Using Computer Modeling for the Development of Gas Chromatographic Stationary Phases and Columns

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“Old Days of GC”

- Chromatography has become a “history lesson” rather than a science
- Applications compromised to fit existing columns and stationary phases
- Most phases not designed with any application in mind
- Marketing based on “subtle” differences

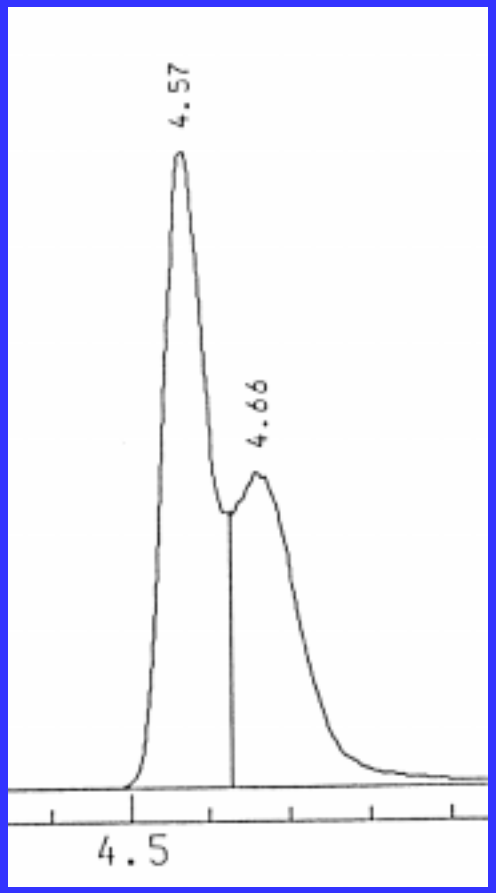
Future of GC

- Columns and stationary phases designed around applications
- Potential for specific phase and column for an individual separation
- Marketing based on real differences
- Requires understanding of analyte-phase interactions
- Can this be done economically?

Stationary Phase Optimization Techniques

- Window diagramming
- Computer simulation of Rt and W1/2 (ezGC™)
- Computer prediction of optimized stationary phase composition and column dimensions
- Computer prediction of solute/stationary phase interactions for new polymer designs

How Resolution Affects Quantitation
VRX phase



Results of Resolution Tests @ 20ppb

$MeCl_2$ & Freon 113	*Rep 1*	*19.85*	*18.48*
	Rep 2	*19.29*	*18.48*
	Rep 3	*19.36*	*18.52*
Methylene Chloride	*Rep 1*	*21.48*	
	Rep 2	*20.79*	
	Rep 3	*20.95*	
Freon 113	*Rep 1*		*16.3*
	Rep 2		*16.46*
	Rep 3		*16.25*

