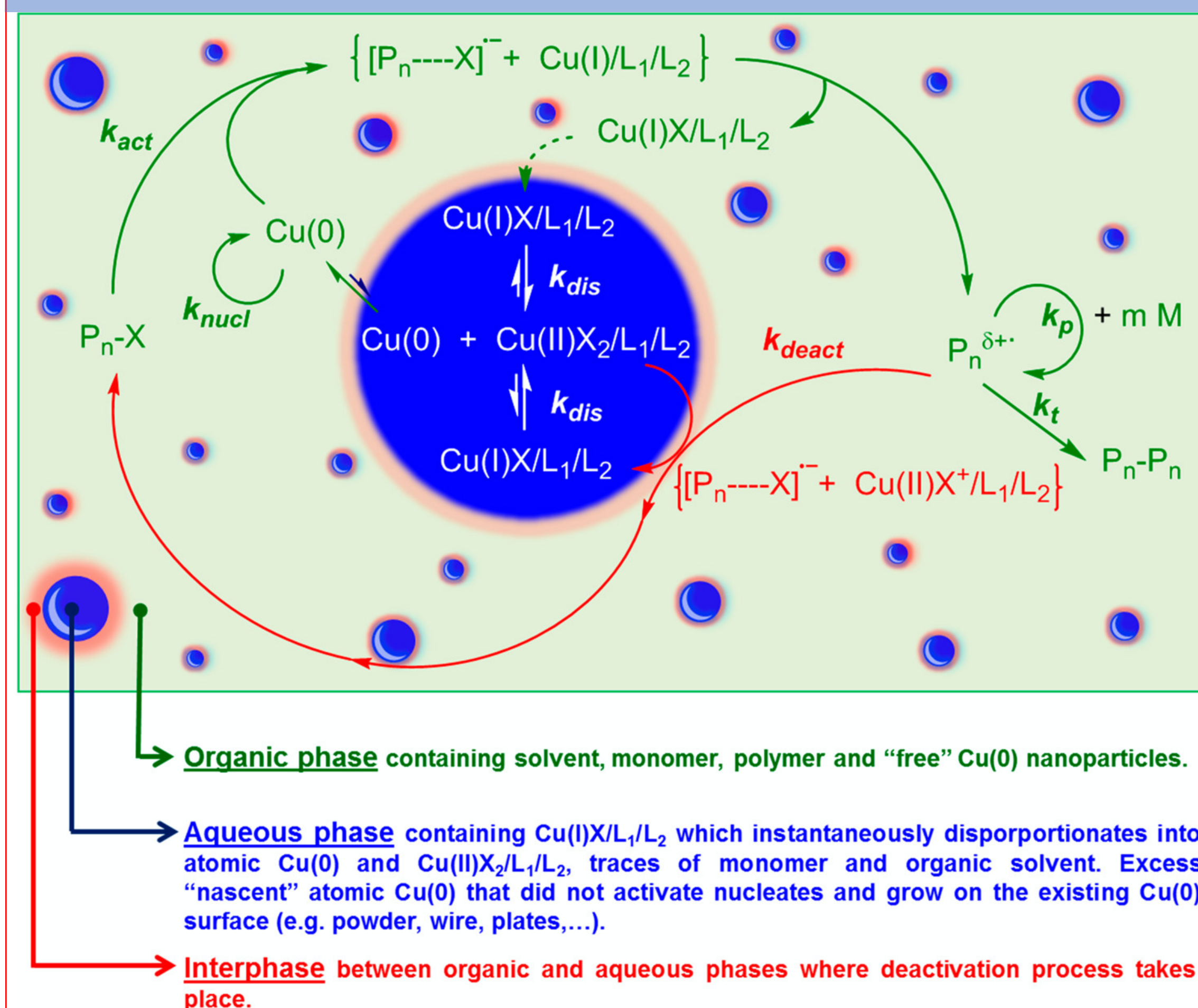


## Introduction

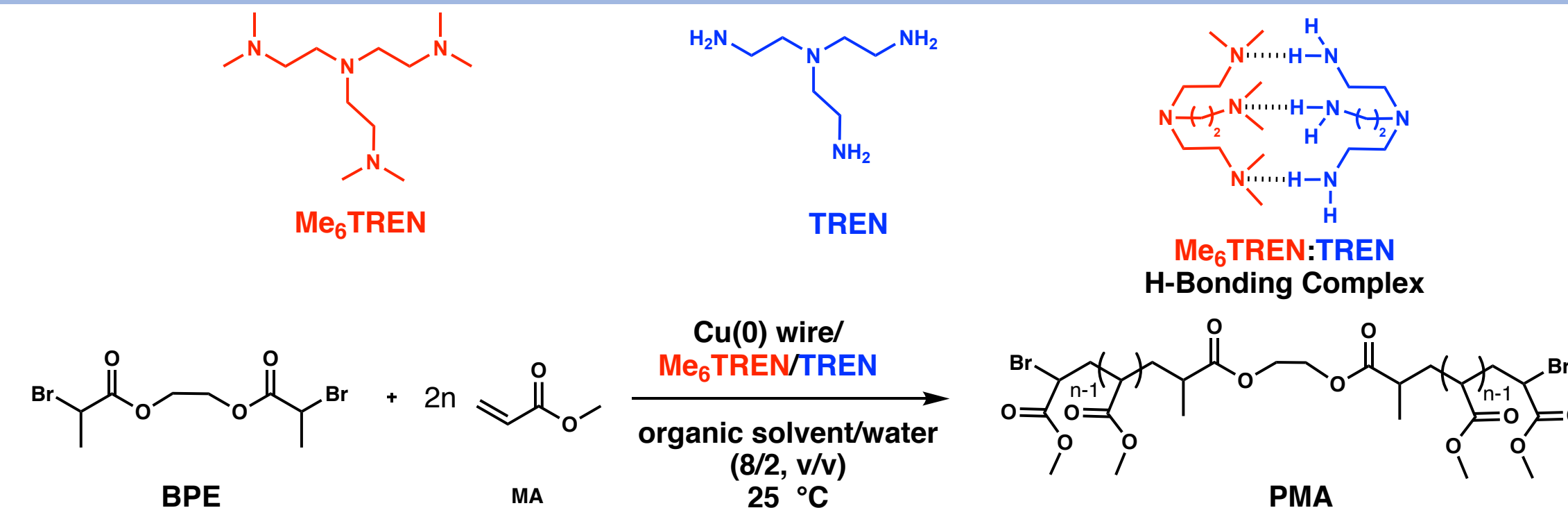
- Currently most of the SET-LRP and Atom Transfer Radical Polymerization (ATRP) techniques uses tris(2-dimethylaminoethyl)amine (Me<sub>6</sub>-TREN) as ligand which is 80 times more expensive than its precursor tris(2-aminoethyl)amine (TREN) however, TREN is much less efficient, thus limiting the commercial application of SET-LRP and ATRP mediated by TREN.
- In this work the efficiency of TREN was increased via two mechanisms: (i) the mixed ligand effect, (ii) the catalytic effect of solvent.
- Me<sub>6</sub>-TREN and TREN mixed ligand effect was studied in programmed “biphasic” mixtures of the dipolar aprotic solvents N-methylpyrrolidone (NMP), dimethylformamide (DMF) and N,N-dimethylacetamide (DMAc) with H<sub>2</sub>O and in the homogenous dimethyl sulfoxide (DMSO) system with methyl acrylate (MA) as monomer, initiated by bis(2-bromopropionyl)-ethane(BPE).
- The catalytic effect of DMSO was studied with Me<sub>6</sub>-TREN, mixed-ligand and TREN.

## Mechanism



- Programmed “biphasic” SET-LRP is one of the living polymerizations in which the Cu(0) acts as a catalyst to activate an alkyl halide by an outer sphere electron donation (reductive dehalogenation) to radicals in the organic phase while Cu(II)X<sub>2</sub> acts as radical deactivator at the interphase and aqueous region to provide a LRP.
- The biphasic reaction mixture are “programmed” by partitioning the Cu(I)X produced during the activation step in the water phase where it disproportionate quantitatively to highly active Cu(0) and Cu(II)X<sub>2</sub>
- The kinetic studies, molecular weight evolution and chain end analysis was carried out to demonstrate mixed ligand and catalytic effect of solvent.

