

HPLC Method Development: Standard Practices and New Columns

LC Columns and Consumables

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What are Some Standard Method Development Practices?

1. **Follow preferred method development scheme and do “hands-on” method development – based on selectivity-changing parameters— e.g., pH, column, or mobile phase types**
2. **Use method development software – run a few predictive runs and get prediction for best method**
3. **Evaluate multiple columns/multiple mobile phases in a manual or automated fashion, determine best results (e.g., using valve switching to change between columns, software to track peaks etc.)**

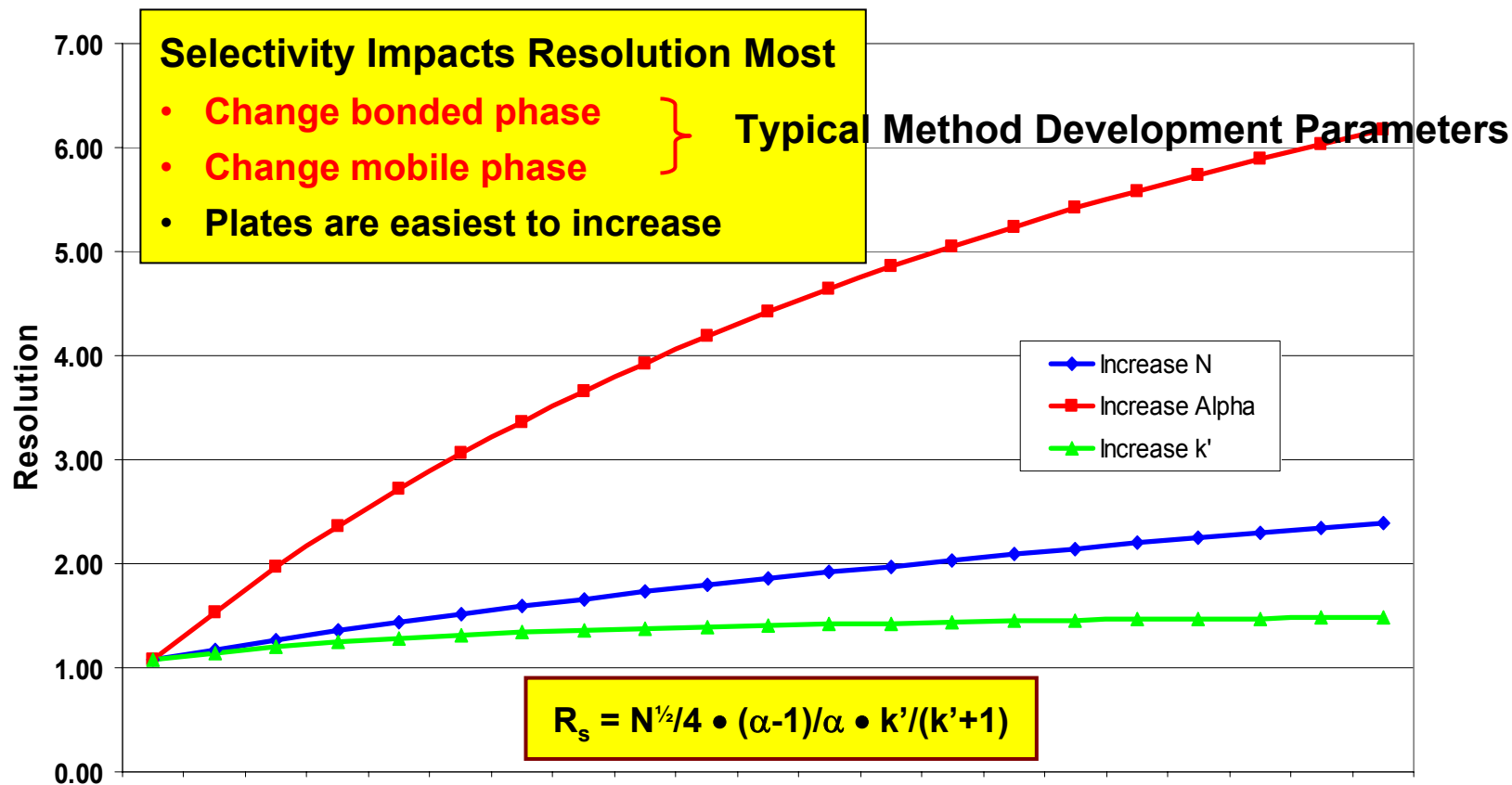
Practice #1 is used by many and incorporates “hands on” learning.

It requires nothing special to make it work, so we will work through a method development scheme for this practice.

What Makes a Good Starting Point for Hands-on Method Development?

1. Choose a C18 column – many choices, well known technologies
 - a) A short column minimizes method development time
 - b) Smaller particle sizes provide the resolution needed in a short time
 - c) Newer C18 column choices can improve results – based on efficiency, and improved peak shape**
2. Choose a simple mobile phase – reliable, works with many samples
 - a) Phosphate buffer pH 3, TFA, or formic acid in aqueous portion
 - b) Acetonitrile or methanol as organic modifier
3. Adjust mobile phase to get the desired retention and **resolution**
 - a) Adequate resolution of all peaks, $R_s \geq 2.0$ – requires highest efficiency
 - b) Retention of first peak preferred to be at least $k = 1$
 - c) Analysis time below 20 minutes – shorter
 - d) Newer column choices, short columns with small particle sizes can provide more efficiency and resolution in a very short time, thereby speeding up method development**

Typical Method Development Parameters - Effects of Selectivity, Efficiency, and Retention on Resolution

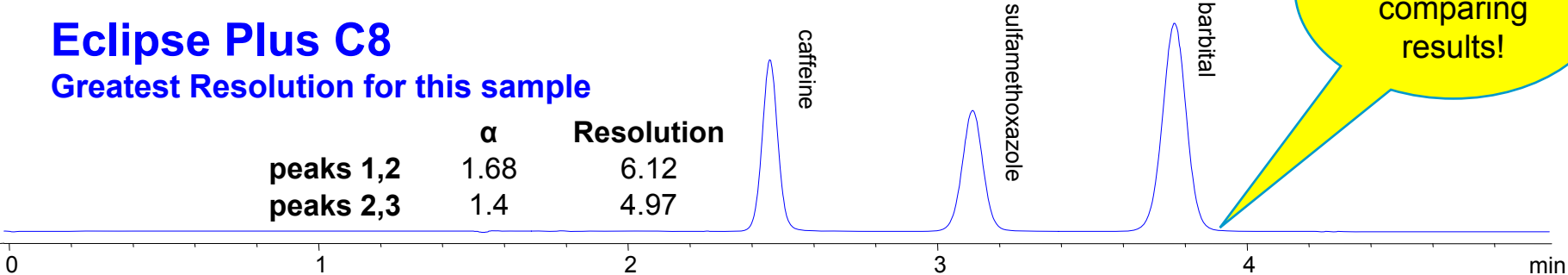


Plates:	5000	10000	15000	20000	25000
Alpha:	1.10	1.35	1.60	1.85	2.1
k':	2.0	4.5	7.0	9.5	12.0

Small Differences in α – Selectivity - Can Provide Large Differences in Resolution

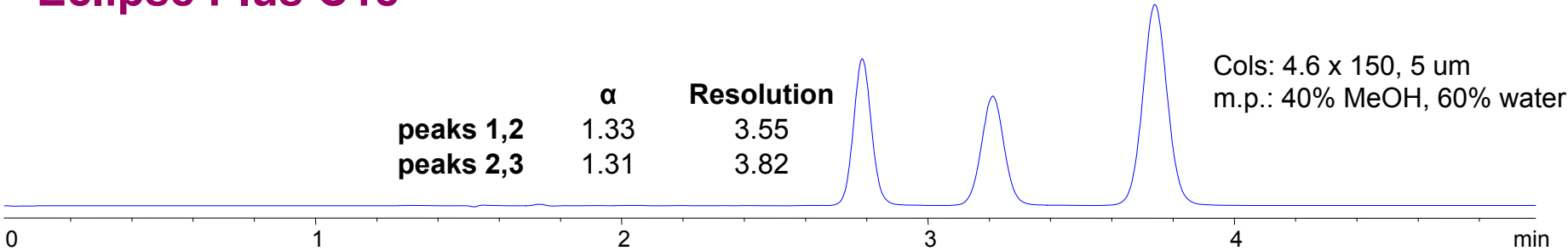
Eclipse Plus C8

Greatest Resolution for this sample

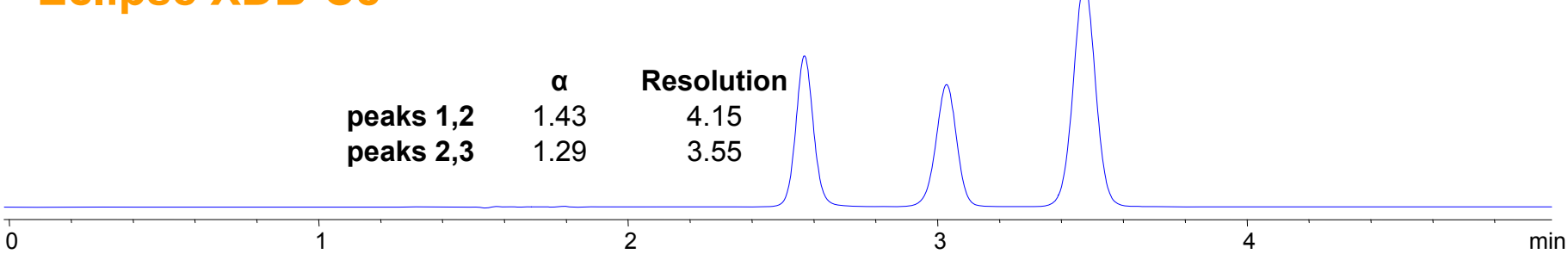


Remember to assess T_f when comparing results!

Eclipse Plus C18



Eclipse XDB-C8



What Do We Want to Base Our Complete Method Development Scheme On? (Beyond the Start)

Changing selectivity to improve resolution with the two key parameters – mobile phase and bonded phase

Mobile phase (1st choice to change because it's easy)

- Mobile phase – organic modifier (ACN, MeOH, etc.)
- Mobile phase – pH – over a wide pH range – pH 1-12 if needed

Bonded phase (provides a lot of optimization potential)

- Many choices other than C18 – C8, Phenyl, CN (most orthogonal!)
- AQ for highly aqueous mobile phases
- Choose new columns with best peak shape performance

New Column Choices To Use for Standard Method Development

1. Shorter columns with smaller particle sizes

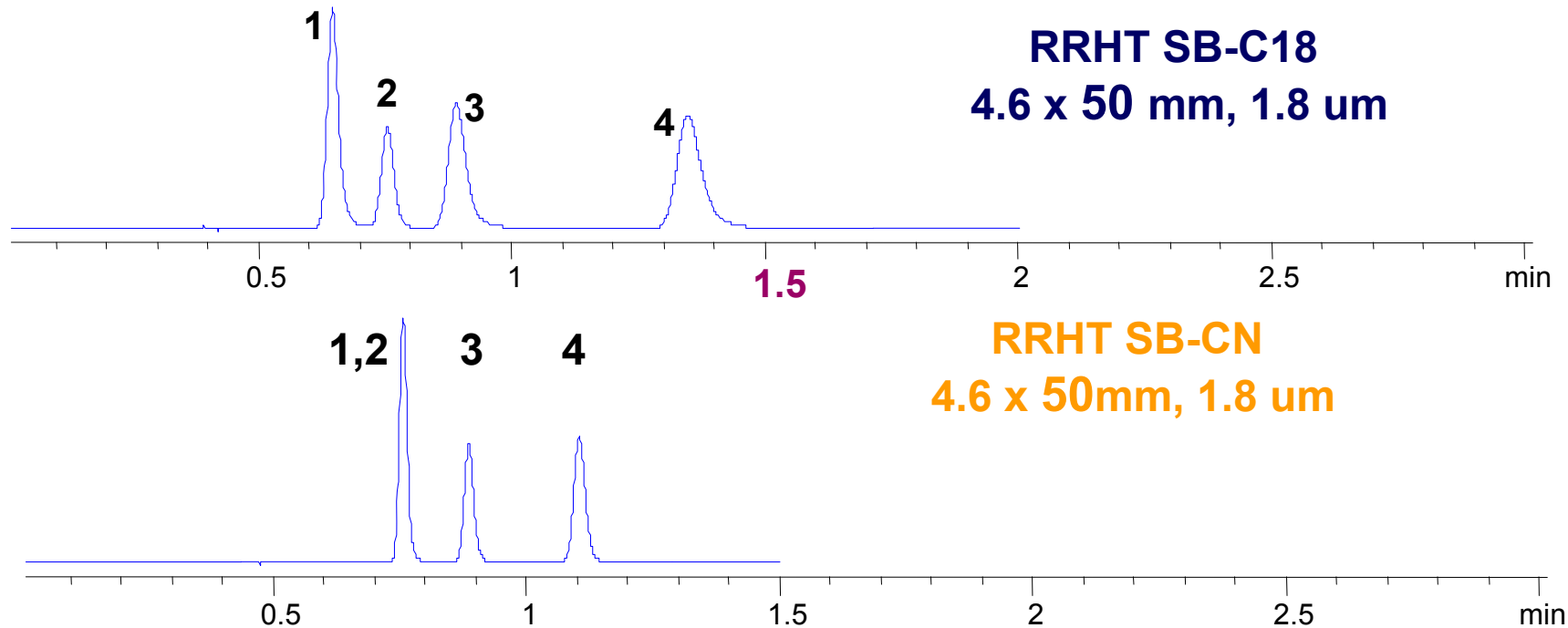
- Rapid Resolution High Throughput Columns (RRHT) with a 1.8 μm particle size – 50 mm or shorter for fastest method development
- Longer columns for maximizing efficiency
- Many bonded phase choices for a complete method development scheme