Equations and Terms

Resolution

$$R = 1/4 \sqrt{L / h} \times (k / k+1) \times (\alpha - 1 / \alpha)$$

Capacity Factor

$$k = t_R - t_0 / t_0$$

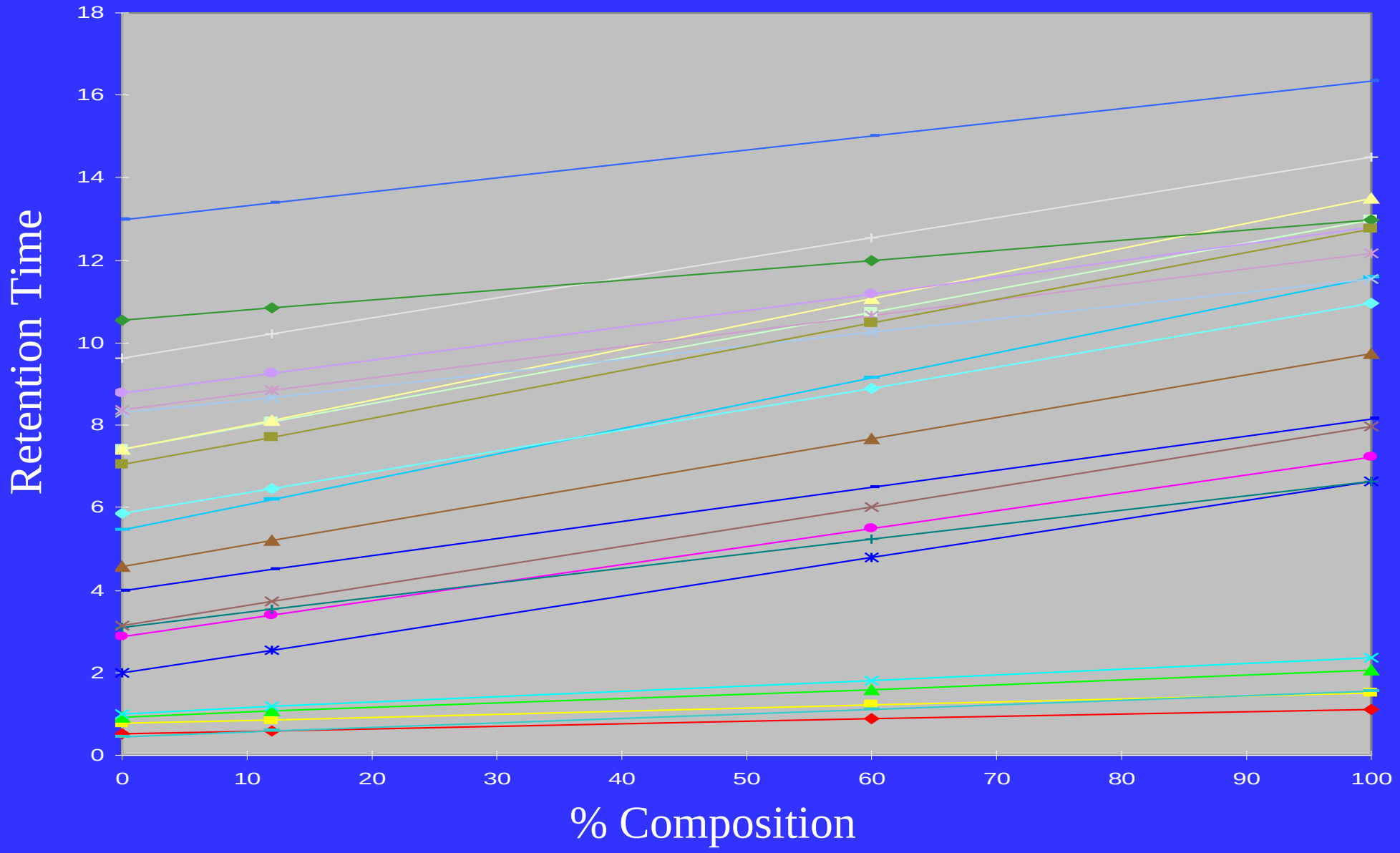
Selectivity

$$\alpha = k_2 / k_1$$

Stationary Phase Optimization

- Window diagramming (Rtx-502.2)
- Computer simulation of selectivity, independent of Rt and $W_{1/2}$ (ezGC™)
  - Rtx®-CLPesticides, Rtx-CLPesticides2
- Computer prediction of optimized stationary phase composition and column dimensions
  - Rtx-TNT, Rtx-TNT2, Rtx-VMS, Rtx-VGC, Rtx-5SilMS, Rtx-VRX
- Computer prediction of solute/stationary phase interactions for new polymer designs

