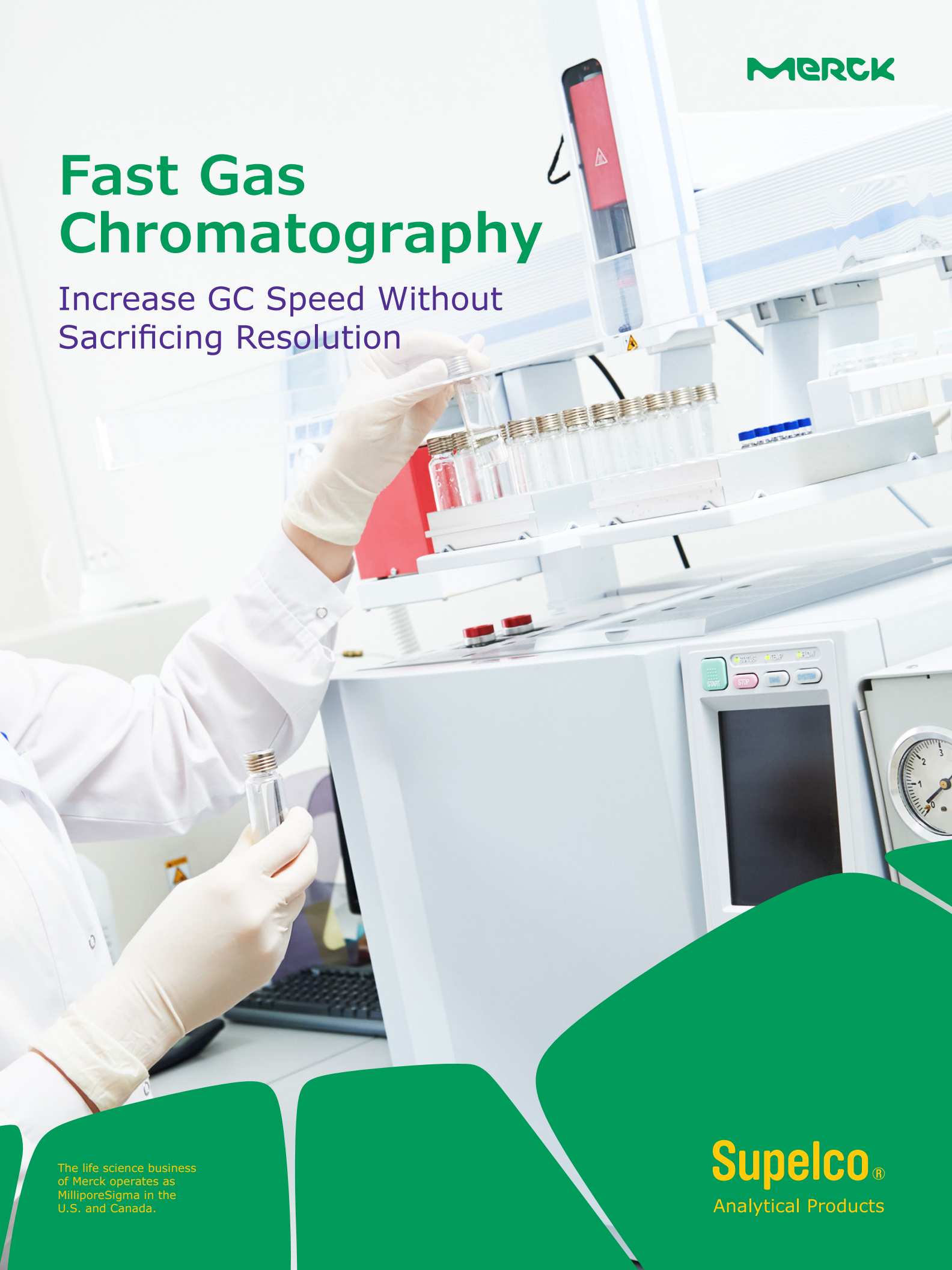
Fast Gas Chromatography

Increase GC Speed Without Sacrificing Resolution



Supelco®
Analytical Products

Overview

Shorter analysis times allow increased sample throughput, which translates to the completion of more runs per shift. However, any decrease in analysis time must not diminish the resolution necessary to adequately resolve peaks of interest, or to identify specific elution patterns. The information presented in this brochure will show how to apply the Principles of Fast GC to increase GC speed without sacrificing resolution for any application in any industry.

The Six Principles of Fast GC

Simply stated, Fast GC is the manipulation of a number of parameters to provide faster analysis times while maintaining resolution. Analysis times are decreased by using:

1. Short columns
2. Fast oven temperature ramp rates
3. High carrier, gas linear velocities
4. Narrow I.D. columns
5. Hydrogen carrier gas
6. Low film thickness

Many of these parameters are related to each other. Changing just one may produce a shorter analysis, but may result in a loss in quality. Therefore, all parameters must be evaluated to make sure they are set correctly. The more principles that are applied, the greater the benefit!

Why Do Fast GC?