2. Improved bonded phases for superior performance

- Better peak shape and efficiency result in more resolution
- Critical to the best methods
- New Eclipse Plus columns can deliver improved performance

1. Start with Short RRHT C18 Columns with Highest Efficiency for Fastest Method Development

Column: 4.6 x 50mm, 1.8um Mobile Phase: A= 0.1% Formic Acid, B=ACN + 0.1%Formic Acid (95:5) Flow rate: 1.5 mL/min
Inj. Vol: 2 ul Sample: Xanthines: 1. 1-methylxanthine, 2. 1,3-dimethyluric acid, 3. 3,7-dimethylxanthine, 4. 1,7-dimethylxanthine

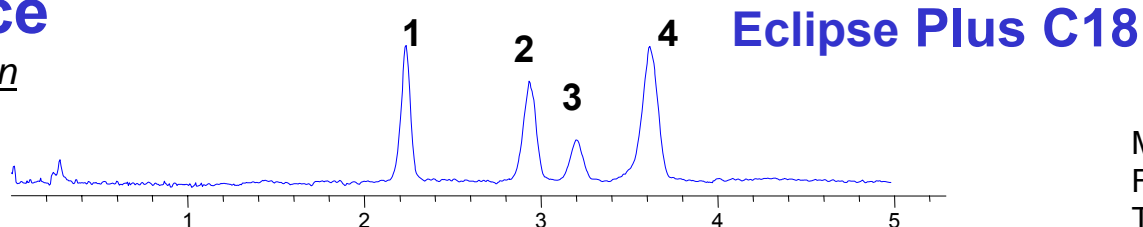


- The C18 gives the most effective resolution – and with a 4.6 x 50 mm, 1.8um column the initial results are achieved in just a couple of minutes, with the highest efficiency.
- The 50 mm length is short and fast – methods can be approximated or completed in just minutes!!

1. Start Method Development with RRHT Columns: Different ZORBAX RRHT C18 Bonded Phases for Max Selectivity

1st choice

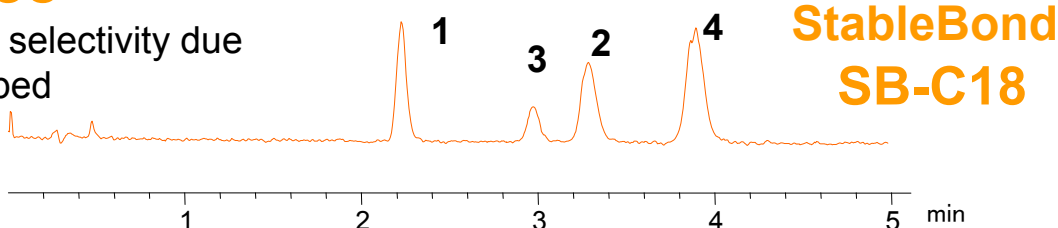
Best Resolution
& Peak Shape



Mobile phase: (69:31) ACN:water
Flow 1.5 mL/min.
Temp: 30 °C
Detector: Single Quad ESI
positive mode scan
Columns: RRHT
4.6 x 50 mm 1.8 um

2nd choice

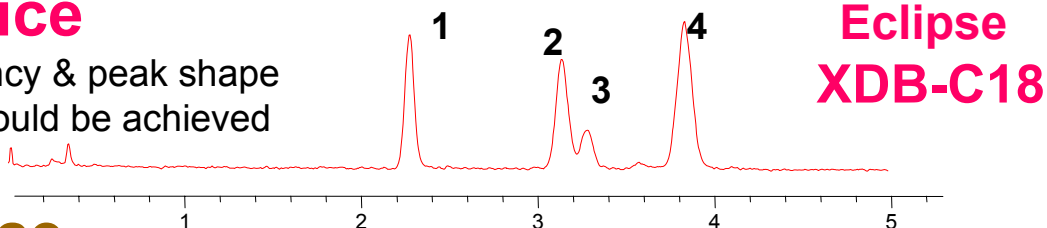
Good alternate selectivity due
to non-encapped



Sample:
1. anandamide (AEA)
2. Palmitoylethanolamide (PEA)
3. 2-arachinoylglycerol (2-AG)
4. Oleoylethanolamide (OEA)

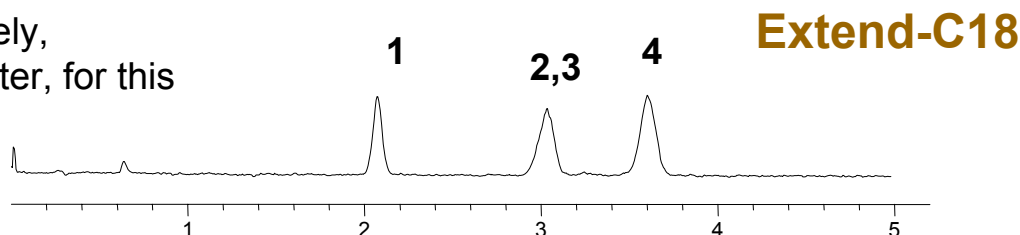
3rd choice

Good efficiency & peak shape
Resolution could be achieved



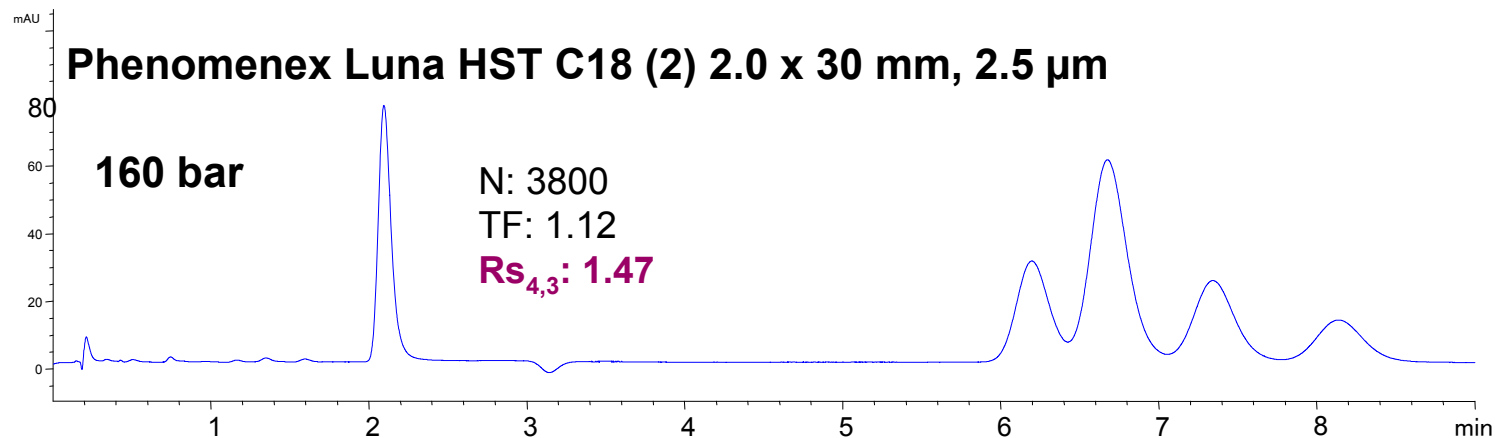
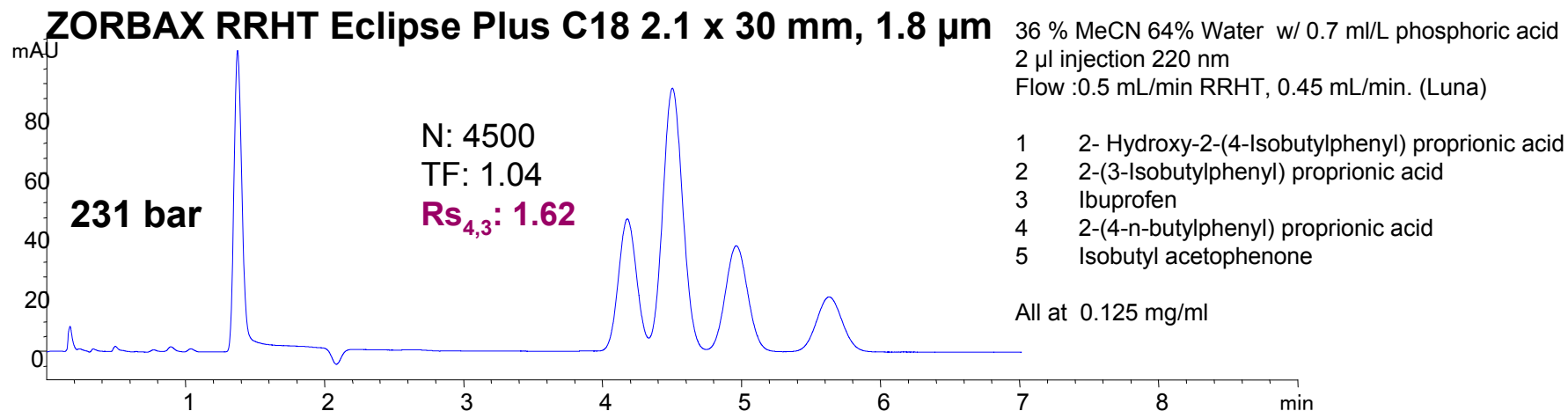
4th choice

Resolution not likely,
Other choices better, for this
separation.



Multiple bonded phases
for most effective method
development.
Match to one you are
currently using.

2. Agilent Rapid Resolution HT Eclipse Plus C18 Provides Superior Peak Shape and Efficiency

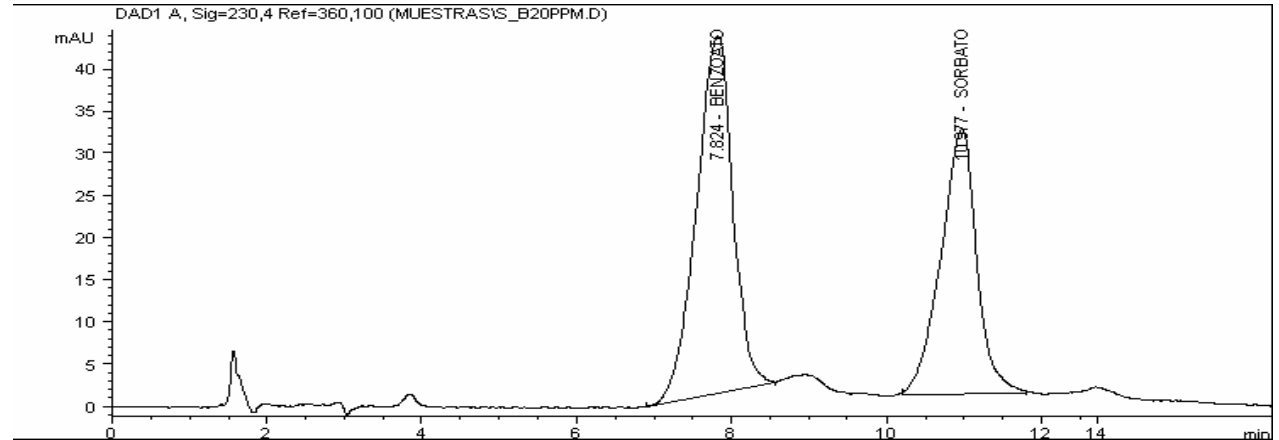


**ZORBAX RRHT has at least 18% more efficiency than Luna HST C18(2)
That means greater than baseline resolution when needed.**

2. Choose New Eclipse Plus C18 for Superior Efficiency and Peak Shape

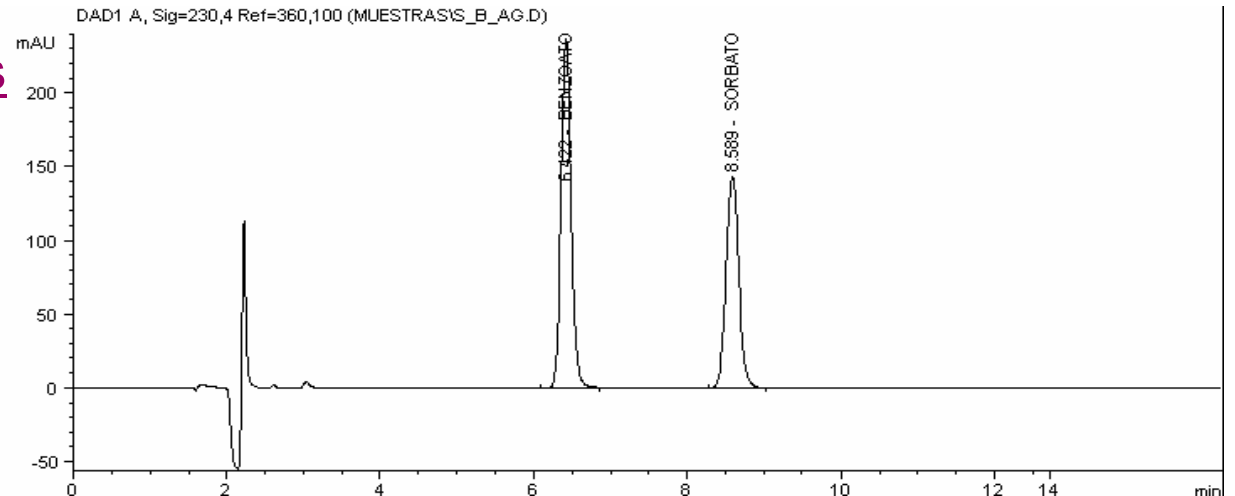
Analysis on Other C18

- Poor sensitivity
- Due to broad peaks
- Peaks do not tail, but are distorted.