“Window Diagram” Model



Stationary Phase Optimization

- Window diagramming
- Computer simulation of Rt and $W_{1/2}$ (ezGC)
  - Rtx®-CLPesticides, Rtx-CLPesticides2
- Computer prediction of optimized stationary phase composition and column dimensions
  - Rtx®-CLPesticides, Rtx-CLPesticides2, Rtx-TNT Rtx-TNT2, Rtx-VMS, Rtx-VGC, Rtx-5SilMS, Rtx-VRX
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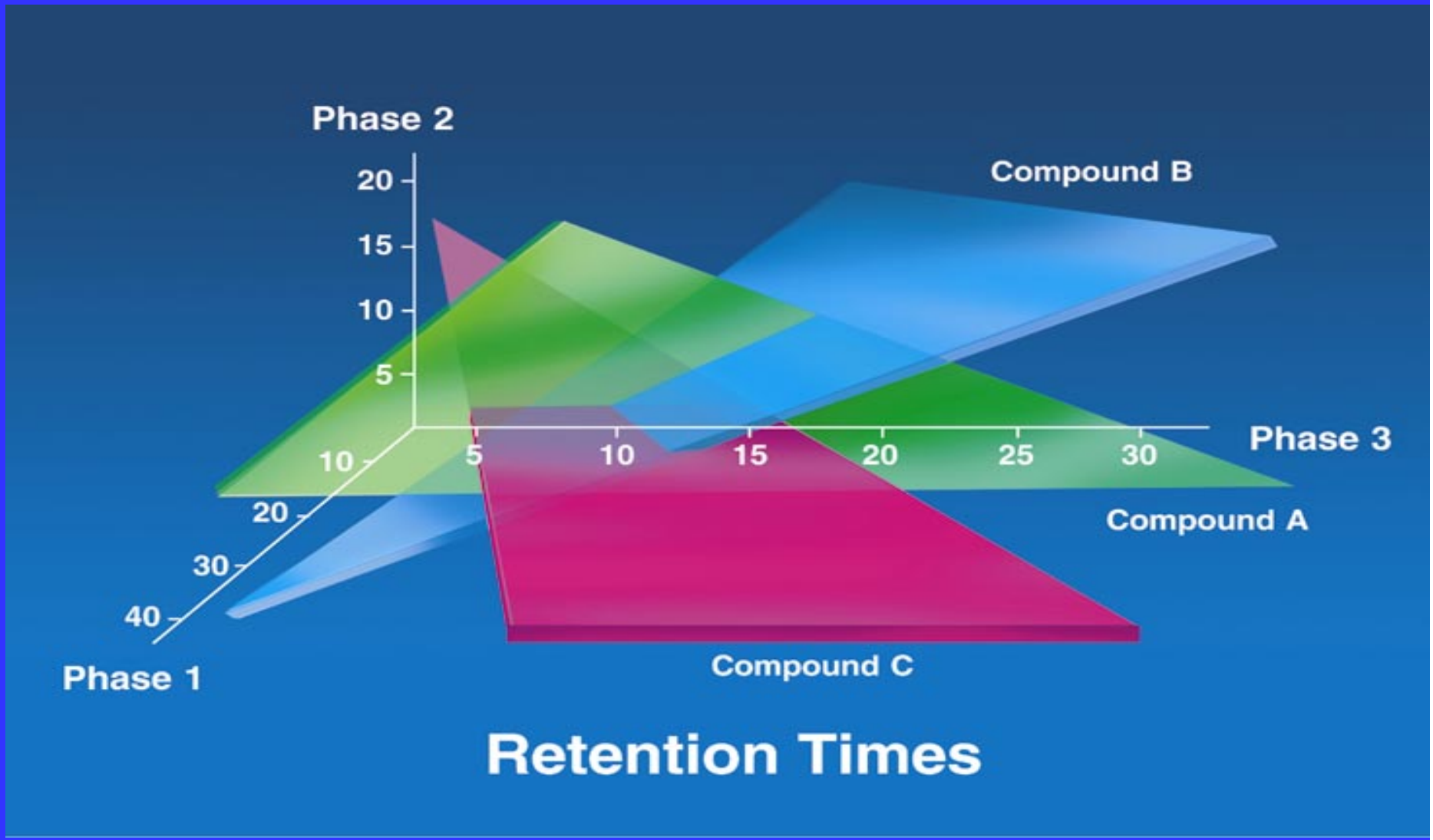
3-Space Selectivity Model for 3 Compounds