Time and money! Fast GC yields faster analysis times than conventional GC, often three to ten times faster. The benefits are:

- Costs can be decreased if fewer analysts and/or instruments are needed
- Revenue can be increased if more samples are analyzed
- It can be applied to any application with no sacrifice in quality
- It typically does not require any additional equipment

To highlight why Fast GC should be considered, **Figure 1** directly compares conventional GC to Fast GC.

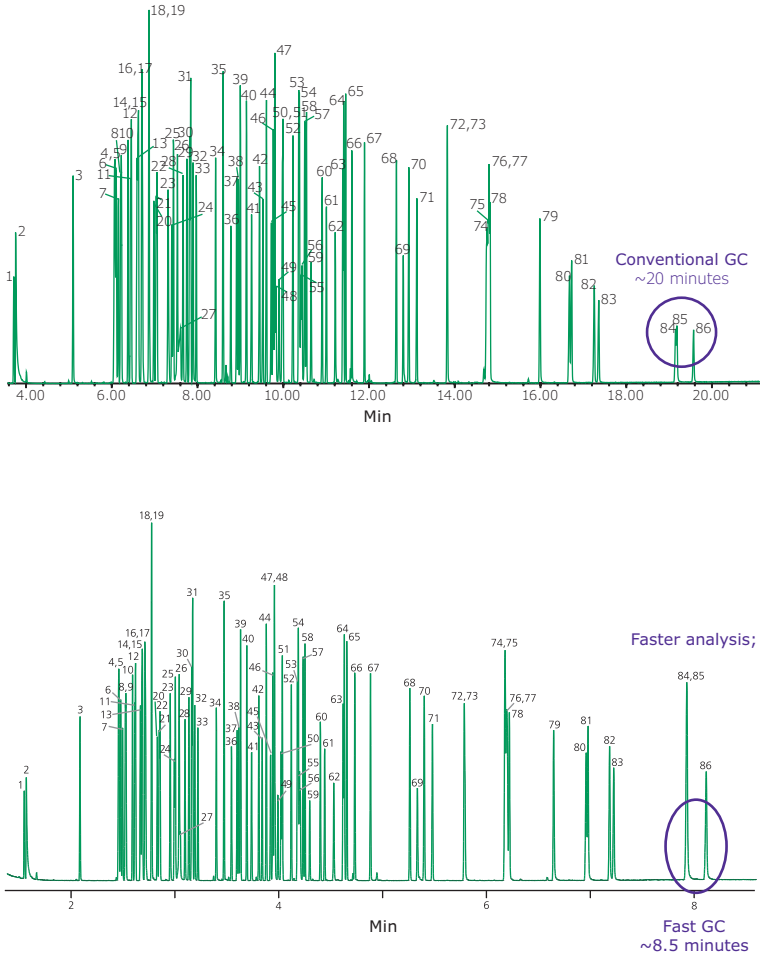
The example shown is the GC/MS analysis of semivolatiles, an application routinely performed in environmental laboratories.

The conventional GC method requires 20 min for this analysis, whereas the same resolution can be achieved in just 8.5 min after applying the Principles of Fast GC. Equally important is that this increase in sample throughput does not require any increase in staff or equipment.

Peak IDs for Figure 1

1. *N*-Nitrosodimethylamine
2. Pyridine
3. 2-Fluorophenol (surr.)
4. Phenol-d_6 (surr.)
5. Phenol
6. Aniline
7. Bis(2-chloroethyl)ether
8. 2-Chlorophenol-d_4 (surr.)
9. 2-Chlorophenol
10. 1,3-Dichlorobenzene
11. 1,4-Dichlorobenzene-d_4 (I.S.)
12. 1,4-Dichlorobenzene
13. Benzyl alcohol
14. 1,2-Dichlorobenzene-d_4 (surr.)
15. 1,2-Dichlorobenzene
16. 2-Methylphenol
17. Bis(2-chloroisopropyl)ether
18. *N*-Nitroso-di-*n*-propylamine
19. 4-Methylphenol
20. Hexachloroethane
21. Nitrobenzene-d_5 (surr.)
22. Nitrobenzene
23. Isophorone
24. 2-Nitrophenol
25. 2,4-Dimethylphenol
26. Bis(2-chloroethoxy) methane
27. Benzoic acid
28. 2,4-Dichlorophenol
29. 1,2,4-Trichlorobenzene
30. Naphthalene-d_8 (I.S.)
31. Naphthalene
32. 4-Chloroaniline
33. Hexachlorobutadiene
34. 4-Chloro-3-methylphenol
35. 2-Methylnaphthalene
36. Hexachlorocyclopentadiene
37. 2,4,6-Trichlorophenol
38. 2,4,5-Trichlorophenol
39. 2-Fluorobiphenyl (surr.)
40. 2-Chloronaphthalene
41. 2-Nitroaniline
42. Dimethyl phthalate
43. 2,6-Dinitrotoluene
44. Acenaphthylene
45. 3-Nitroaniline
46. Acenaphthene-d_{10} (I.S.)
47. Acenaphthene
48. 2,4-Dinitrophenol
49. 4-Nitrophenol
50. Dibenzofuran
51. 2,4-Dinitrotoluene
52. Diethyl phthalate
53. 4-Chlorophenyl phenyl ether
54. Fluorene
55. 4-Nitroaniline
56. 2-Methyl-4,6-dinitrophenol
57. N-nitrosodiphenylamine
58. Azobenzene
59. 2,4,6-Tribromophenol (surr.)
60. 4-Bromophenyl phenyl ether
61. Hexachlorobenzene
62. Pentachlorophenol
63. Phenanthrene-d_{10} (I.S.)
64. Phenanthrene
65. Anthracene
66. Carbazole
67. Di-*n*-butyl phthalate
68. Fluoranthene
69. Benzidine
70. Pyrene
71. Terphenyl-d_{14} (surr.)
72. 3,3'-Dimethylbenzidine
73. Butylbenzyl phthalate
74. 3,3'-Dichlorobenzidine
75. Benzo(a)anthracene
76. Bis(2-ethylhexyl)phthalate
77. Chrysene-d_{12} (I.S.)
78. Chrysene
79. Di-*n*-octyl phthalate
80. Benzo(b)fluoranthene
81. Benzo(k)fluoranthene
82. Benzo(a)pyrene
83. Perylene-d_{12} (I.S.)
84. Indeno(1,2,3-cd)pyrene
85. Dibenzo(a,h)anthracene
86. Benzo(g,h,i)perylene

