

Gas Separation Systems: Modular Tools for Process Intensification

W. J. Koros: Modular Manufacturing Workshop; Arlington, VA

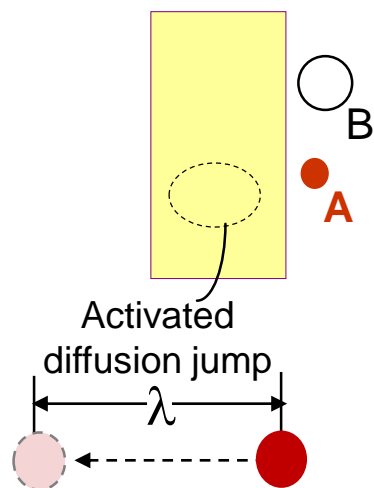
- Downstream inefficient gas separations translate to higher energy costs and CO₂ footprints



- 80% of chemical manufacturing energy is associated with processing industries that rely upon methane, ethane, propane and aromatics as starting materials*
- Efficient separation units provide large reductions in energy intensity, and by ***debottlenecking*** energy intensive units, early adopters can transform the chemical industry with minimal risk!
- Permselective ($\alpha_p = \alpha_s \times \alpha_D$) membranes use multiplicative sorption (α_s) & diffusion (α_D)—but engineering α_D is *crucial* to separate *similar volatility components* that are hard by distillation
- Module manufacturing, *rather than special materials per se*, are usually the limiting cost factors— which makes device engineering & manufacturing key issues to consider!

* NAS Chemical Sustainability 2005 Workshop, Feb. 8, 2005, Washington, DC

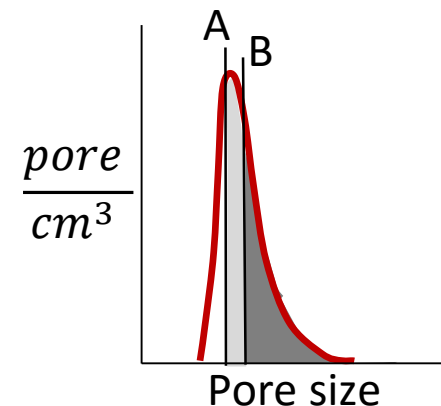
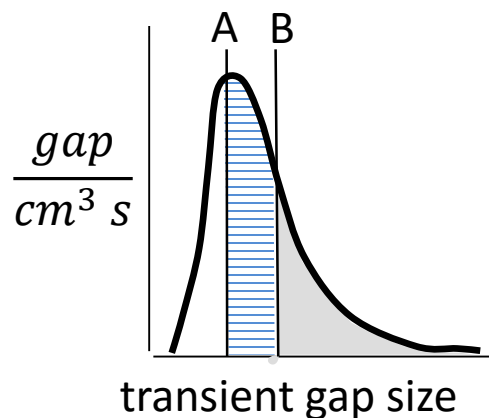
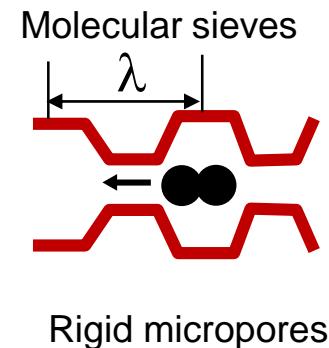
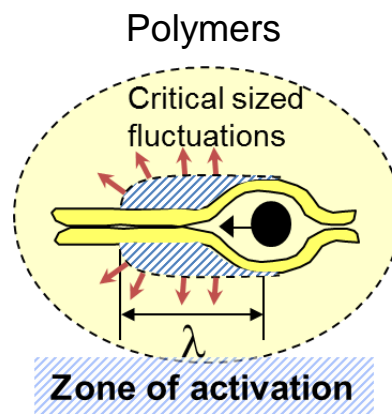
Tuning diffusivity and α_D relies upon sub-Å size discrimination



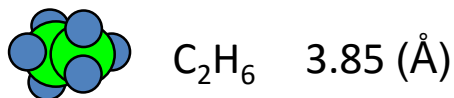
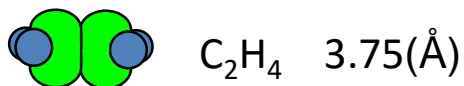
$$D = D_0 \exp\left[\frac{-\Delta E_D}{RT}\right]$$

$$D = \frac{\lambda^2}{6} \left[\frac{kT}{h}\right] \exp\left[\frac{\Delta S^\ddagger}{R}\right] \exp\left[\frac{-\Delta H^\ddagger}{RT}\right]$$