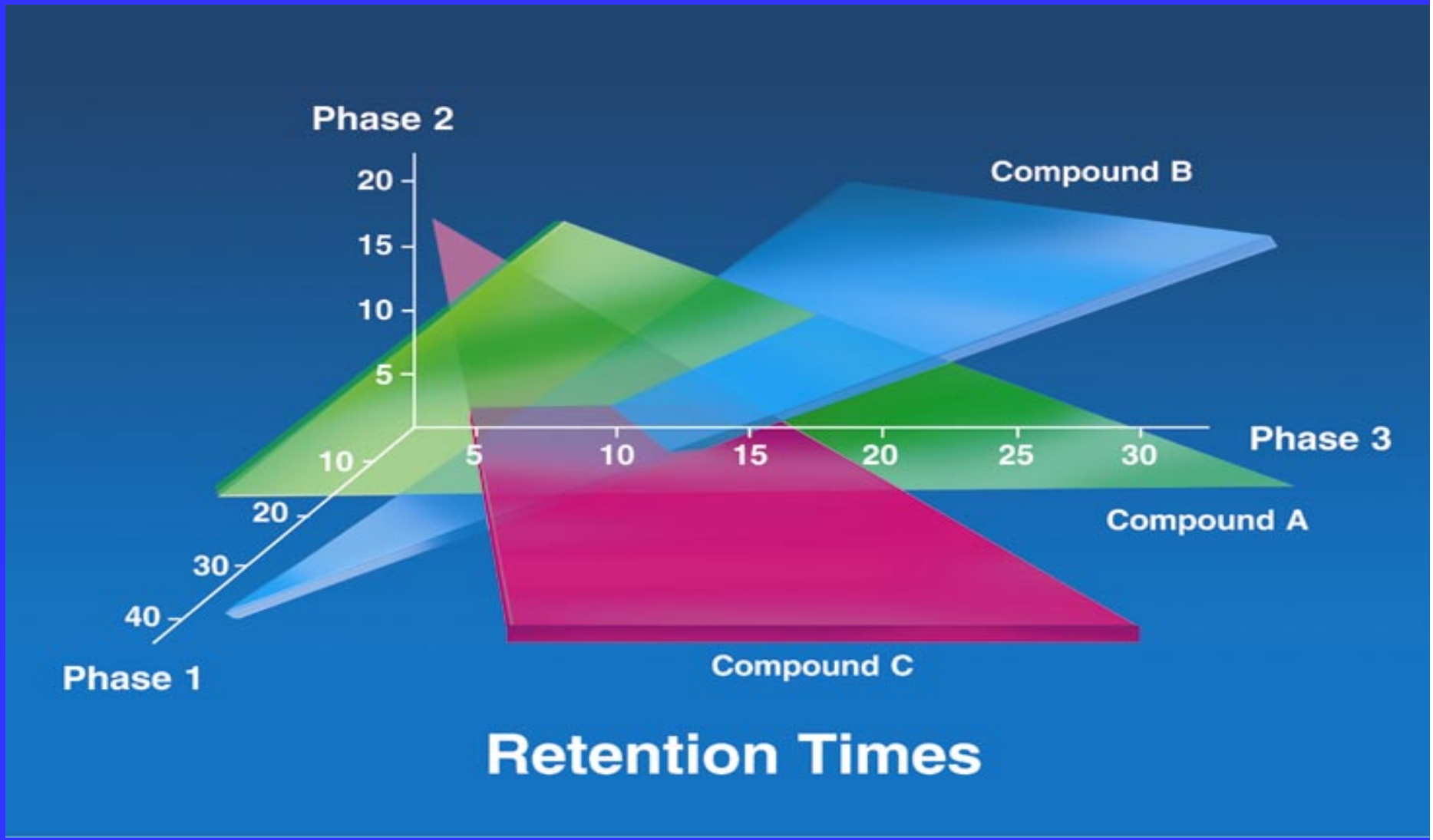
Stationary Phase Optimization

- Window diagramming
- Computer simulation of Rt and $W_{1/2}$ (ezGC)
- Rtx®-CLPesticides, Rtx-CLPesticides2
- Computer prediction of optimized stationary phase composition **AND** column dimensions
  - Rtx-TNT Rtx-TNT2, Rtx-VMS, Rtx-VGC, Rtx-5SilMS, Rtx-VRX, Rtx-OPPesticides2, Customer-specific columns
- Computer prediction of solute/stationary phase interactions for new polymer designs

Process for Rtx-OPPesticides2 Column

- Acquire data for target compounds under two temperature programs for functionalities displaying selectivity
- Computer Assisted Stationary Phase Design (CASPD)
  - Calculate ΔH and ΔS for each compound
  - Working in Retention Index, perform optimization of Selectivity and Dimensions
- Synthesize and coat column

3-Space Selectivity Model for 3 Compounds



Compounds 1 – 25 of 53 OP Pesticides

Target Compound	Predicted Rt	Actual Rt	Difference (min)
dichlorvos	4.08	4.05	-0.03
HMPA	4.70	4.70	0.00
mevinphos	6.43	6.34	-0.09
trichlorfon	6.44	6.43	-0.01
TEPP	8.20	8.40	0.20
demeton-o	8.46	8.52	0.06
thionazin	8.58	8.52	-0.06
TBP	8.60	8.52	-0.08
ethoprop	8.84	8.74	-0.10
naled	9.34	9.32	-0.02
sulfotepp	9.42	9.56	0.14
phorate	9.53	9.56	0.03
dicrotophos	9.61	9.59	-0.02
monocrotophos	9.70	9.62	-0.08
demeton-s	9.80	9.62	-0.18
terbufos	10.44	10.32	-0.12
dimethoate	10.67	10.62	-0.05
dioxathion	10.78	10.77	-0.01
fonophos	10.91	10.79	-0.11
diazinon	10.93	10.90	-0.04
disulfoton	11.13	11.09	-0.03
phosph isomer	11.19	11.16	-0.04
dichlorofenthion	11.38	11.37	-0.01
chlorpyrifos methyl	11.94	12.03	0.09
phosphamidon	12.14	12.03	-0.11

Individual Custom Column?