Figure 1. Conventional GC vs Fast GC Analysis



Column	SLB®-5ms, 30 m × 0.25 mm I.D., 0.25 µm (**28471-U**)
Oven	40 °C (2 min), 22 °C/min to 240 °C, 10 °C/min to 330 °C (1 min)
Inj. temp.	250 °C
Detector	MS, scan range m/z 40 – 450
MSD interface	330 °C
Carrier gas	helium, 1.0 mL/min (11 min), 10 mL/min² to 1.5 mL/min (hold remainder of run)
Injection	0.5 µL, splitless (0.50 min)
Liner	2 mm I.D., splitless type, straight design (**2051301**)
Sample	80 component semivolatile standard at 50 ppm plus 6 internal standards (at 40 ppm) in methylene chloride

Column	SLB®-5ms, 20 m × 0.18 mm I.D., 0.18 µm (**28564-U**)
Oven	40 °C (0.7 min), 55 °C/min. to 240 °C, 28 °C/min to 330 °C (2 min)
Inj. temp.	250 °C
Detector	helium, 40 cm/sec
MSD interface	330 °C
Carrier gas	helium, 40 cm/sec
Injection	0.5 µL, 10:1 split
Liner	2.3 mm I.D., split/splitless type, wool packed single taper FocusLiner™ design (**2879501-U**)
Sample	80 component semivolatile standard at 50 ppm plus 6 internal standards (at 40 ppm) in methylene chloride

Theoretical Discussion

This section defines how Fast GC works through a theoretical discussion.

Principles 1 – 3 (Decrease Analysis Time)

How long analytes are retained in a column dictates the overall analysis time. The retention time (t_R) of an analyte is a function of column length (L), retention factor (k), and carrier gas linear velocity (μ). The equation shown in **Figure 2** defines those relationships.

Figure 2. Retention Time Equation

$$t_R = \frac{L\,(k + 1)}{\mu}$$

The correct units for each term are not needed for this discussion. Rather, the relationships (cause and effect) are important. There are three options for reducing t_R:

1. Decrease L: Use a shorter column
2. Decrease k: Increase oven temperature and/or ramp rate to reduce analyte partitioning into the stationary phase
3. Increase μ: Increase the carrier gas linear velocity to move analytes through the column quicker

These are Principles 1 – 3. They accomplish shorter analysis time, but sacrifice resolution in doing so. Principles 4 – 6 focus on gaining back the resolution.

Resolution

Before discussing Principles 4 – 6 (increase resolution), the relationships between resolution and plate height needs to be understood. The resolution equation shown in **Figure 3** reveals that resolution (R_s) is the result of selectivity times efficiency times capacity.

Figure 3. The Resolution Equation

R_s = Selectivity	*	Efficiency	*	Capacity
R_s = ((-1)/a)	*	(N½/4)	*	(k/(1+k))

The equation in **Figure 4** shows that efficiency (N, expressed as plates) is inversely related to plate height (H).

Figure 4. Relationship of Efficiency and Plate Height

$$N = L/H$$

Working through both equations reveals that a decrease in plate height (H) will increase efficiency (N) which in turn will increase resolution (R_s). Therefore, Principles 4 – 6 deal with decreasing H as the means to increase resolution.

Principles 4 – 6 (Increase Resolution)

How can plate height (H) be decreased? The Golay equation shown in **Figure 5**, is the classic van Deemter equation minus the A term, which does not apply to open tubes.