## Result and Discussion



- The mixed ligand effect was reported in “programmed” biphasic mixtures of polar diprotic solvents NMP, DMF and DMAc with water in ratio of 8/2 v/v (above scheme).
- From kinetic studies it was observed that the apparent rate constant of polymerization at 1/1 ratio of Me<sub>6</sub>-TREN and TREN was faster than that of the individual ligand and any other ligands ratio in all “programmed” biphasic mixtures.
- From the kinetic studies, molecular weight evolution and chain end analysis it was concluded that Me<sub>6</sub>-TREN complemented TREN to enhance its apparent rate constant of propagation, monomer conversion, and molecular weight control in the absence of externally added Cu(II)Br<sub>2</sub>.

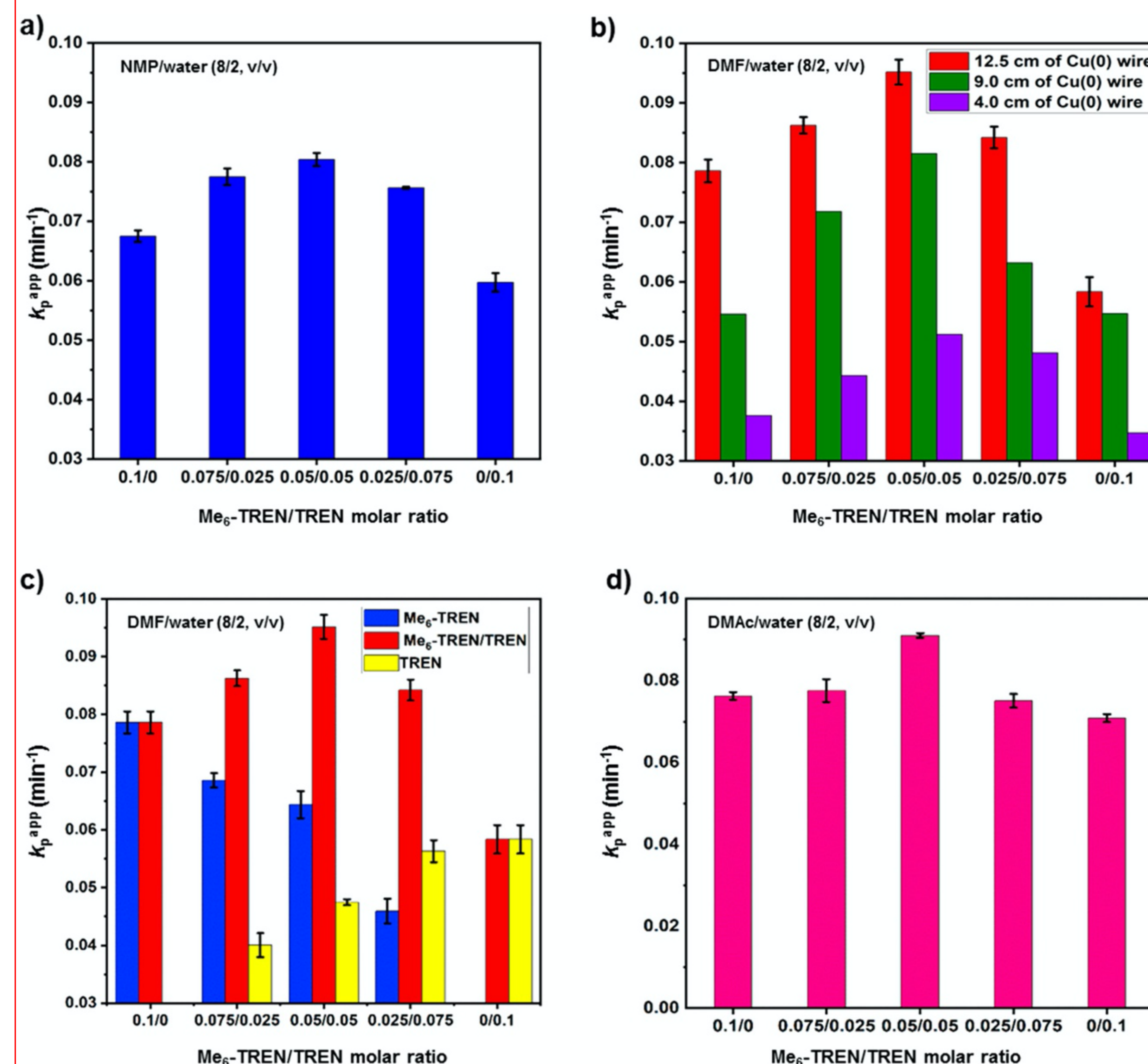


Figure 1. Evolution of  $k_p^{app}$  for the SET-LRP of MA initiated with BPE in various “programmed” biphasic reaction mixtures at 25 °C. (a) NMP/water mixture (8/2, v/v) using 9.0 cm nonactivated Cu(0) wire as catalyst. (b) DMF/water mixture (8/2, v/v) using 12.5, 9.0, and 4.0 cm of nonactivated Cu(0) wire as catalyst. (c) DMF/water mixture (8/2, v/v) using 12.5 cm of nonactivated Cu(0) wire as catalyst and (d) DMAc/water mixture (8/2, v/v) using 9.0 cm of nonactivated Cu(0) wire as catalyst. Reaction conditions: MA = 1 mL, organic solvent = 0.4 mL, water = 0.1 mL, and [MA]<sub>0</sub>/[BPE]<sub>0</sub>/[L]<sub>0</sub> = 222/1/0.1 (a,b, and d) [MA]<sub>0</sub>/[BPE]<sub>0</sub>/[L]<sub>0</sub> = 222/1/0.1–0.0 (c).