- Customer contacted us about custom column for separation of volatile silanes and hydrocarbons
- Customer provided data on Rtx-1 Rtx-35, and Rtx-200 under two different temperature programs
- Data was input to CASPD, and phase was successfully predicted and developed

CASPD 2.2 Output Table

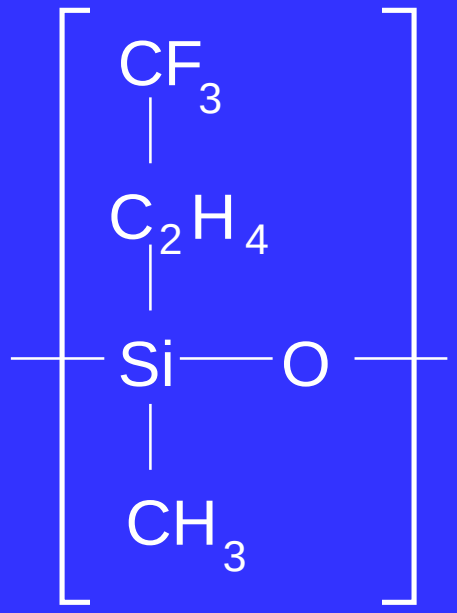
Col ID	# failures	# rel fails	run time(m	L(m)	d0 (mm)	fd(um)	pi (psig)	po (psia)	td (sec)	T-td(C)	T Prog #	Funct. A	Funct. B
RL321	0	0	31.67	90	0.32	1.8	15	14.7	529.1	35.0	4	0.1847	0.8153
RL395	0	0	31.67	90	0.32	1.8	15	14.7	529.1	35.0	4	0.1845	0.8155
RL369	0	0	31.67	90	0.32	1.8	15	14.7	529.1	35.0	4	0.1843	0.8157
RL443	0	0	31.67	90	0.32	1.8	15	14.7	529.1	35.0	4	0.1843	0.8157
RL623	0	0	31.67	90	0.32	1.8	15	14.7	529.1	35.0	4	0.1841	0.8159
RL836	0	0	31.67	90	0.32	1.8	15	14.7	529.1	35.0	4	0.1841	0.8159
RL724	0	0	31.67	90	0.32	1.8	15	14.7	529.1	35.0	4	0.1839	0.8161
RL199	0	0	31.70	90	0.32	1.8	15	14.7	529.1	35.0	4	0.1550	0.8450
RL93	0	0	31.70	90	0.32	1.8	15	14.7	529.1	35.0	4	0.1550	0.8450
RL52	1	1	31.65	90	0.32	1.8	15	14.7	529.1	35.0	4	0.2102	0.7898
RL1010	3	3	31.78	90	0.32	1.8	15	14.7	529.1	35.0	4	0.0659	0.9341

What If No Selective Functionality Can be Found?

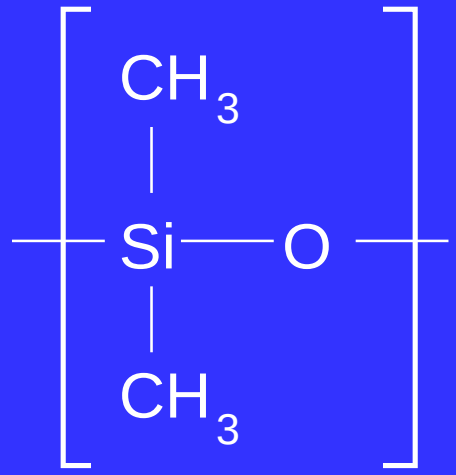
- Accept less than ideal separation
  - Effect on quantitation and/or run time
- Use “old method” of trial and error
  - Slow, and inefficient
  - No guarantee that solution will be found
- Test functionalities electronically
  - Unproven technique
  - CPU intensive
  - Fast

Conventional Stationary Phases Used for Capillary GC

trifluoropropylmethyl polysiloxane



dimethyl polysiloxane



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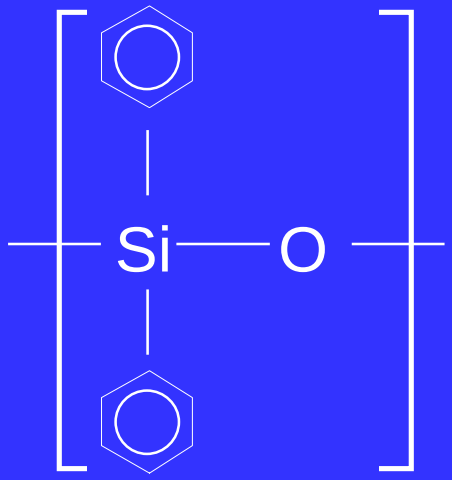
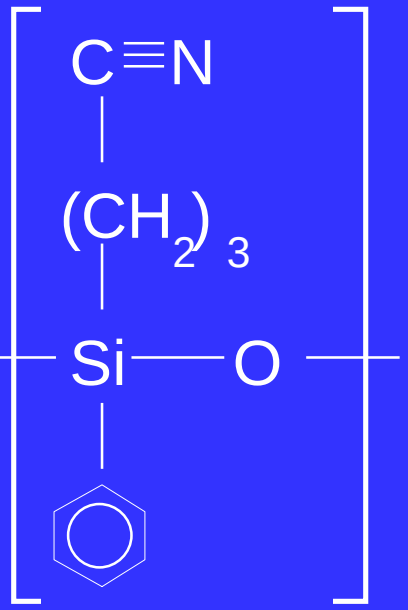
diphenyl polysiloxane