Figure 5. Golay Equation

$$H = \frac{2D_m}{\mu} + \left[\frac{(1+6k+11k^2)r^2}{24(1+k)^2D_m}\right] * \mu + \left[\frac{k_3r^2}{6(1+k)^2k^2D_s}\right] * \mu$$

This equation is useful because it describes H, and its relationships to several terms. The correct units for each term are not needed for this discussion. Rather, the relationships (cause and effect) are important. There are three options for decreasing H:

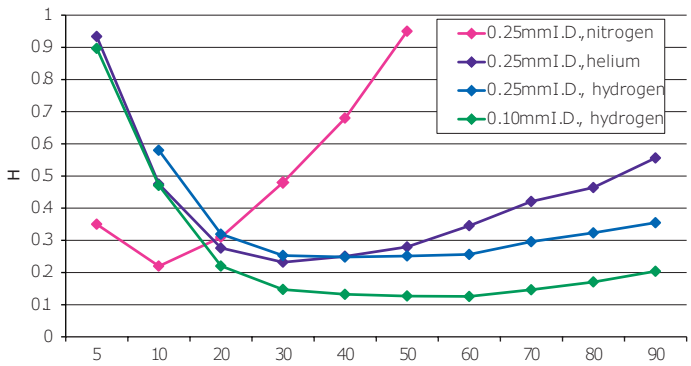
4. Decrease r (radius): Use a column with a narrower I.D.
5. Increase D_m (mobile phase diffusivity): Use hydrogen instead of helium as the carrier gas
6. Increase D_s (stationary phase diffusivity): Use a column with a thinner film thickness

These are Principles 4 – 6. They recover the resolution lost when Principles 1 – 3 were applied.

Narrow I.D. and Hydrogen

The combined effect of a narrow I.D. column (Principle 4) and hydrogen carrier gas (Principle 5) is very powerful. The Golay plots shown in **Figure 6** represent various combinations of column I.D. and carrier gas. The X-axis shows linear velocity (μ), and the Y-axis shows plate height (H). The phrase optimal linear velocity (μ_{opt}) is used to define the linear velocity value when the Golay plot is at its lowest point. Data for a 0.10 mm I.D. column with helium carrier gas is not included due to the high backpressure generated by this combination.

Figure 6. Golay Plots



Higher μ values result in shorter analysis times, whereas lower H values result in greater efficiency and resolution. A 0.10 mm I.D. column used with hydrogen provides:

- A high μ_{opt}
- A low H value
- A flat Golay relationship, allowing the use of $\mu > \mu_{opt}$ without a significant increase in H
- The ability to use μ = 90 cm/sec and still achieve lower H than other combinations

Practical Considerations

There are a few practical considerations to be aware of.

1. **Oven Ramp Rates.** Fast oven temperature ramp rates (Principle 2) can be used to decrease analysis time. However, it is important to stay within the ramp rate limits of the GC for the temperature ranges it will be operated at. Programming a ramp rate faster than the GC can maintain may result in variations from run to run. Therefore, do not set a ramp rate faster than the instrument can manage. If it is desired to use a faster ramp rate, decreasing the internal oven volume with an oven insert is an inexpensive and simple way to increase ramp rate capability.
2. **Sample Capacity.** Narrow I.D. columns (Principle 4) have lower sample capacity compared to conventional GC column dimensions. To prevent peak shapes from being distorted, a smaller amount of sample must be introduced. Therefore, use high split ratios (100:1 to 400:1) to prevent column overload. Note that sensitivity will not suffer because narrow I.D. columns generate peaks with greater signal-to-noise ratios.
3. **Acquisition Rates.** Compared to conventional GC, Fast GC will produce more frequent and much narrower peaks, which the detector must handle. Therefore, verifying the detector can obtain sufficient data points per peak to ensure proper peak quantitation. Most detectors in service should in fact be compatible with Fast GC.
4. **GC/MS.** The preferred carrier gas for Fast GC is hydrogen (Principle 5). However, many mass spectrometer detectors (MSDs) will not work properly with hydrogen as the carrier gas. Therefore, when using an MSD that is not compatible with hydrogen carrier gas, this Principle cannot be applied. However, the other five Principles can and should be applied.

Tutorial

In this section, seven chromatograms show how performance changes as a conventional GC method is converted to a Fast GC method. Table 1 lists conditions other than those listed with each figure, and Table 2 lists peak IDs.

Table 1. Conditions for Figures 7 – 13

Inj. Temp.	250 °C
Detector	FID, 325 °C
Liner	2 mm I.D., split/splitless type, wool packed single taper FocusLiner™ design
Sample	16 PAHs, each at 100 µg/mL in methylene chloride

Table 2. Peak IDs for Figures 7 – 13

1.	Naphthalene	9.	Benzo[a]anthracene
2.	Acenaphthylene	10.	Chrysene
3.	Acenaphthene	11.	Benzo[b]fluoranthene
4.	Fluorene	12.	Benzo[k]fluoranthene
5.	Phenanthrene	13.	Benzo[a]pyrene
6.	Anthracene	14.	Indeno[1,2,3-cd]pyrene
7.	Fluoranthene	15.	Dibenzo[a,h]anthracene
8.	Pyrene	16.	Benzo[g,h,i]perylene

Table 3 displays which figures correlate to each Principle. Note that some Principles were applied more than once.