## Result and Discussion

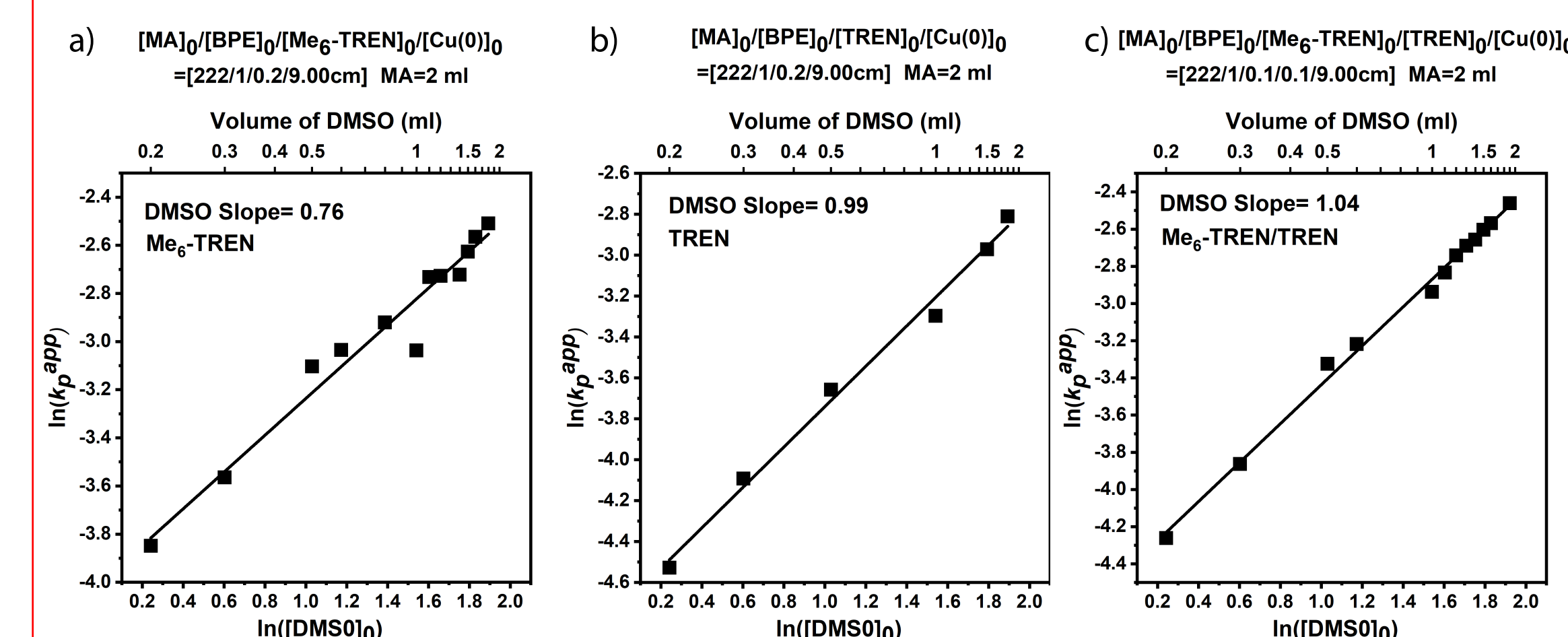


Figure 2. Determination of the external order of reaction in [DMSO]<sub>0</sub> for the Cu(0) wire/ligand-catalyzed polymerization of methyl acrylate (MA) in DMSO at 25 °C, initiated with BPE.  $\ln(k_p^{app})$  vs  $\ln([DMSO]_0)$  with DMSO varied from 0.2 to 1.9 mL, with 2 mL of MA for (a) [MA]<sub>0</sub>/[BPE]<sub>0</sub>/[Me<sub>6</sub>-TREN]<sub>0</sub>/[Cu(0)]<sub>0</sub> = 222/1/0.2/9 cm; (b) [MA]<sub>0</sub>/[BPE]<sub>0</sub>/[TREN]<sub>0</sub>/[Cu(0)]<sub>0</sub> = 222/1/0.2/9 cm; (c) [MA]<sub>0</sub>/[BPE]<sub>0</sub>/[Me<sub>6</sub>-TREN]<sub>0</sub>/[TREN]<sub>0</sub>/[Cu(0)]<sub>0</sub> = 222/1/0.1/0.1/9 cm.

- It was demonstrated that DMSO shows a catalytic effect in homogenous SET-LRP of methyl acrylate (MA) with bis(2-bromopropionyl)-ethane (BPE) as initiator and catalyzed by copper wire in Me<sub>6</sub>-TREN, TREN and 1/1 mixture of Me<sub>6</sub>-TREN and TREN (Figure 2).
- Similar to “programmed” biphasic SET-LRP, homogenous SET-LRP using DMSO also showed a mixed ligand effect with higher rate achieved in a 1/1 mixture of Me<sub>6</sub>-TREN and TREN. The catalytic effect of DMSO was used to enhance the reactivity of TREN and its 1/1 mixture with of Me<sub>6</sub>-TREN, while decreasing the basicity of ligand system to avoid side reaction.

## Conclusions

- By using the mixed ligand concept, the library of solvent which can be used with TREN was expanded. The perfect chain end generated by 1/1 ratio of Me<sub>6</sub>-TREN and TREN without the addition of external Cu(II)Br<sub>2</sub> make SET-LRP a method of choice for the synthesis of biomacromolecules at commercial and laboratory scale.
- In the catalytic effect of solvent during SET-LRP by increasing the amount of DMSO during the polymerization, the rate of reaction increases with the increased amount of DMSO. This was used to enhance the rate of polymerization of TREN and its 1/1 mixture of Me<sub>6</sub>-TREN. This catalytic effect of solvent could be used to improve the polymerization reaction to decrease its price in between 80 and 40 times.
- Since the highest rate of reaction in mixed-ligand system is observed at a 1/1 ratio of ligands, this suggested three possible mechanisms: (i) either a fast exchange of ligands in the catalytic system, (ii) a new single dynamic ligand generated by hydrogen-bonding of the two ligands, (iii) or a combination of both (i) and (ii).

## References

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