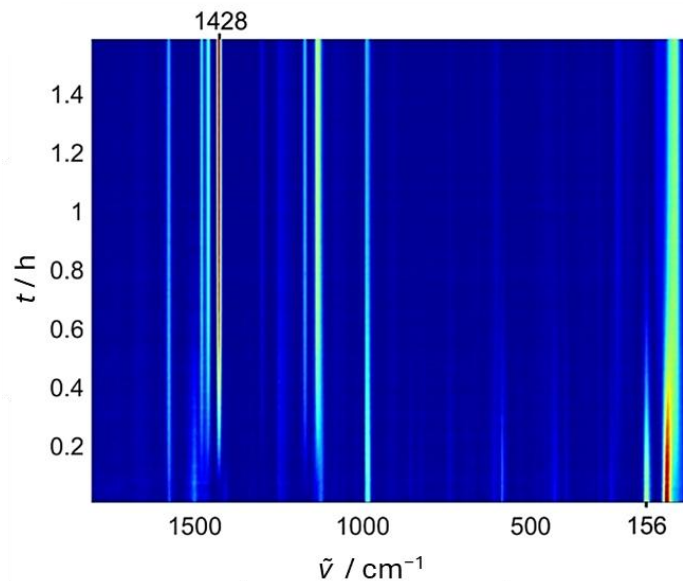
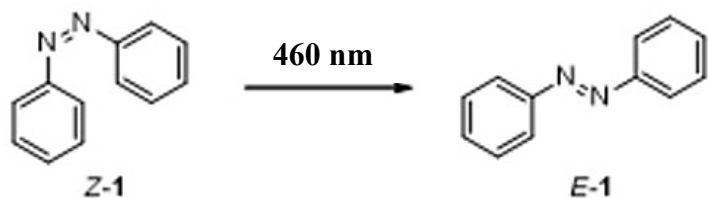


Fotomehanokemija

mehanokemija
+
LED svjetlo
+
in-situ Raman



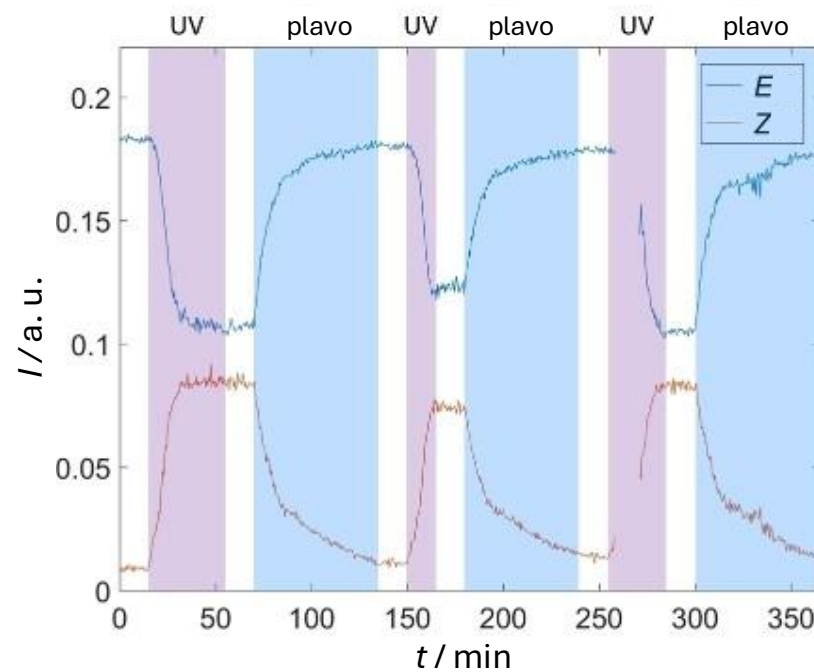
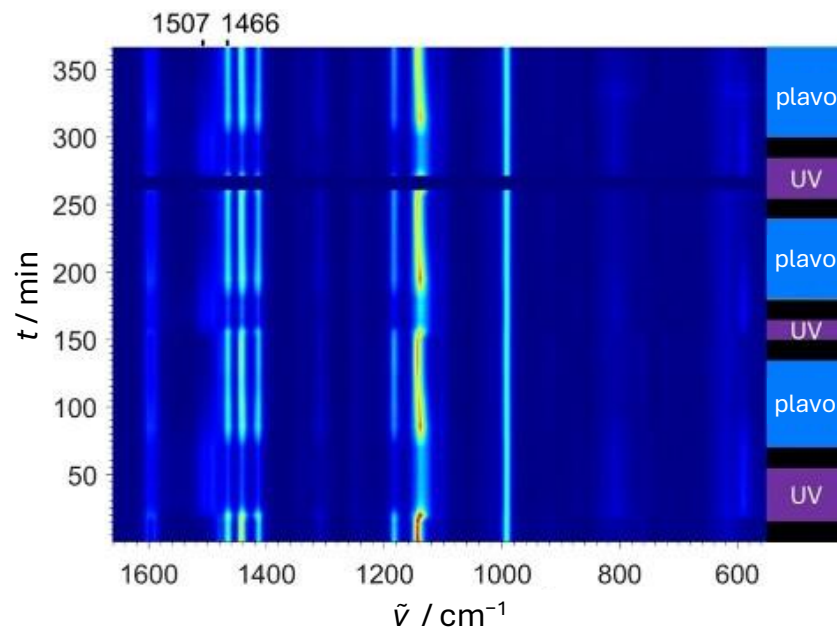
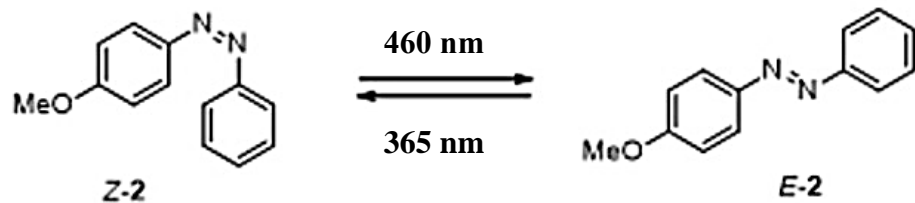
- izomerizacija azobenzena



Fotomehanokemija

mehanokemija
+
LED svjetlo
+
in-situ Raman

- izomerizacija azobenzena



Zaključak

- **Mehanokemijska sinteza**
– održiva i ekološki prihvatljiva metoda za provođenje reakcija bez otapala
- **Selektivna mehanokemijska sinteza (posebno stereoselektivna) u kombinaciji s organokatalizom, otvara nove mogućnosti za sintezu složenih organskih spojeva**
- **Kombinacija mehanokemijskih uvjeta s dodatnim izvorima energije – poboljšana selektivnost i prinos reakcija**
- **Daljnja istraživanja – razvoj naprednih tehnika karakterizacije – predvidljivost**
- **Povećavanje skale – industrijska primjena**



Hvala na pažnji!

Lea Čolakić

Laboratorij za sintezu i katalizu u čvrstom stanju

Zavod za fizičku kemiju

Institut Ruđer Bošković, Bijenička cesta 54, 10000 Zagreb



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halasz.irb.hr