Table 3. Correlation of Figures to Principles

Principle	Description	Figure
1	Use shorter column	8,11
2	Use higher temp and/or faster ramp rate	13
3	Use faster linear velocity	9,12
4	Use narrower I.D.	10
5	Use hydrogen carrier gas	9
6	Use thinner film	10

Figure 7 is a conventional GC analysis of 16 polycyclic aromatic hydrocarbons (PAHs) using a 30 m × 0.25 mm I.D. column and flame ionization detector (FID). The oven temperature ramp rate of 20 °C/min is the maximum single rate possible over the 70 – 325 °C temperature range. The difficult separations are peaks 5/6, 9/10, 11/12, and 14/15. Resolution values of 1.7, 1.1, and 0.6 are reported for the first three pairs. A value of 1.5 or greater signifies baseline resolution. The last pair shows no separation. To achieve better resolution for all pairs, a lower initial oven temperature could be used. However, this would extend the analysis time even longer than the 19 minutes shown.

Figure 8 shows the same application with a shorter column. Analysis time is decreased, and resolution values are lower. This is a shorter run (desired), but the resolution is unacceptable (not desired).

Figure 7. Initial (Conventional GC)

Column	SLB®-5ms, 30 m × 0.25 mm I.D., 0.25 µm
Oven	70 °C (0.2 min), 20 °C/min to 325 °C (3 min)
Carrier gas	helium at 25 cm/sec
Injection	0.5 µL, 10:1 split

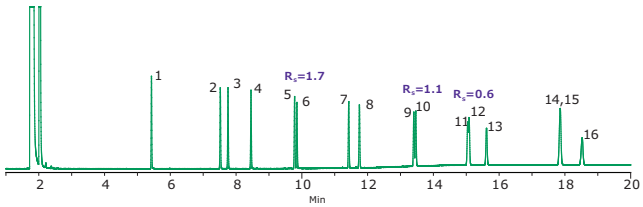


Figure 8. Decrease Column Length

Column	SLB®-5ms, 15 m × 0.25 mm I.D., 0.25 µm
Oven	70 °C (0.2 min), 20 °C/min to 325 °C (3 min)
Carrier gas	helium at 25 cm/sec
Injection	0.5 µL, 10:1 split

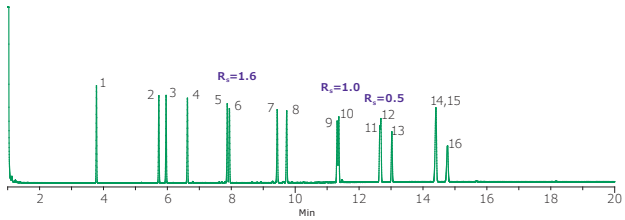


Figure 9 shows what happens when carrier gas is changed from helium at 25 cm/sec to hydrogen at 40 cm/sec. Analysis time is decreased, and the resolution values are higher. Why did resolution get better? Hydrogen at its optimal linear velocity with a 0.25 mm I.D. column (μ_{opt} = 40 cm/sec) has a lower plate height (H) value than helium at its optimal linear velocity with a 0.25 mm I.D. column (μ_{opt} = 25 cm/sec).

Principle 4 states that decreasing column I.D. will decrease plate height (H), which increases efficiency (N) and subsequently resolution (R_s). **Figure 10** shows the same application using a smaller I.D. column. The film thickness was also lowered to keep the same ratio of stationary phase film thickness to column cross-sectional area. Additionally, the split ratio was increased to minimize the risk of column overload. Observe that analysis time is unchanged, and that resolution values are higher.

Figure 9. Switch to Hydrogen Carrier Gas

Column	SLB®-5ms, 15 m × 0.25 mm I.D., 0.25 µm
Oven	70 °C (0.2 min), 20 °C/min to 325 °C (3 min)
Carrier gas	hydrogen at 40 cm/sec
Injection	0.5 µL, 10:1 split

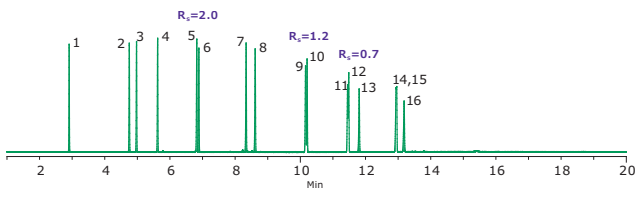
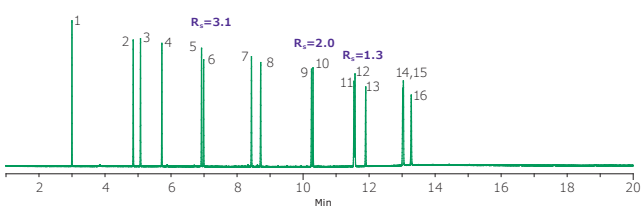


Figure 10. Decrease Column I.D.

Column	SLB®-5ms, 15 m × 0.10 mm I.D., 0.10 µm
Oven	70 °C (0.2 min), 20 °C/min to 325 °C (3 min)
Carrier gas	hydrogen at 40 cm/sec
Injection	0.5 µL, 100:1 split



Decreasing column length again results in **Figure 11**. As expected, analysis time decreases. Resolution values are lower, except for the fourth pair. How is this possible? This pair now elutes during the oven temperature ramp and not the final isothermal portion of the run, resulting in sharper peak shapes. Generating sharper peak shapes can also be used to increase resolution.