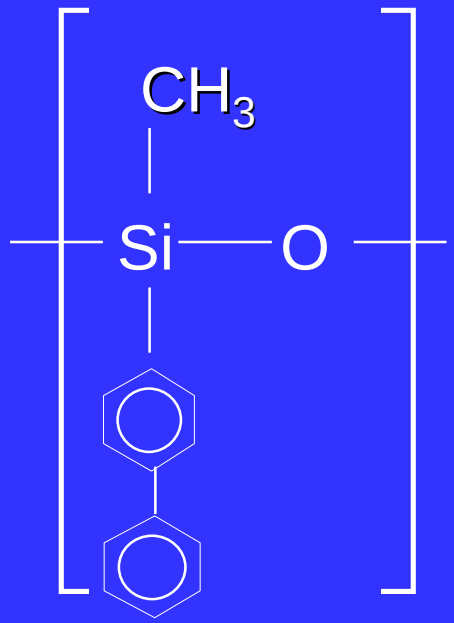


cyanopropylphenyl polysiloxane

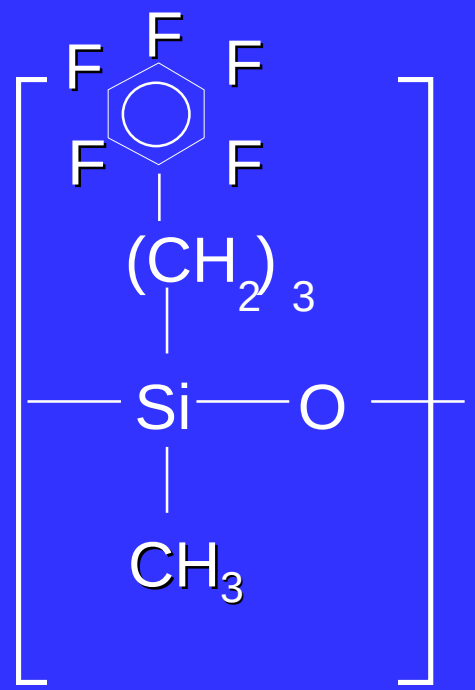


Alternative Stationary Phases Used for Capillary GC

biphenyl polysiloxane

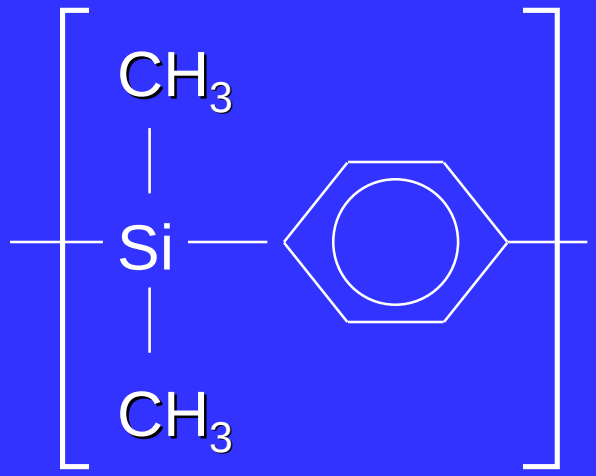


pentafluorophenyl polysiloxane

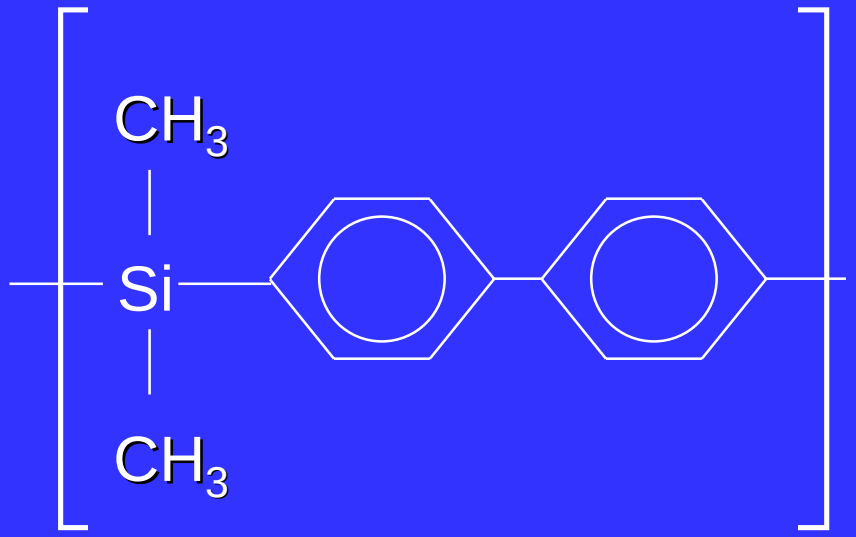


Alternative Stationary Phases Used for Capillary GC

Silarylene



Silbiarylene



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Achieving Analyte Separation