Analysis on Eclipse Plus

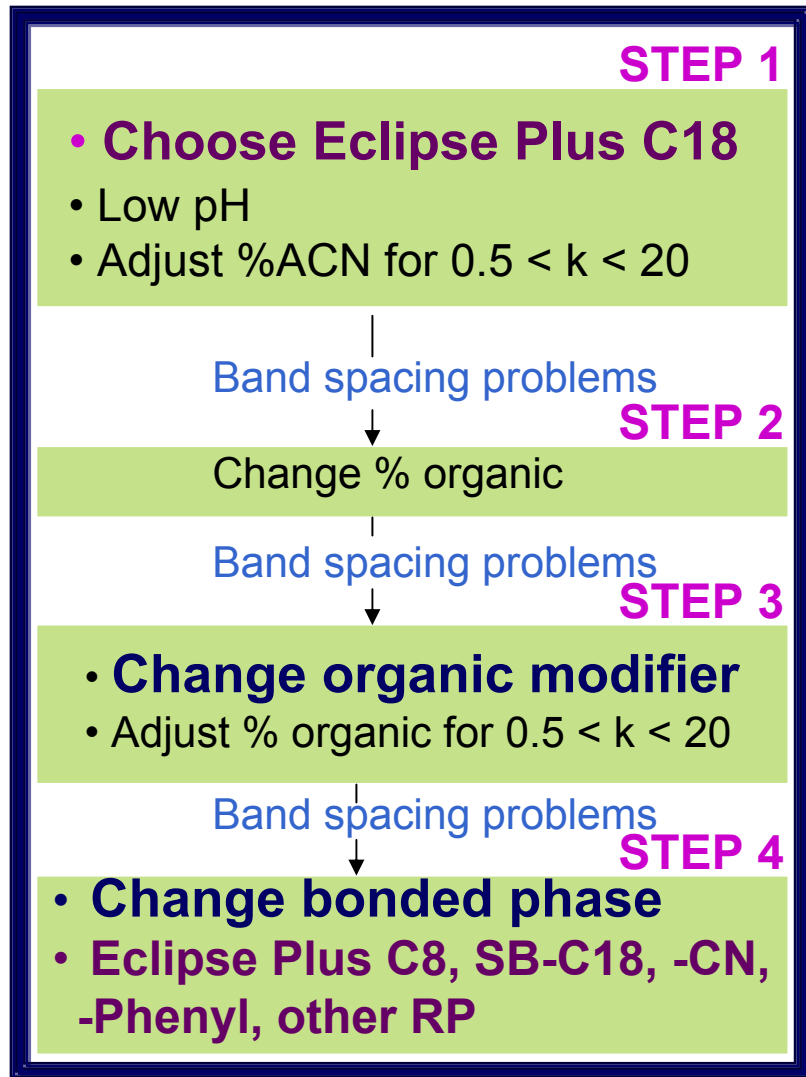
- Better Sensitivity
- Sharp, Efficient Peaks
- Excellent peak shape



How Do We Implement These New Column Choices in the Method Development Process?

- ❑ Follow a method development process around standard practices – **ONLY** when the first steps allow you to incorporate new products for fast, good results!
- ❑ A method development scheme based on simple strategies for optimizing selectivity and resolution can incorporate new products.
- ❑ **The 3 key parameters must be:**
 - mobile phase
 - mobile phase pH
 - bonded phase

First Steps in a Method Development Scheme



- Select a high quality C18 or C8 bonded phase first for good peak shape, retention and resolution with typical acidic, basic and neutral samples.
- Optimize the organic component of the mobile phase to change selectivity
- Choose alternate bonded phases to completely optimize method, if needed
- **Choose SB-C18 for pH 1-2**

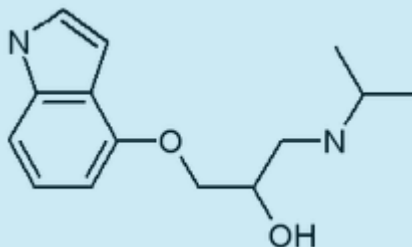
- **With new RRHT column choices, these steps can be done quickly, making it possible to truly find the best method.**

Let's Look at Method Development of These Compounds

propranolol



pindolol



dipyridamole



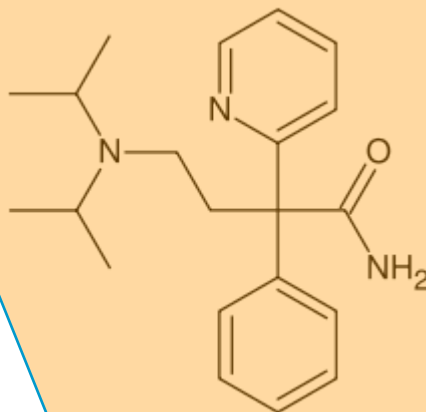
β -blocker

Anti-arrhythmic

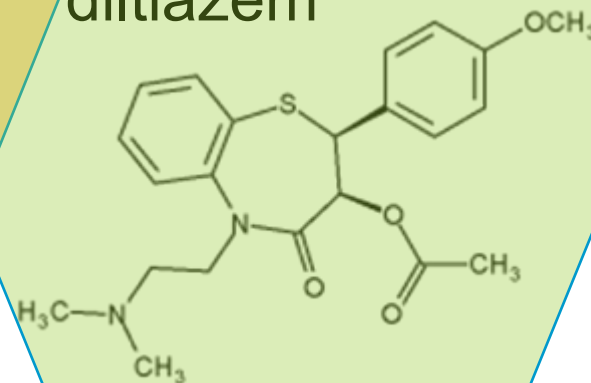
Vasodilator

Ca²⁺ channel blocker

disopyramide



diltiazem



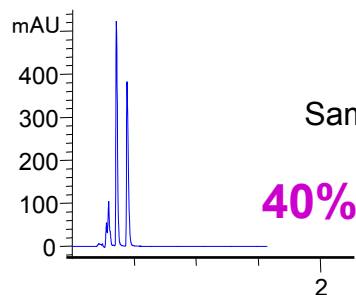
Start at Low pH, Adjust % Organic Eclipse Plus C18 Cardiac Drugs with Acetonitrile

Column: ZORBAX RRHT Eclipse Plus C18, 4.6 x 50 mm, 1.8 μ m

Mobile Phase: A: 25 mM NaH_2PO_4 , pH 3.0 B: ACN

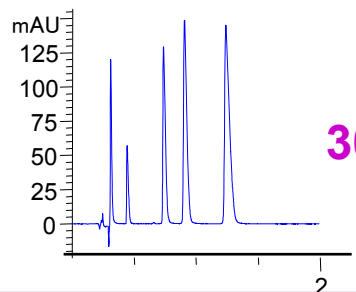
Flow Rate: 2.0 mL/min Temperature: 30°C Detection: UV 240 nm

Sample: Cardiac Drugs 1.Pindolol 2. Di-isopyridamide 3.Propranolol 4.Dipyridamole 5. Diltiazem



40% ACN

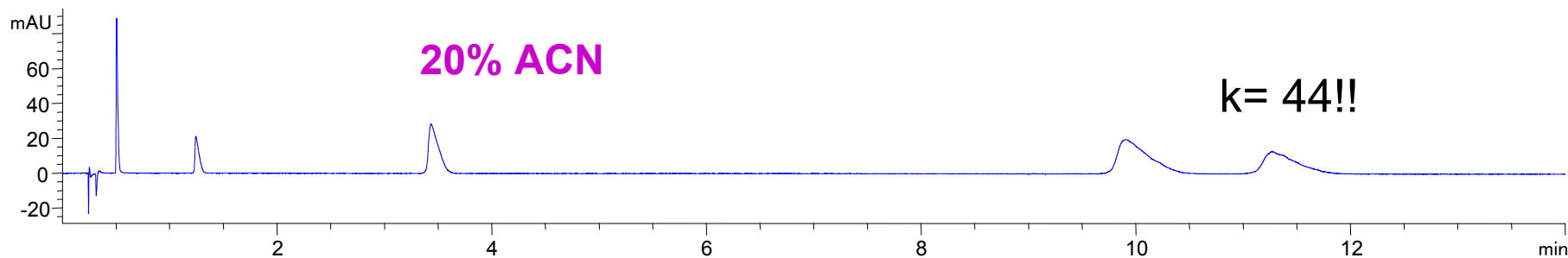
RRHT Eclipse Plus C18 allows for very fast optimization of % organic in mobile phase.



30% ACN



- Good resolution
- Fast analysis
- No time wasted

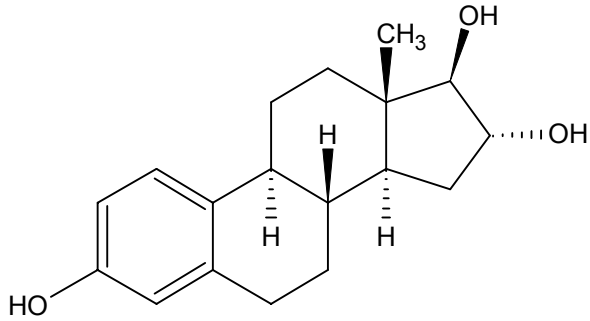


20% ACN

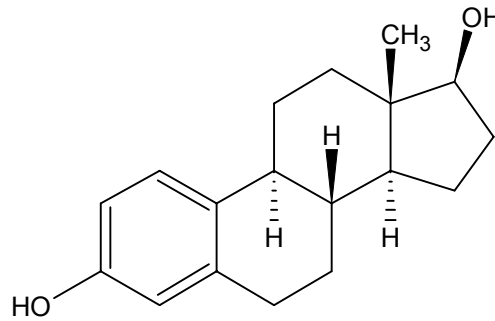
k= 44!!