Figure 12 is the result after linear velocity is increased. As expected, analysis time decreases. Why are the resolution values higher? Because the linear velocity used in Figures 10 and 11 was sub-optimal. How did that happen?

1. In **Figure 9**, linear velocity was increased from 25 cm/sec to 40 cm/sec when the carrier gas was changed from helium to hydrogen. This was done to maintain optimal linear velocity (μ_{opt}).
2. In **Figure 10**, column I.D. was changed from 0.25 mm to 0.10 mm without adjusting linear velocity. This is a common mistake. The Golay plots in **Figure 6** show that μ_{opt} is 40 cm/sec for hydrogen with a 0.25 mm I.D. column and 60 cm/sec with a 0.10 mm I.D. column.

The error was corrected in **Figure 12** when μ_{opt} was used. To achieve the best resolution, it is critical to operate at the optimal linear velocity for the combination of column I.D. and carrier gas being used.

Figure 11. Decrease Column Length

Column	SLB®-5ms, 10 m × 0.10 mm I.D., 0.10 µm
Oven	70 °C (0.2 min), 20 °C/min to 325 °C (3 min)
Carrier gas	hydrogen at 40 cm/sec
Injection	0.5 µL, 100:1 split

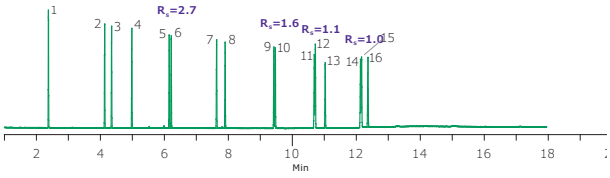


Figure 12. Increase Linear Velocity

Column	SLB®-5ms, 10 m × 0.10 mm I.D., 0.10 µm
Oven	70 °C (0.2 min), 20 °C/min to 325 °C (3 min)
Carrier gas	hydrogen at 60 cm/sec
Injection	0.5 µL, 100:1 split

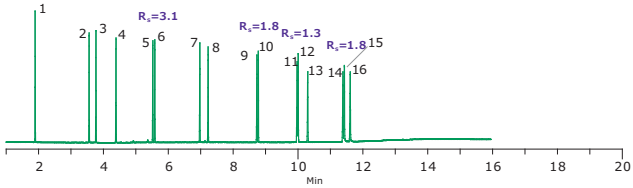


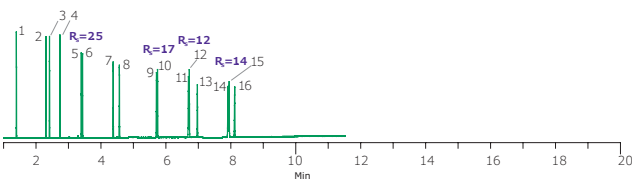
Figure 13 shows the result of using the maximum ramp rate possible over several temperature ranges. These maximum rates are typically published in the instrument manual. As expected, analysis time decreased, and resolution values are lower. Note that the resolution values did not suffer significantly. Why not? The discussion of **Figure 11** mentioned that sharper peak shapes and better resolution are achieved if a pair elutes during the oven temperature ramp and not the final isothermal portion of the run.

Sharper peak shapes are also obtained with a steeper temperature ramp. While the faster ramp will cause lower resolution values, the effect is minimized due to the sharper peak shapes that are produced.

Converting this PAH method from conventional GC (**Figure 7**) to Fast GC (**Figure 13**) resulted in a 57% decrease in analysis time and vastly improved resolution. The greatest benefits can be achieved when all six principles are applied.

Figure 13. Increase Ramp Rate

Column	SLB®-5ms, 10 m × 0.10 mm I.D., 0.10 µm
Oven	70 °C (0.2 min), 40 °C/min to 175 °C, 25 °C/min to 270 °C, 20 °C/min to 325 °C
Carrier gas	hydrogen at 60 cm/sec
Injection	0.5 µL, 100:1 split



Maximize Performance!

Gas Chromatography Accessories and Gas Purification/Management Products

To learn more visit,
SigmaAldrich.com/gc

Last GC Applications

The 22 chromatograms listed in Table 4 are included in this section. The greatest benefits can be achieved when all six principles are applied. However, this is not always possible. When helium is used instead of hydrogen as the carrier gas (such as when using GC/MS), only five principles can be applied. The carrier gas used is clearly listed in the conditions for each chromatogram.