Resolution

$$R = 1/4 \sqrt{L / h} \times (k / k+1) \times (\alpha-1 / \alpha)$$

Capacity Factor

$$k = (t_R - t_0) / t_0$$

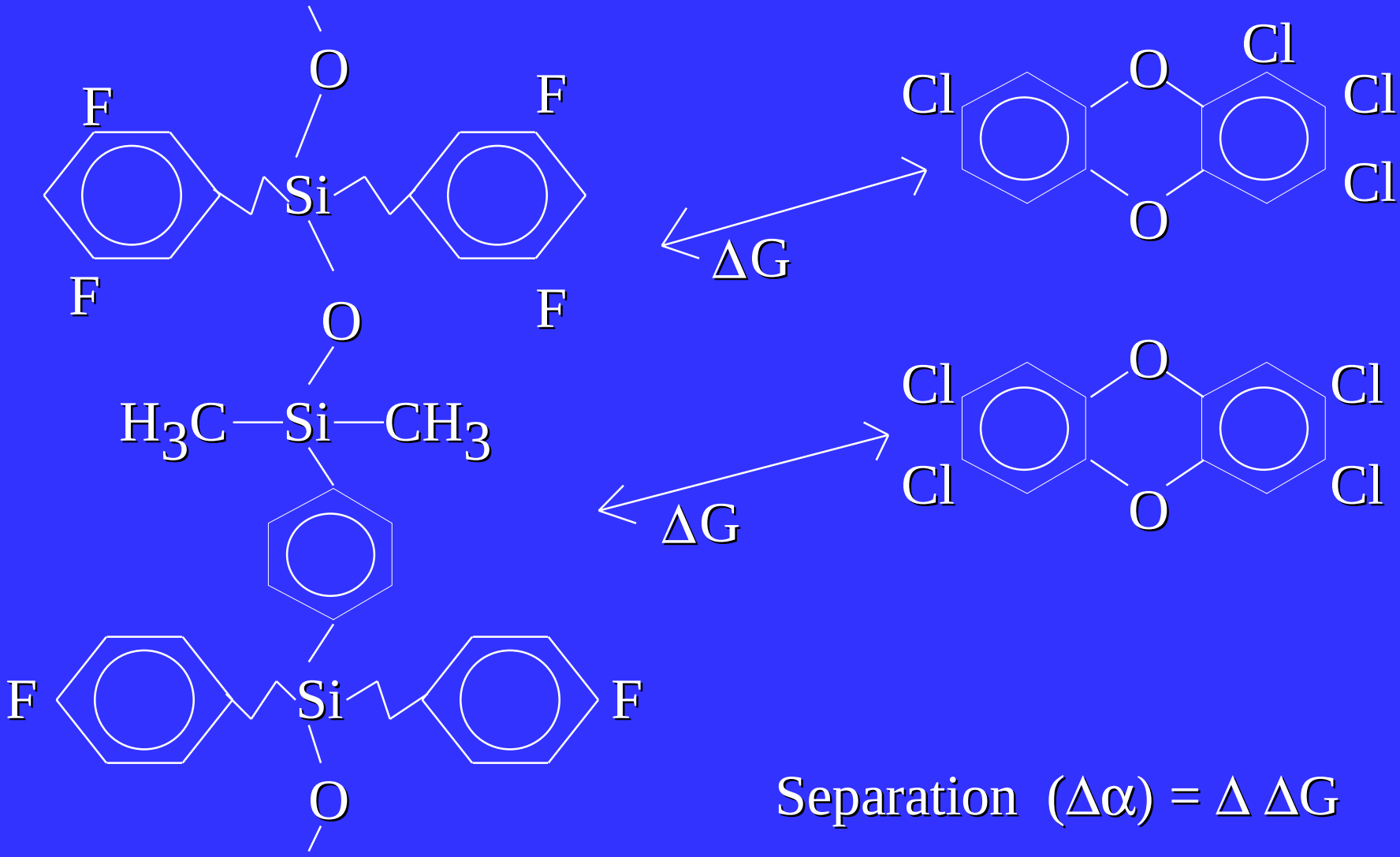
Selectivity

$$\alpha = k_2 / k_1$$

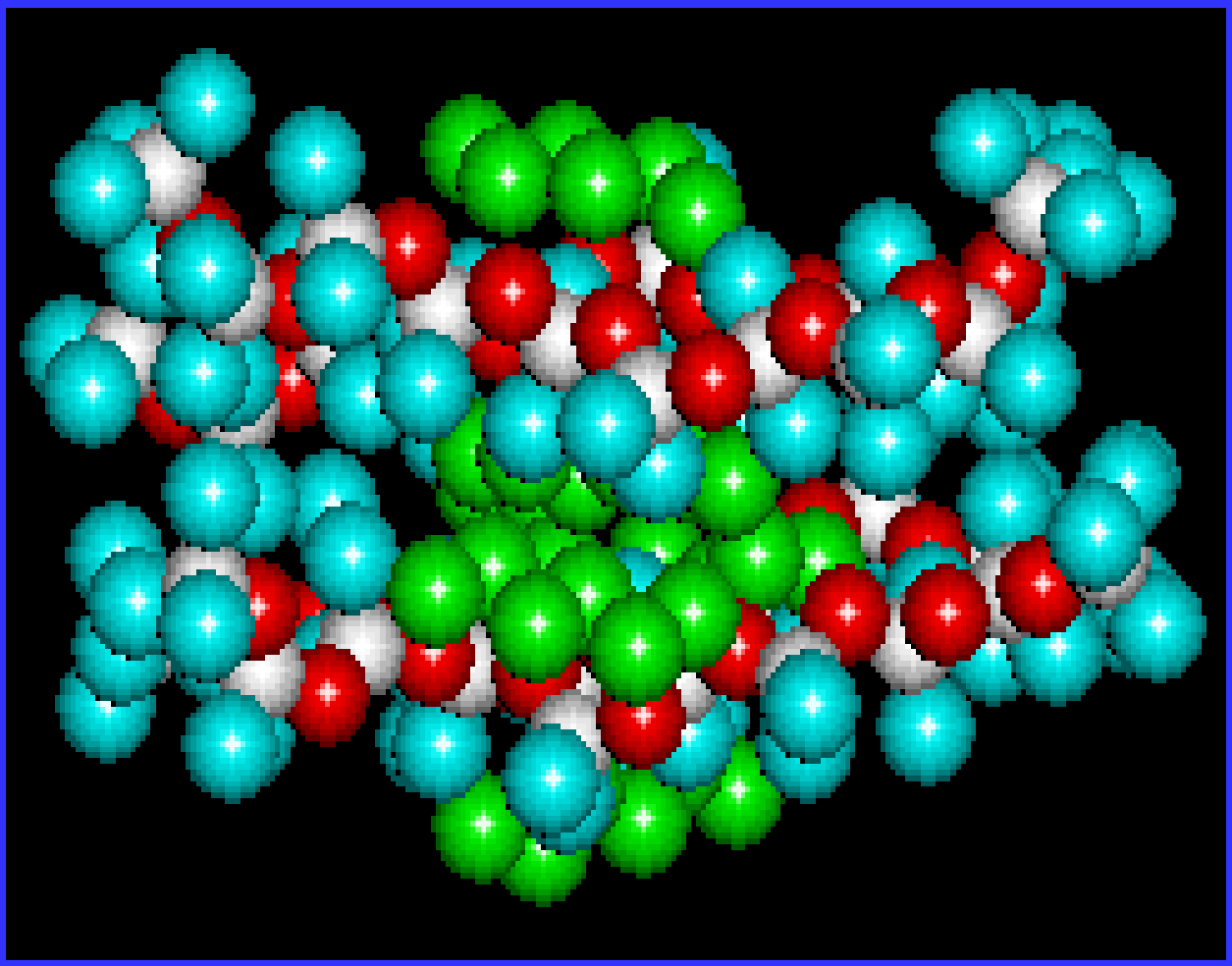
Thermodynamics:

$$\Delta G = \Delta H - T\Delta S \qquad \Delta G = RT \ln K_D$$

Modeling - Energies of Interaction



Separation ($\Delta\alpha$) = $\Delta\,\Delta G$



Summary

- Column optimization program complete
- Allowed for 10 new phases over last three years
- Individual customer columns possible:
  - Cost of polymer synthesis (1-5 K$ typical) – one time fee
  - Custom column cost
- Development of program to electronically “test” possible future functionalities underway