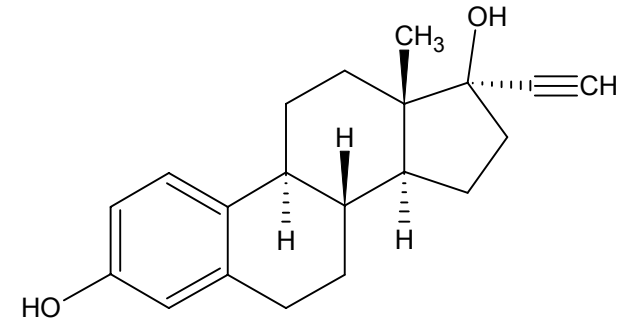
Steroidal Compounds



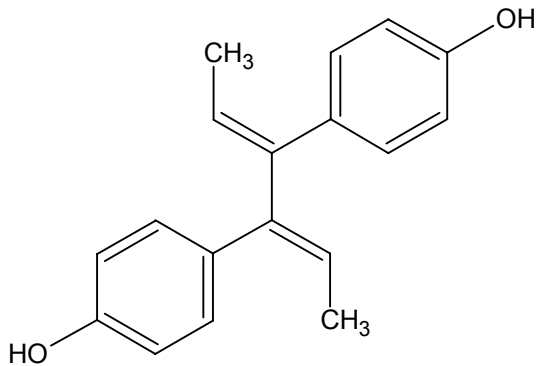
estriol



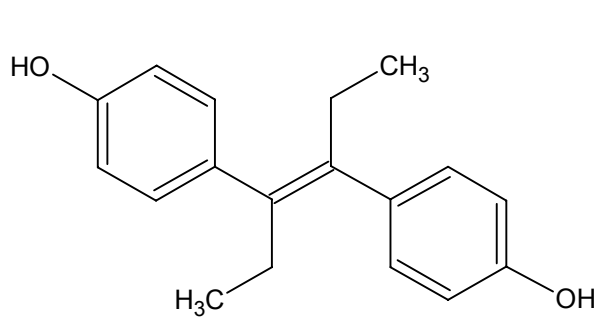
estradiol



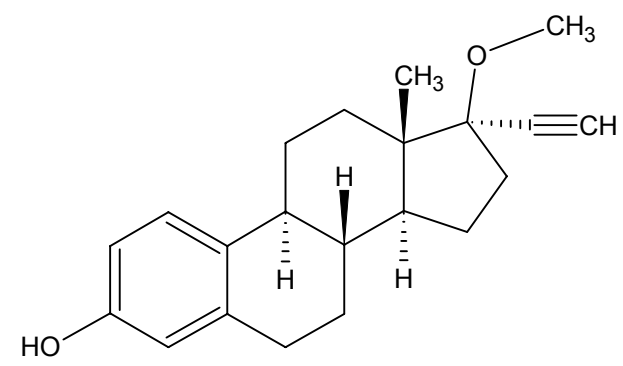
ethinyl estradiol



dienestrol

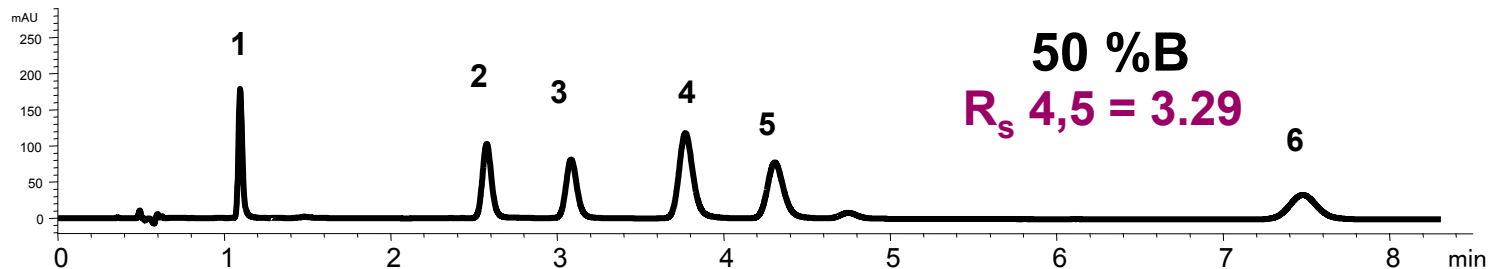
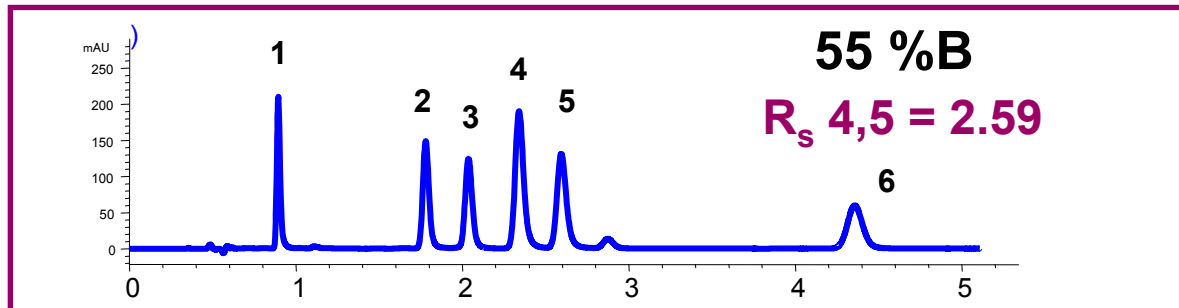
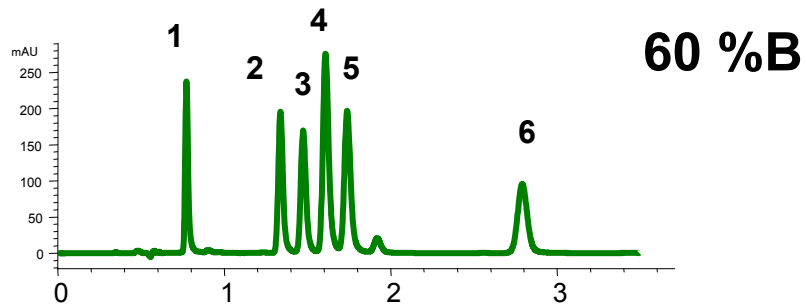


diethylstilbestrol



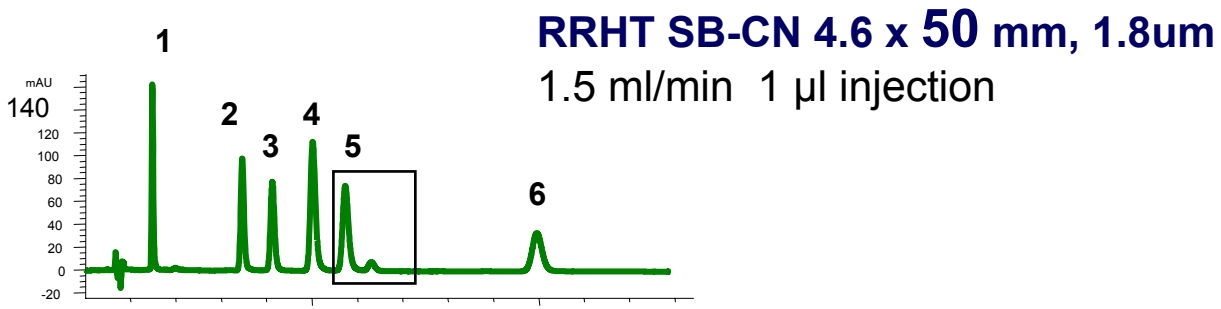
ethinyl estradiol 3-methyl ether

Mobile Phase Optimization on Short RRHT 4.6 x 50 mm, SB-CN Column

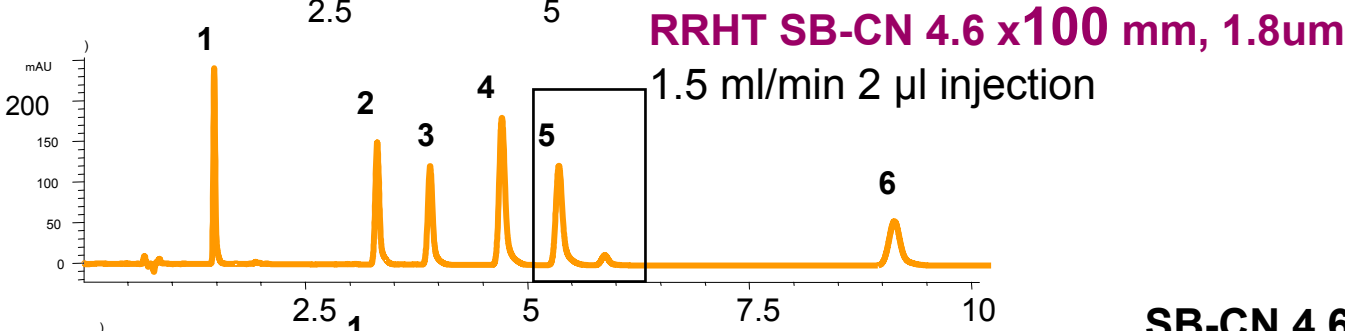


➤ RRHT columns allow for very fast optimization of % organic in mobile phase.

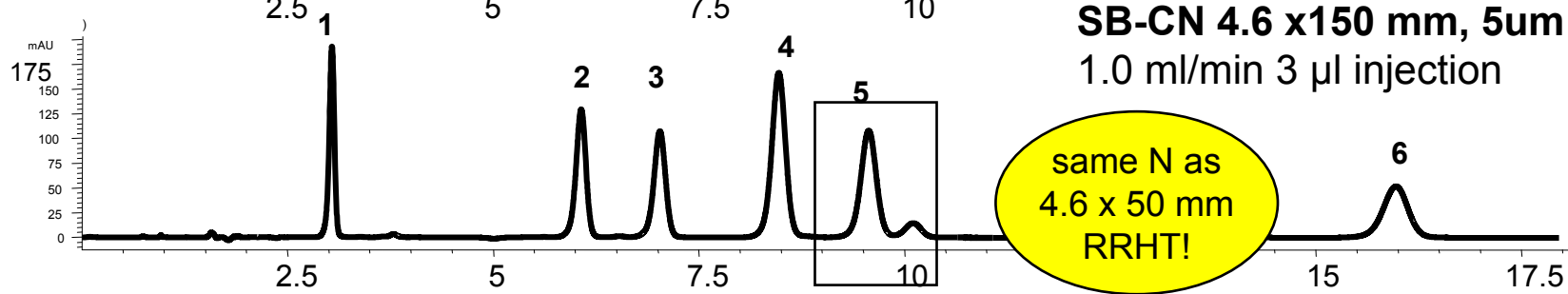
Comparison of Optimal Conditions On Columns with Different Dimensions – Length, Particle Size, Resolution



- 1. Estriol
- 2. Estradiol
- 3. Ethinyl Estradiol
- 4. Dienestrol
- 5. Diethylstilbestrol
- 6. Ethinyl estradiol methyl ether



A: Water
B: 30 % MeOH/ 70 %MeCN
40 % B
Detection: UV 210 nm



RRHT Columns allow rapid resolution optimization during initial method development. Column lengths compared quickly.

Why Do We Recommend Changing Organic Modifier Before Changing the Bonded Phase?

- **It's easy – acetonitrile and methanol are readily available!**
- **It works on any bonded phase, so it gives you a tool to possibly optimize a separation no matter the column choice!**



Start at Low pH on Eclipse Plus-C18 RRHT Cardiac Drugs with Methanol, Changing Organic Modifier

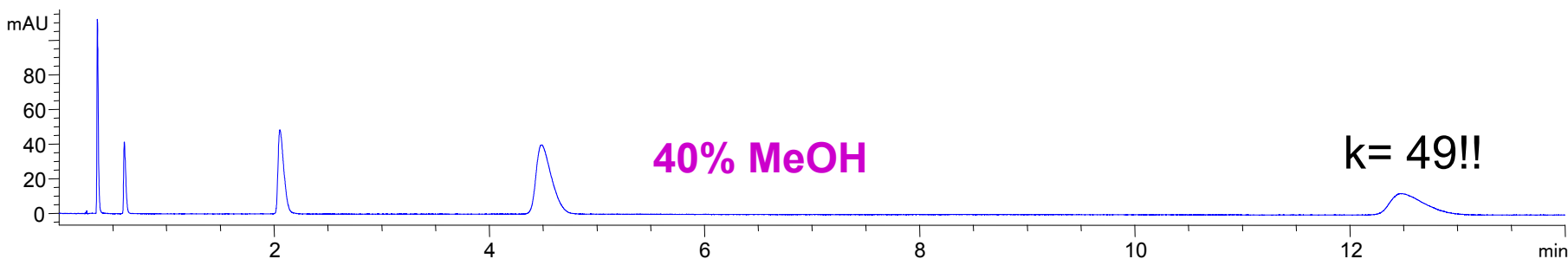
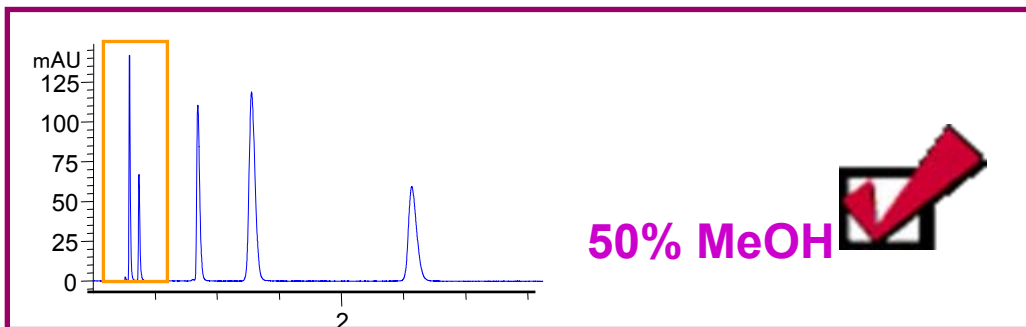
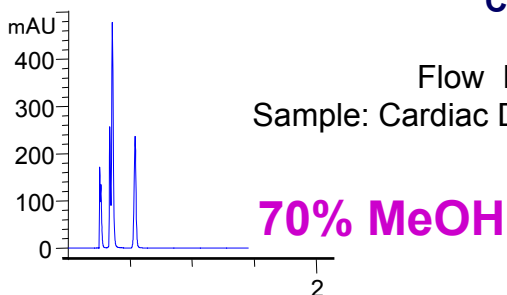
Remember to use buffer!

Column: ZORBAX RRHT Eclipse Plus C18, 4.6 x 50 mm, 1.8 μ m

Mobile Phase: A: 25 mM NaH_2PO_4 , pH 3.0 B: MeOH

Flow Rate: 2.0 mL/min Temperature: 30°C Detection: UV 240 nm

Sample: Cardiac Drugs 1.Pindolol 2. Di-isopyridamide 3.Propranolol 4.Diltiazem 5. Dipyridamole



- Adjusting [MeOH] influences retention like adjusting ACN
- Solvents can be compared quickly with RRHT columns
- MeOH changes selectivity and gives longer analysis time for these analytes

Method Development - Change Organic Modifier

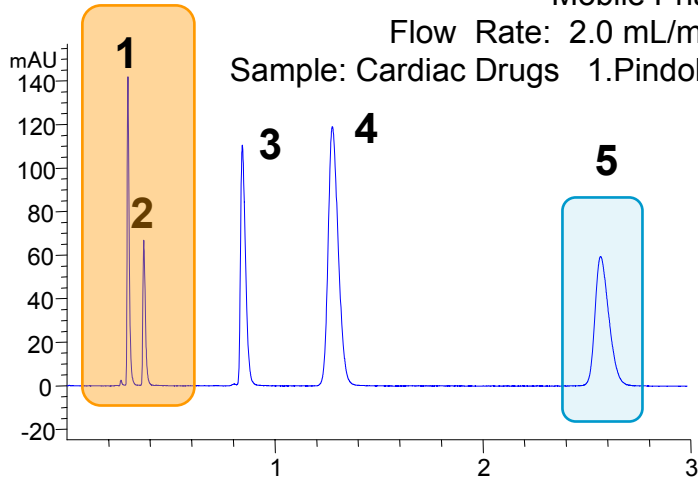
Comparison of Acetonitrile and MeOH

Column: ZORBAX RRHT Eclipse Plus C18, 4.6 x 50 mm, 1.8 μ m

Mobile Phase: A: 25 mM NaH_2PO_4 , pH 3.0 B: organic

Flow Rate: 2.0 mL/min Temperature: 30°C Detection: UV 240 nm

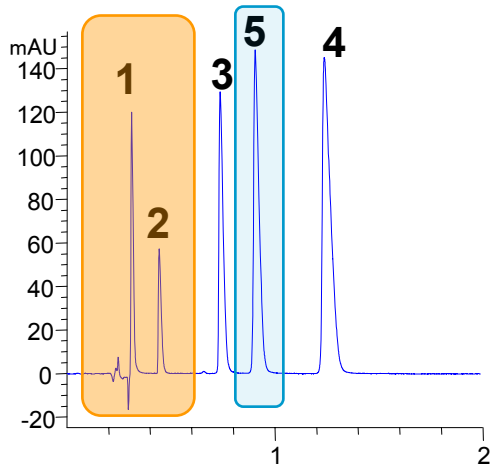
Sample: Cardiac Drugs 1.Pindolol 2. Diisopyridamide 3.Propranolol 4.Diltiazem 5. Dipyridamole



50% MeOH

Resolution of pairs
(2,3), (3,4), (4,5)
is better in MeOH.