Table 4. List of Applications

Industry	Description	Page
Environmental	US EPA Method 624 Volatiles on SPB®-624	12
	US EPA Method 8260 Volatiles on a VOCOL® column	13
	US EPA Method 8270 Semivolatiles on SLB®-5ms (0.18 µm)	14
	US EPA Method 8270 Semivolatiles on SLB®-5ms (0.36 µm)	15
	US EPA Method 8081 Organochlorine Pesticides on SLB®-5ms	16
	US EPA Method 8081 Organochlorine Pesticides on Equity®-1701	16
	US EPA Method 8082 PCBs as Aroclors on SLB®-5ms	17
	US EPA Method 8082 PCBs as Aroclors on Equity®-1701	17
Petroleum/Chemical	Unleaded Gasoline on Equity®-1 column	18
	Fuel Oil #2 on Equity®-1 column	18
	Kerosene on SLB®-5ms	19
	Aviation Gasoline on Equity®-1 column	19
Food and Beverage	PUFA No. 1 Mix (Marine Source) FAMEs on an Omegawax® column	20
	PUFA No. 2 Mix (Animal Source) FAMEs on an Omegawax® column	20
	PUFA No. 3 Mix (Menhaden Oil) FAMEs on an Omegawax® column	21
	Amino Acids on SLB®-5ms	21
Flavor and Fragrance/Cosmetic	Lemon Essential Oil on SLB®-5ms	22
	Distilled Lime Essential Oil on Equity®-1	22
	Sweet Orange Essential Oil on SLB®-5ms	23
	Allergens in Commercial Perfume on SLB®-5ms	23
Clinical	Bacterial Acid Methyl Esters (BAMEs) on Equity®-1	24
	FAMEs in Plasma on SUPELCOWAX® 10	24

Figure 14. US EPA Method 624 Volatiles on SPB®-624

Sample/matrix	each analyte at 50 ppb in 5 mL water
Purge trap	VOCARB® 3000 "K" (**24940-U**)
Purge	40 mL/min at 25 °C for 11 min
Dry purge	2 min
Desorption temp.	210 °C for 2 min
Desorption flow	150 mL/min
Bake.	260 °C for 10 min
Transfer line/ valve temp.	110 °C
Column	SPB®-624, 20 m × 0.18 mm I.D., 1.0 µm (**28662-U**)
Oven	40 °C (1 min), 11 °C/min to 125 °C, 35 °C/min to 230 °C (2 min)
Inj.	150 °C
MSD interface	200 °C
Scan range	m/z = 35–400
Carrier gas	helium, 1.5 mL/min
Injection	100 1 split
Liner	0.75 mm I.D. SPME

1. Chloromethane
2. Vinyl chloride
3. Bromomethane
4. Chloroethane
5. Trichlorofluoromethane
6. 1,1-Dichloroethene
7. Methylene chloride
8. *trans*-1,2-Dichloroethene
9. 1,1-Dichloroethane
10. Chloroform
11. Dibromofluoromethane (surr.)
12. 1,1,1-Trichloroethane
13. Carbon tetrachloride
14. 1,2-Dichloroethane-d_4 (surr.)
15. Benzene
16. 1,2-Dichloroethane
17. Fluorobenzene (I.S.)
18. Trichloroethene
19. 1,2-Dichloropropane
20. Bromodichloromethane
21. 2-Chloroethyl vinyl ether
22. *cis*-1,3-Dichloropropene
23. Toluene-d_8 (surr.)
24. Toluene
25. *trans*-1,3-Dichloropropene
26. 1,1,2-Trichloroethane
27. Tetrachloroethene
28. Dibromochloromethane
29. Chlorobenzene-d_5 (I.S.)
30. Chlorobenzene
31. Ethylbenzene
32. Bromoform
33. 4-Bromofluorobenzene (surr.)
34. 1,1,2,2-Tetrachloroethane
35. 1,3-Dichlorobenzene
36. 1,4-Dichlorobenzene-d_4 (I.S.)
37. 1,4-Dichlorobenzene
38. 1,2-Dichlorobenzene