Entropic Enthalpic



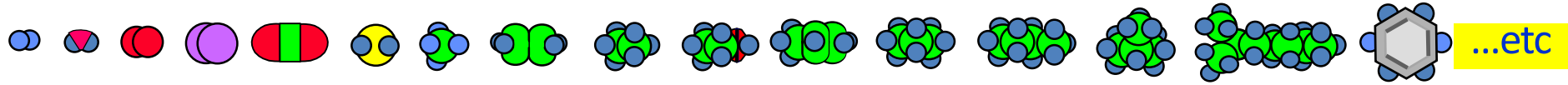
Finer discrimination, e.g. olefin vs paraffin (0.1 Å), must go beyond simple E_D tuning



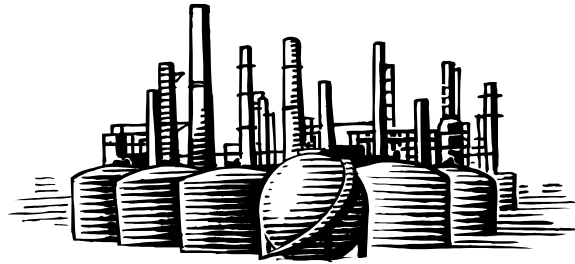
Tuning of activation energy, E_D , is adequate for A/B pairs with 0.5-1 Å size differences

Precise micropores allow tuning *entropic* activation factors.

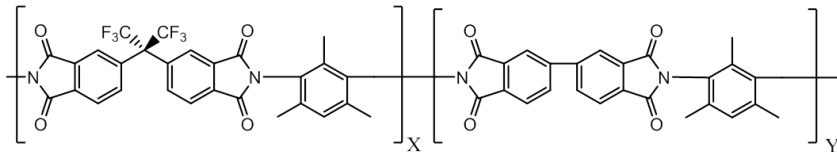
Transforming separations demands ultra-fine discrimination at huge scales



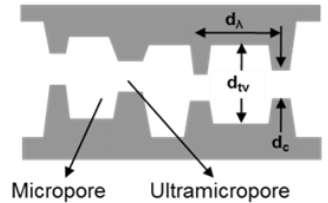
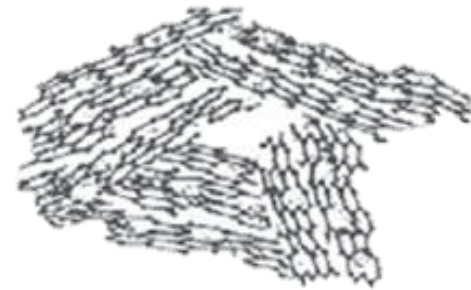
- Propylene-propane, ethylene-ethane, and normal/branched isomers cases requiring ultra fine discrimination are within reach, but require careful introduction to ensure success



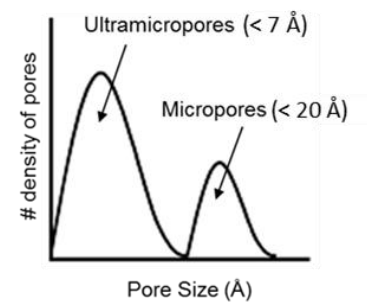
- Many molecular sieve materials exist, but I believe only carbon molecular sieve materials currently combine required processibility and separation properties needed to succeed



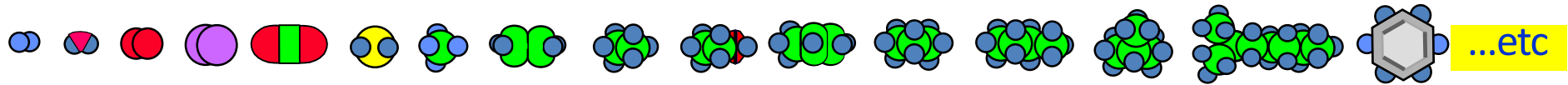
6FDA:BPDA-DAM (X=1, Y=1)



d_c : Ultramicropore dimension
 d_{IV} : Adsorptive pore dimension
 d_λ : Jump length (λ)



Transforming large scale separations also needs multi-domain collaboration



- Intersection of advanced materials and morphology science and module manufacturing technology must occur to enable these transformational steps
- Carbon molecular sieves are the leading edge of a new membrane age, since they are derived from spinnable polymer precursors and can be engineered at multiple dimensions