Peak 5 selectivity shift



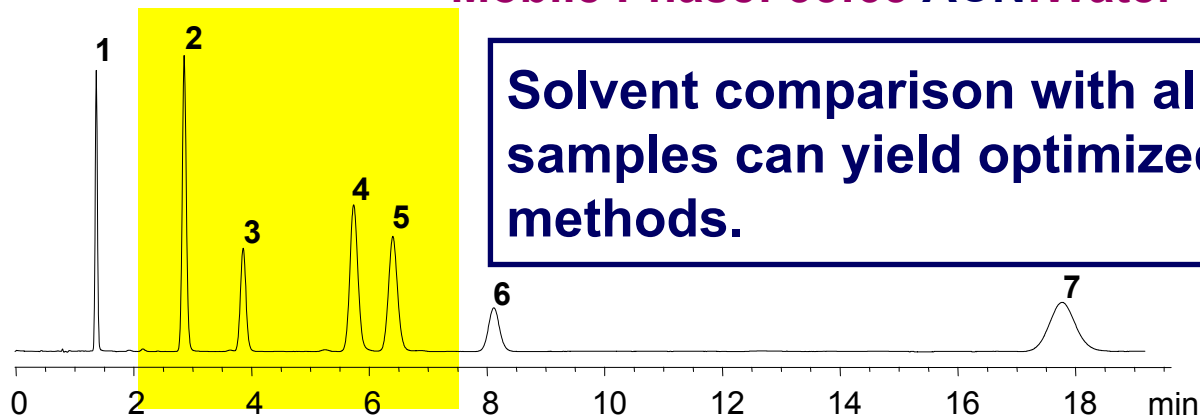
30% ACN

Resolution of critical pair
(1,2), is better in ACN

Change Mobile Phase - Acetonitrile vs. Methanol on ZORBAX Eclipse XDB-CN with Estrogens

Column: ZORBAX Eclipse XDB-CN Column Dimensions: 4.6 x 150 mm, 5 μ m Mobile Phase: As shown
Flow Rate: 2.0 ml/min Injection Volume: 2.00 μ l Column Temperature: 25 $^{\circ}$ C Detector: UV, 210 nm

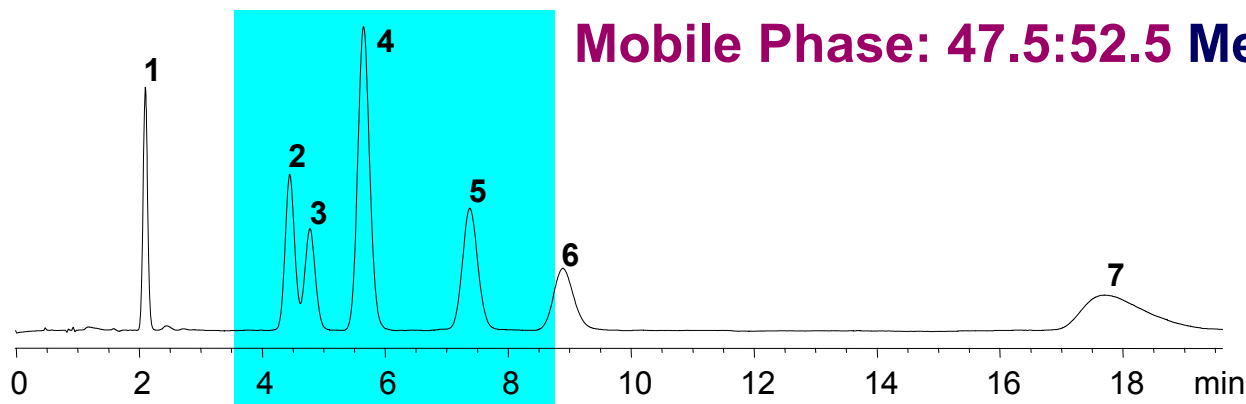
Mobile Phase: 35:65 ACN:Water



Sample:

1. Estriol (0.00130 μ g/ μ l),
2. β -Estradiol (0.00130 μ g/ μ l),
3. Ethinyl Estradiol (0.00147 μ g/ μ l),
4. Dienestrol (0.00123 μ g/ μ l),
5. Diethylstilbestrol (0.00128 μ g/ μ l)
6. Ethinylestradiol 3-methyl ether (0.00103 μ g/ μ l)
7. Ethynodiol Diacetate (0.00139 μ g/ μ l)

Mobile Phase: 47.5:52.5 MeOH:Water



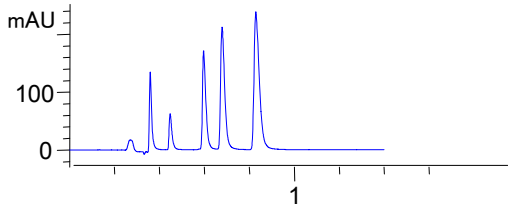
Why Is Changing the Bonded Phase Effective?

- Differences in interactions between polar and non-polar compounds.
- Other types of interactions with a bonded phase can be exploited (pi-pi interactions etc.)
- These all change with bonded phase!
- Changing the bonded phase can improve selectivity/ resolution, reduce analysis time

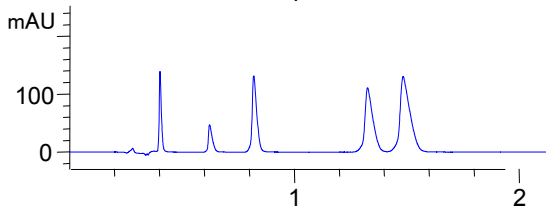
When you use RRHT (1.8um) columns, the comparison of bonded phases can be done quickly!!

- You must have multiple RRHT column choices available

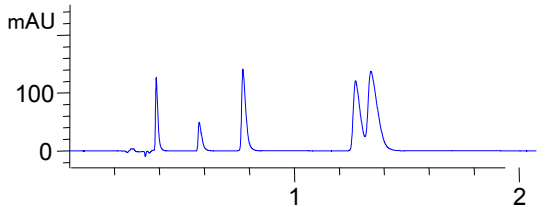
Bonded Phase Selectivity Differences in 30% ACN



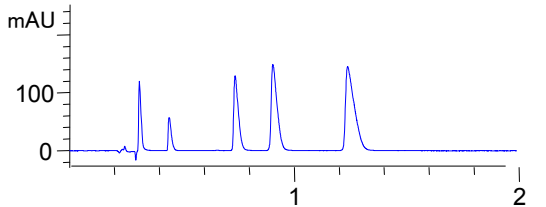
RRHT SB-CN
4.6 x 50 mm, 1.8 μm



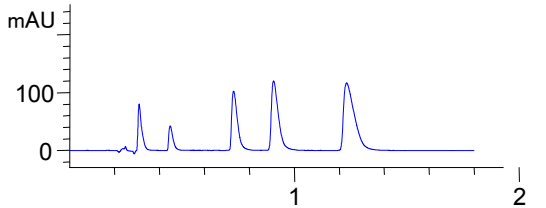
RRHT SB-Phenyl
4.6 x 50 mm, 1.8 μm



RRHT SB-Aq
4.6 x 50 mm, 1.8 μm



RRHT Eclipse Plus C18
4.6 x 50 mm, 1.8 μm

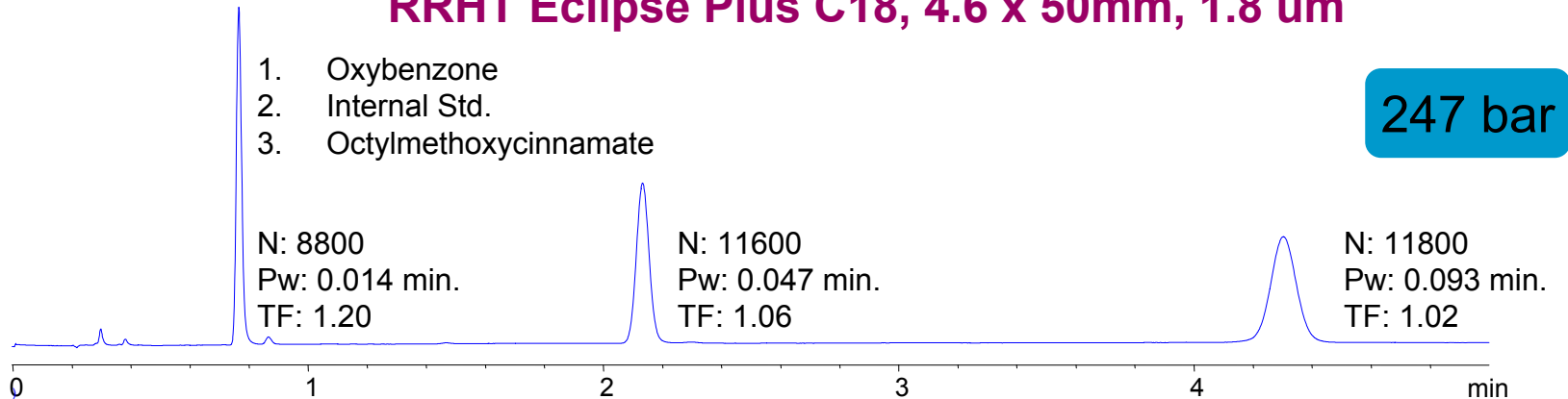


RRHT SB-C18
4.6 x 50 mm, 1.8 μm

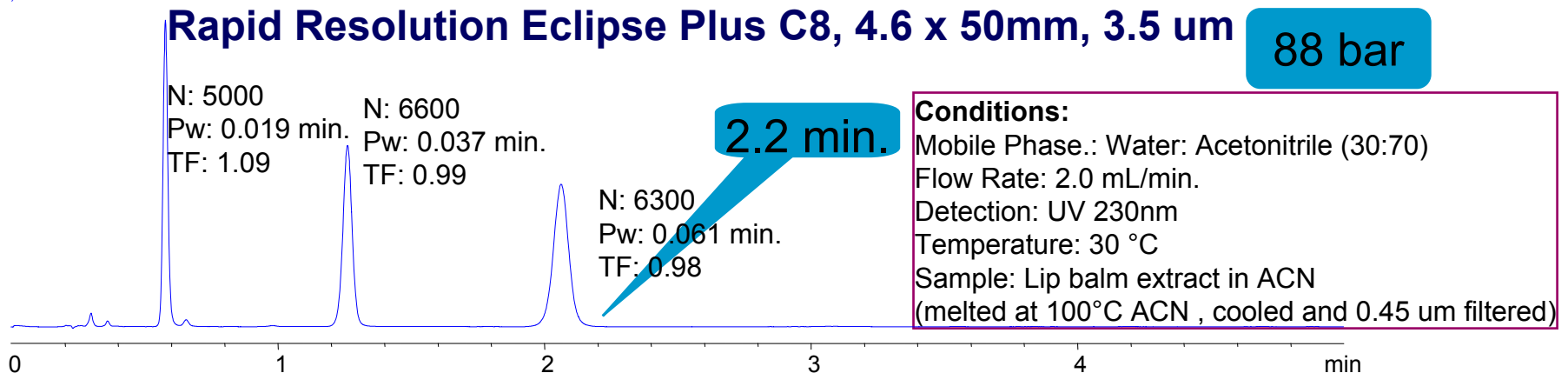
- 5 Different bonded phases compared
- Analysis time of each run is only 2 minutes
- Comparison among phases done in optimum % organic for SB-CN
- The fast runs mean a comparison can be done even if you have a good separation on the C18
- **More chances to optimize!**

Selectivity/Bonded Phase Choices: Eclipse Plus C18 vs. C8 and RRHT vs. RR

RRHT Eclipse Plus C18, 4.6 x 50mm, 1.8 μ m



Rapid Resolution Eclipse Plus C8, 4.6 x 50mm, 3.5 μ m

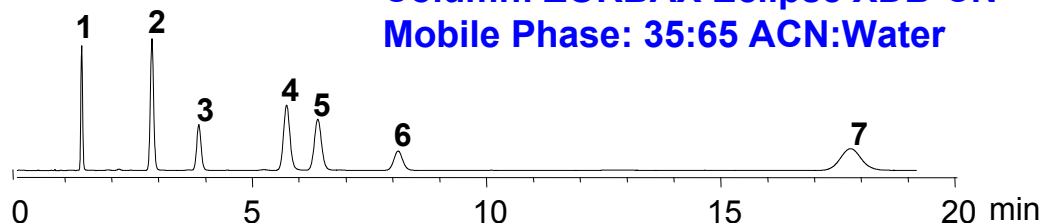


Less retention can save significant time – the C8 is a good choice here.

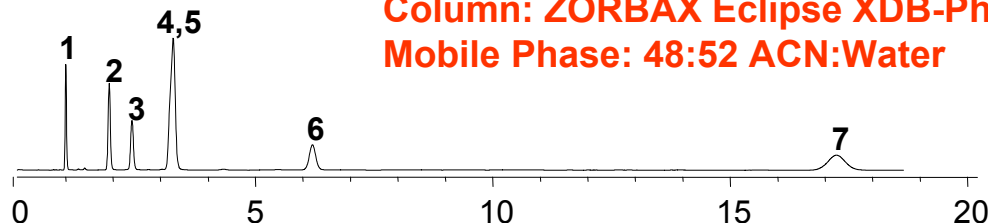
The RRHT column is delivering the efficiency and resolution expected, but the C8 bonded phase may be the better choice.

Selectivity of Polar Phases Provides Optimum Separation of Steroids Versus Non-Polar C18/C8

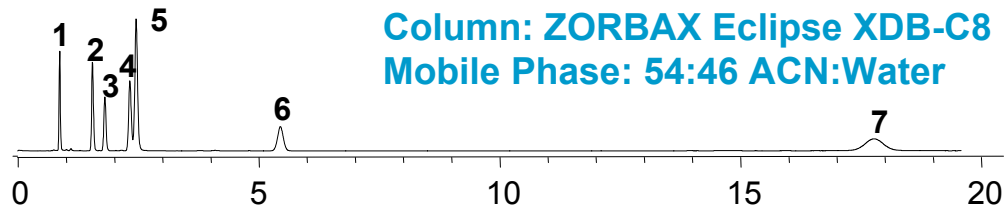
Column: ZORBAX Eclipse XDB-CN
Mobile Phase: 35:65 ACN:Water



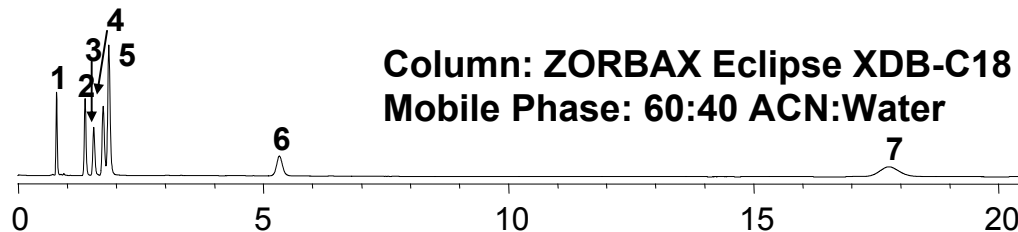
Column: ZORBAX Eclipse XDB-Phenyl
Mobile Phase: 48:52 ACN:Water



Column: ZORBAX Eclipse XDB-C8
Mobile Phase: 54:46 ACN:Water



Column: ZORBAX Eclipse XDB-C18
Mobile Phase: 60:40 ACN:Water



Column Dimensions: 4.6 x 150 mm, 5 μ m
Flow Rate: 2.0 ml/min
Injection Volume: 2.00 μ l
Column Temperature: 25 $^{\circ}$ C
Detector: UV, 210 nm

Sample:

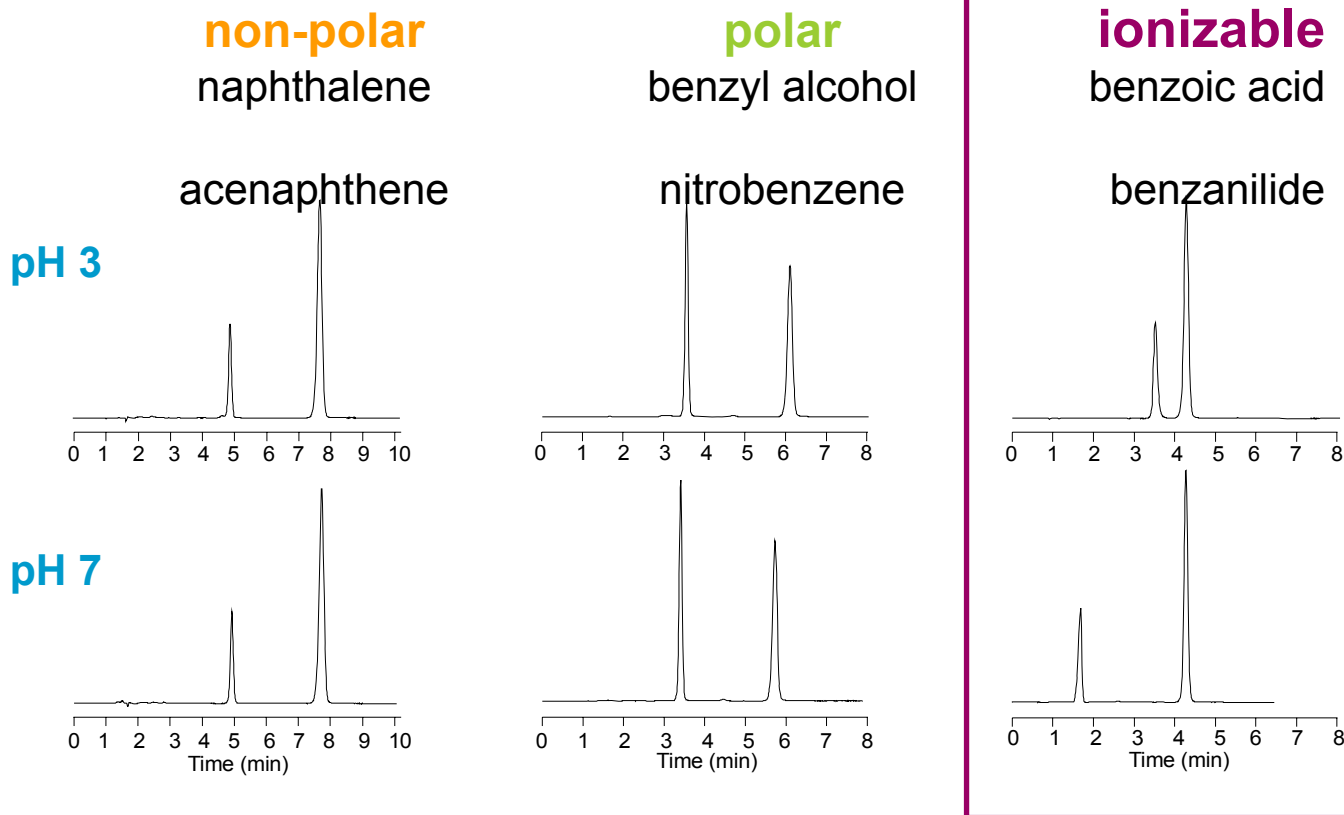
1. Estriol (0.00130 μ g/ μ l),
2. β -Estradiol (0.00130 μ g/ μ l),
3. Ethinyl Estradiol (0.00147 μ g/ μ l),
4. Dienestrol (0.00123 μ g/ μ l),
5. Diethylstilbestrol (0.00128 μ g/ μ l)
6. Ethinyl estradiol 3-methyl ether (0.00103 μ g/ μ l)
7. Ethynodiol Diacetate (0.00139 μ g/ μ l)

➤ **Eclipse XDB-CN is the optimum bonded phase – the only one that can resolve all the components in under 20 minutes.**

So then Why is pH Critical to Method Development?

- **What compounds are pH sensitive?**
- **How does pH affect retention and resolution?**
- **How does pH influence method development?**
- **How does pH influence column choice?**

When Does pH affect Resolution? Compound Type Comparison



- Ionizable compounds – acids and bases can change retention and selectivity the most with changes in pH

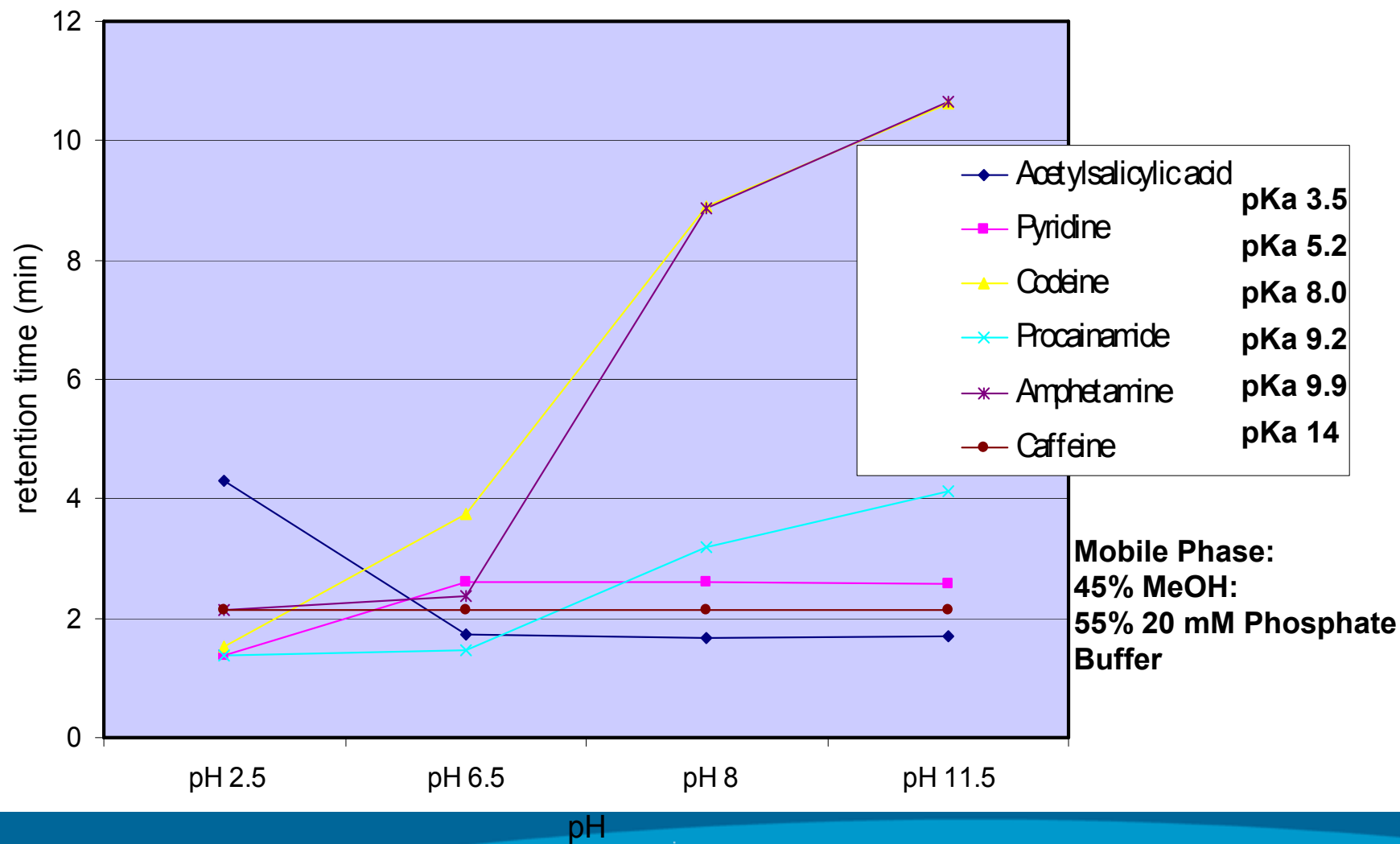
Change in Retention with pH for Ionizable Compounds is Key to Method Development

- Non-charged analytes have better retention (i.e. acids at low pH and bases at high pH)
- Silanols on silica ionize at mid-pH, increasing retention of basic analytes
(i.e possible ion-exchange interactions)
- Choose mobile phase pH to optimize retention and selectivity during method development
- Eclipse Plus can be used over a wide pH range
- Other choices exist for high pH

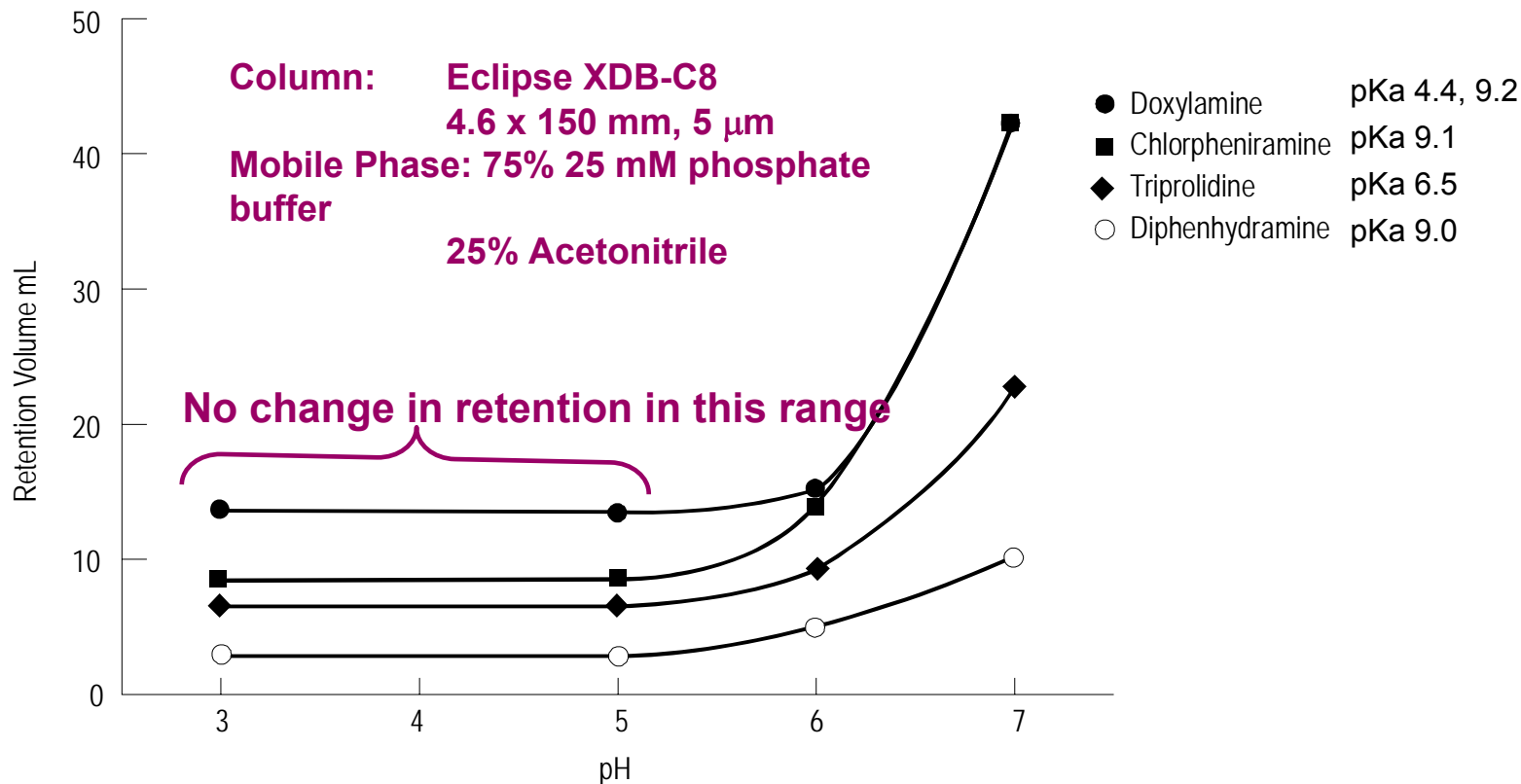


Change in Retention with pH for Ionizable Compounds is Compound Dependent

Non-charged analytes have better retention (i.e. acids at low pH and bases at high pH)



Retention vs. pH for Basic Antihistamines - Less Variation in Retention at Low pH



- Slight changes in pH may dramatically change retention and selectivity
- Always evaluate retention changes with pH during method development

Therefore pH Should be Considered a Key Method Development Parameter

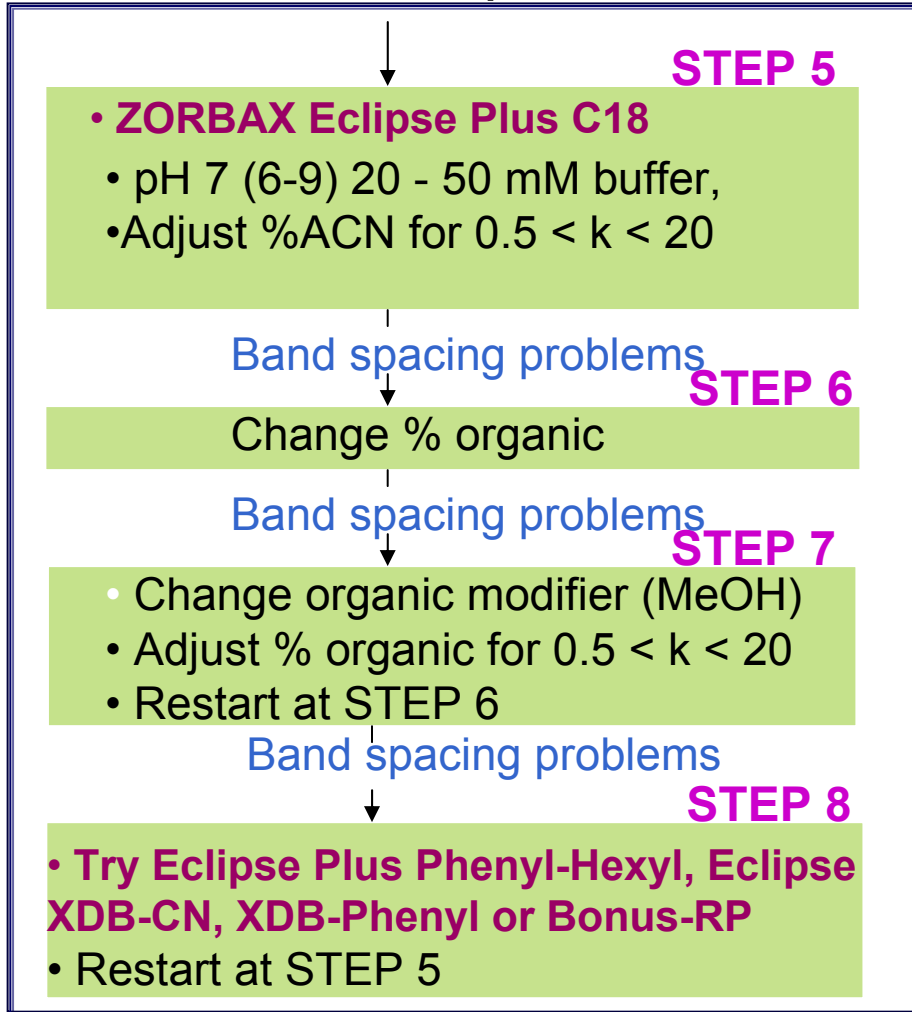
A single column can be used over a wide pH range making selectivity comparisons quick and reliable when pH is changed.

May have better selectivity in the pH range 3 – 8.

Other bonded phases can be reconsidered for mid pH, just like at low pH

Method Development Scheme – Adding Mid pH

From low pH



- Mid pH can provide better selectivity
- It may be more compatible with your sample
- The process for investigating mid pH is the same as for low pH
- Eclipse Plus delivers outstanding performance at mid pH
- Alternate bonded phases should also be considered if improved selectivity is desired



Eclipse Plus Columns Are Ideal for Method Development at Low and Mid pH

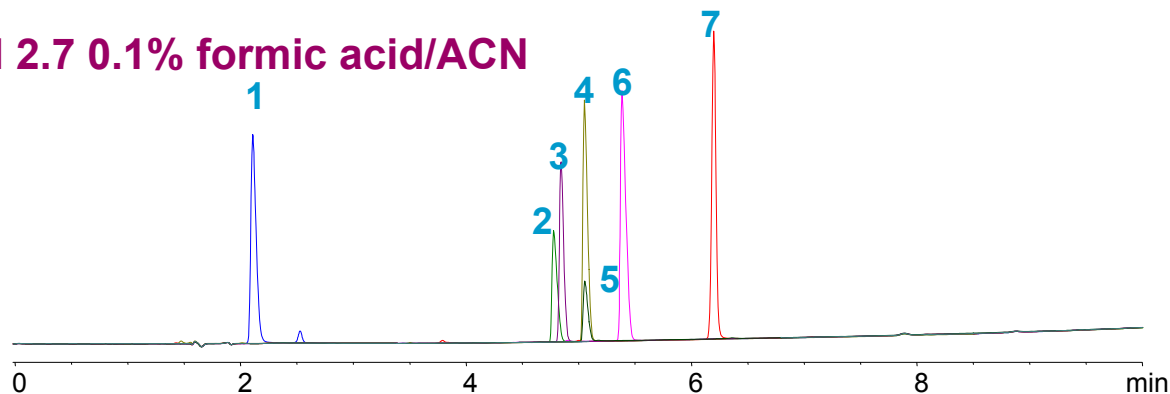
- **Can be used from pH 2-9**
- **Accommodates method development in low and mid pH ranges**
- **Allows pH sensitive separations to be optimized**

Excellent peak shape and efficiency achieved with new Eclipse Plus material

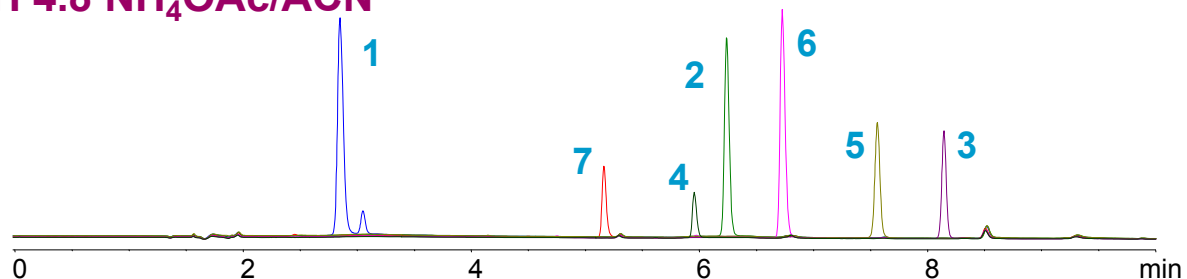


Eclipse Plus Can Be Used Over a Wide pH Range (pH 2 – 9) to Optimize Selectivity

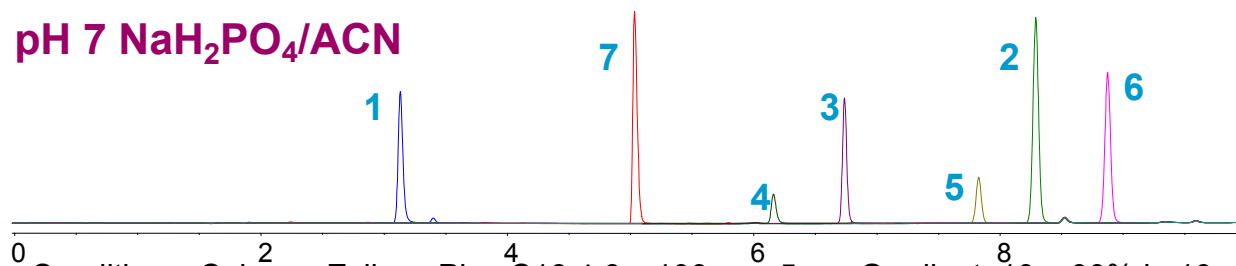
pH 2.7 0.1% formic acid/ACN



pH 4.8 NH₄OAc/ACN



pH 7 NaH₂PO₄/ACN



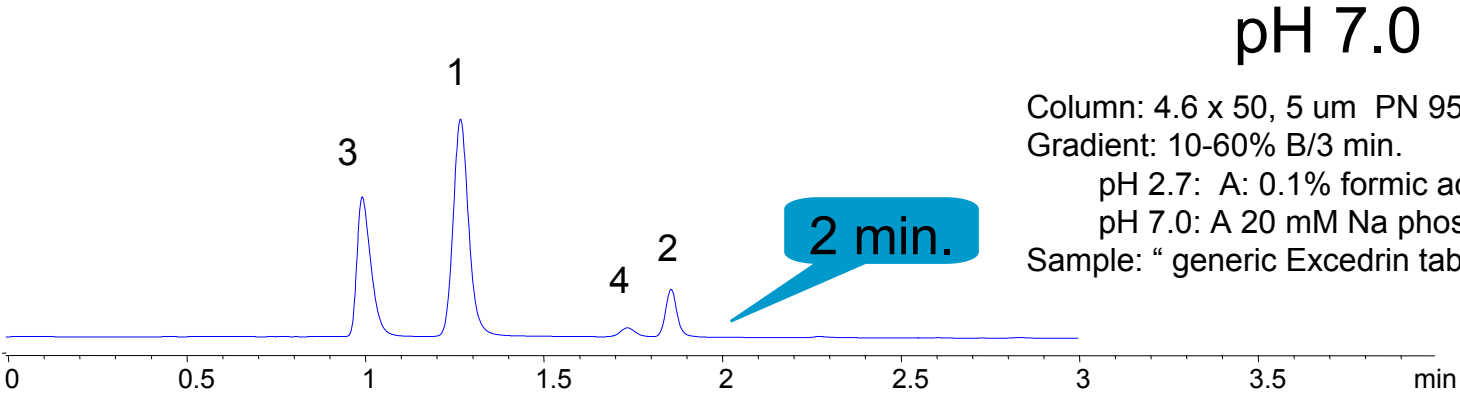
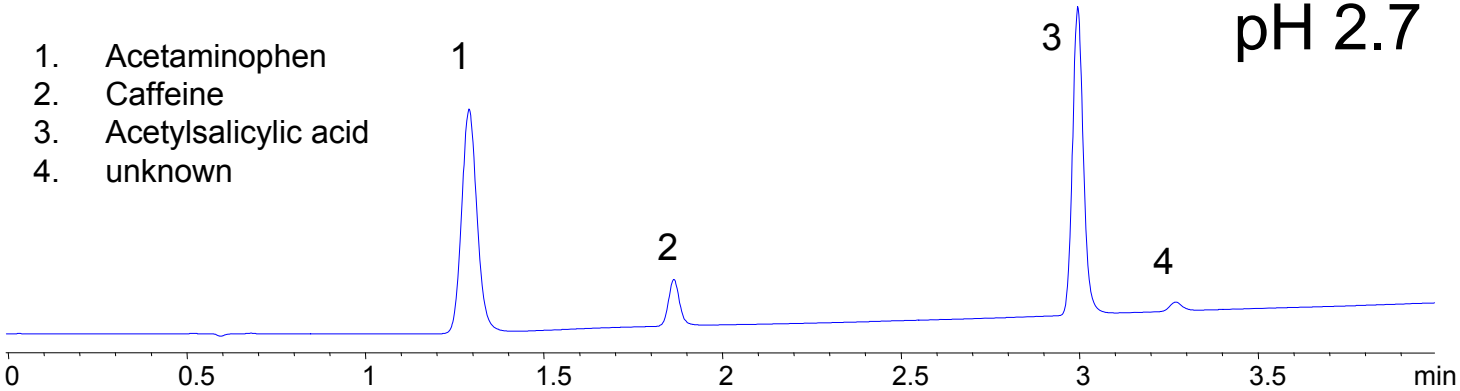
Conditions: Column: Eclipse Plus C18 4.6 x 100mm, 5um Gradient: 10 – 90% in 10 minutes Detection: UV 254 nm

1. procainamide
2. buspirone
3. pioglitazone
4. eletriptan
5. dipyridamole
6. diltiazem
7. furosemide

- Selectivity and resolution can change with pH
- Eclipse Plus can be used with many mobile phases and pHs

Selectivity Differences at pH 2 and pH 7 Can Be Dramatic

Eclipse Plus C8 4.6 x 50mm, 5 um

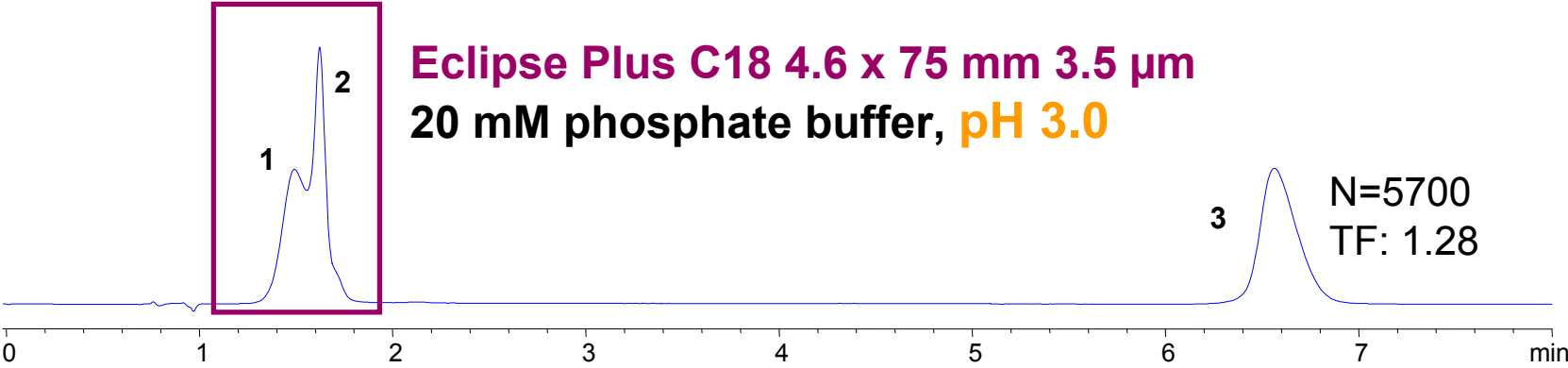


Column: 4.6 x 50, 5 um PN 959946-906
Gradient: 10-60% B/3 min.
pH 2.7: A: 0.1% formic acid B: 0.1% fa in ACN
pH 7.0: A: 20 mM Na phosphate B: ACN
Sample: "generic Excedrin tablet"

- Selectivity can change dramatically from pH 2 – 7 with many samples, such as for the ingredients in this analgesic tablet.
- Eclipse Plus can be used under both conditions

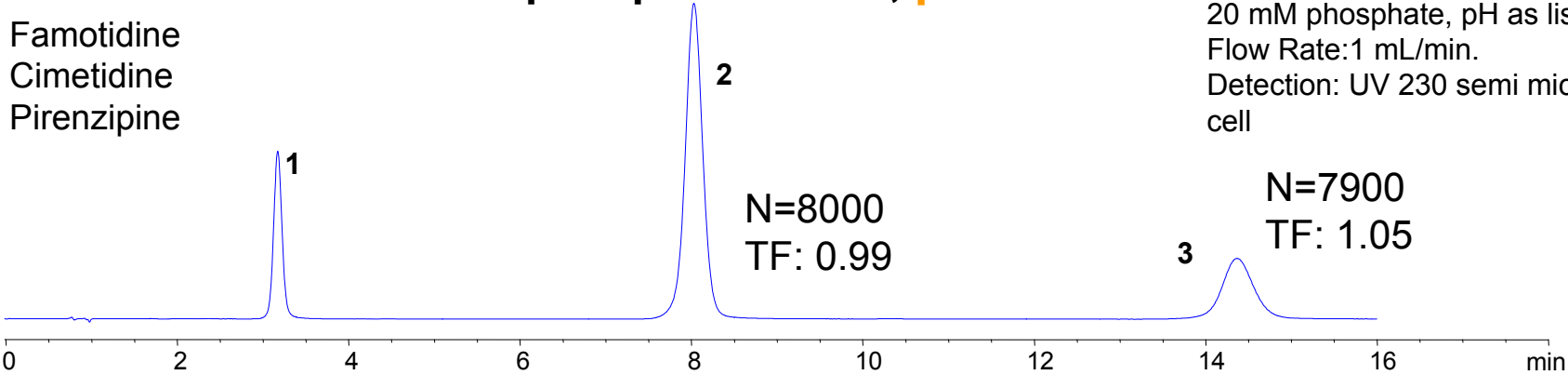
Selectivity Differences at Mid pH Key to Resolution

Eclipse Plus Performs well at Low and Mid pH



Eclipse Plus C18 4.6 x 75 mm 3.5 μm
20 mM phosphate buffer, pH 7.0

- 1. Famotidine
- 2. Cimetidine
- 3. Pirenzipine

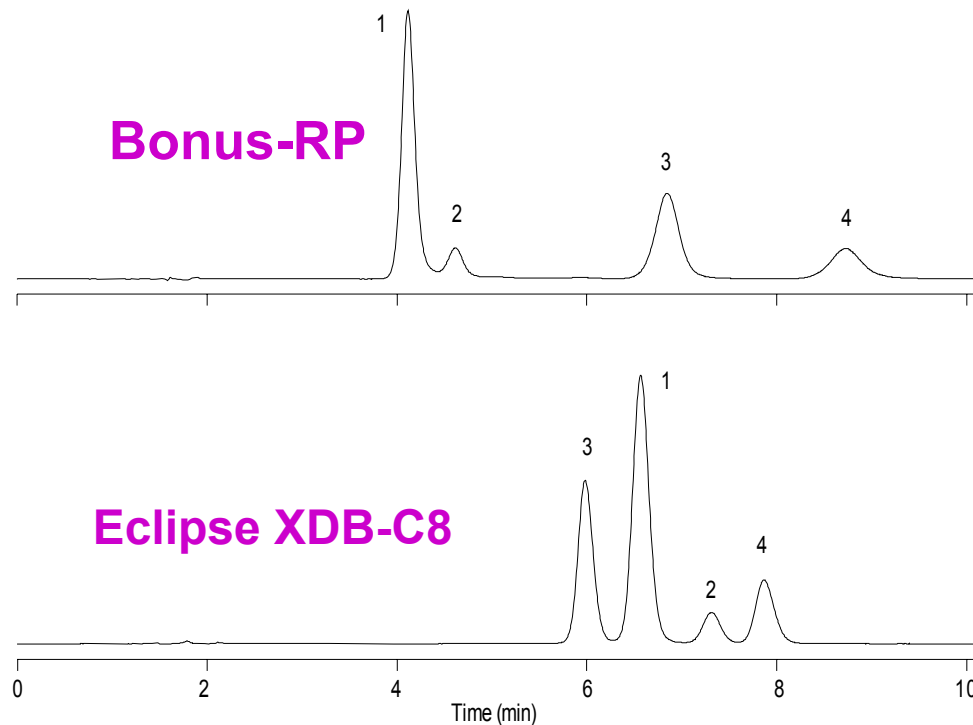


Columns: as listed
 Mobile Phase: 20% MeOH, 80%
 20 mM phosphate, pH as listed
 Flow Rate: 1 mL/min.
 Detection: UV 230 semi micro flow
 cell

- For this sample resolution is not possible at pH 3, but is at pH 7
- Eclipse Plus was used to experiment at both pHs

Try an Alternate Selectivity at Mid pH if Needed

- One choice for alternate selectivity is Bonus-RP.
- The alkyl-amide bonded phase provides very different selectivity at mid-pH



Mobile Phase: 75% mM
NaCitrate, pH 6
25% MeOH
Flow Rate: 1.0 mL/min
Temperature: Ambient
Detection: UV 254 nm
Injection Vol: 3 μ L
Sample: Cephalosporins
1. Cephalexin
2. Cephaclo
3. Cephuroxime
4. Cephoxitin

Mid pH was the second pH region to consider.

High pH can also be considered if low or mid pH do not resolve all analytes.

Method Development at High pH – a Third Choice

From Mid pH



STEP 9

• ZORBAX Extend-C18

- pH 10.5 (9-12) 5 mM ammonia, or TEA, or 10 – 50 mM organic or borate buffers
- T = 25°C (ambient – 40°C)
- Adjust MeOH for $0.5 < k < 20$

Band spacing problems



STEP 10

- Change organic modifier (ACN or THF)
- Adjust for $0.5 < k < 20$

Try different HPLC mode

Reasons to Consider High pH

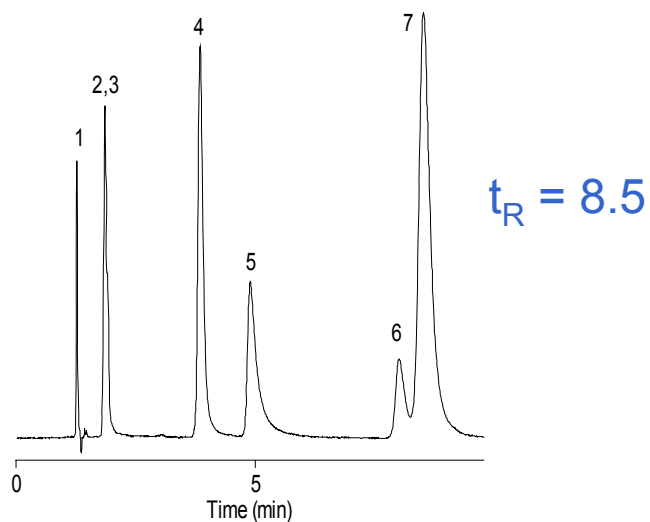
- Increase retention of basic compounds by analyzing them in non-charged form
- Improve selectivity



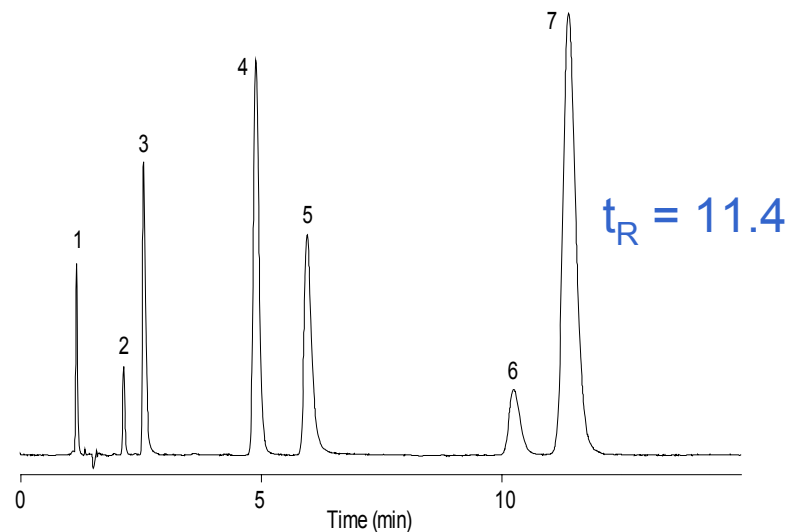
High pH Increases Retention of Antihistamines Extend-C18

Column: ZORBAX Extend-C18, 4.6 x 150 mm, 5 μ m Mobile Phase: See Below Flow Rate: 1.0 mL/min
Temperature: RT Detection: UV 254 nm Sample: 1. Maleate 2. Scopolamine 3. Pseudoephedrine 4. Doxylamine
5. Chlorpheniramine 6. Triprolidine 7. Diphenhydramine

pH 7
30% 20 mM Na₂HPO₄
70% MeOH



pH 11
30% 20 mM TEA (triethylamine)
70% MeOH



➤ The retention of the basic compounds in this sample increases at high pH.

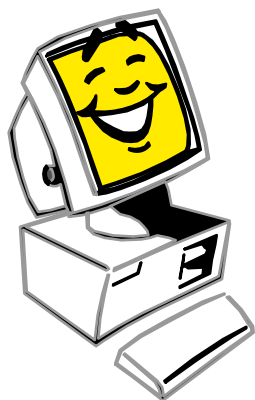
Conclusions

- ✓ New column choices, like 1.8um RRHT columns and Eclipse Plus bonded phases can enhance typical approaches to method development.
- ✓ These columns provide fast analysis, allowing more options to be considered quickly, and with superior performance, the best results are readily achievable.
- ✓ Since many compounds are ionizable, and retention and selectivity of these compounds are greatly impacted by pH, a method development scheme for LC methods should encourage varying pH.
- ✓ Any method development scheme should also include the use of different bonded phases. Different bonded phases and columns can be selected by pH as well.
- ✓ The third key aspect of method development is mobile phase and organic modifier and this is an effective tool for many separations.



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May 14, 2008 – 2:00 p.m. EDT