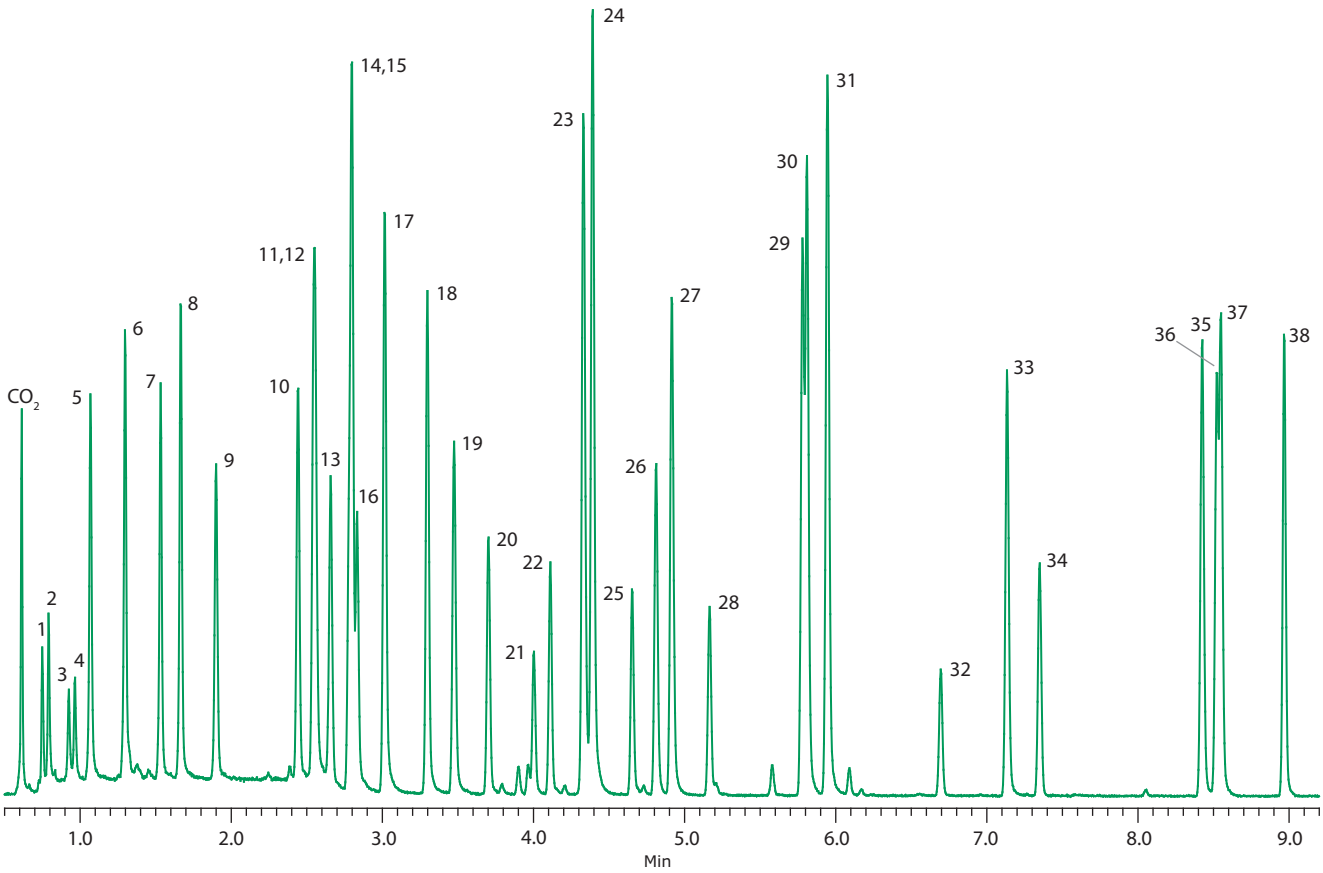


Figure 15. US EPA Method 8260 Volatiles using a VOCOL® column

Sample/matrix	each analyte at 50 ppb in 5 mL water
Purge trap	VOCARB 3000 “K” (**24940-U**)
Purge	40 mL/min at 25 °C for 11 min
Dry purge	1 min
Desorption temp.	210 °C for 1 min
Desorption flow	150 mL/min
Bake.	260 °C for 10 min
Transfer line/ valve temp.	110 °C
Column	VOCOL®, 20 m × 0.18 mm I.D., 1.0 µm (**28463-U**)
Oven	40 °C (0.8 min), 19 °C/min to 125 °C, 32 °C/min to 220 °C (1 min)
Inj.	150 °C
MSD interface	220 °C
Scan range	m/z = 35 – 400
Carrier gas	helium, 1.5 mL/min
Injection	100:1 split
Liner	0.75 mm I.D. SPME

1. Dichlorofluoromethane
2. Chloromethane
3. Vinyl chloride
4. Bromomethane
5. Chloroethane
6. Trichlorofluoromethane
7. Acetone
8. 1,1-Dichloroethene
9. Iodomethane
10. Methylene chloride
11. *trans*-1,2-Dichloroethene
12. 1,1-Dichloroethane
13. 2-Butanone
14. 2,2-Dichloropropane
15. *cis*-1,2-Dichloroethene
16. Chloroform
17. Bromochloromethane
18. Dibromofluoromethane (surr.)
19. 1,1,1-Trichloroethane
20. 1,1-Dichloropropene
21. Carbon tetrachloride
22. 1,2-Dichloroethane-d_4 (surr.)
23. 1,2-Dichloroethane
24. Benzene
25. Fluorobenzene (I.S.)
26. Trichloroethene
27. 1,2-Dichloropropane
28. Bromodichloromethane
29. Dibromomethane
30. 4-Methyl-2-pentanone
31. *cis*-1,3-Dichloropropene
32. Toluene-d8 (surr.)
33. Toluene
34. *trans*-1,3-Dichloropropene
35. 1,1,2-Trichloroethane
36. 2-Hexanone
37. 1,3-Dichloropropane
38. Tetrachloroethene
39. Dibromochloromethane
40. 1,2-Dibromomethane
41. Chlorobenzene-d_5 (I.S.)
42. Chlorobenzene
43. Ethylbenzene
44. 1,1,1,2-Tetrachloroethane
45. m-Xylene & p-Xylene
46. o-Xylene
47. Styrene
48. Isopropylbenzene
49. Bromoform
50. *cis*-1,4-Dichloro-2-butene
51. 1,1,2,2-Tetrachloroethane
52. 4-Bromofluorobenzene (surr.)
53. 1,2,3-Trichloropropane
54. n-Propylbenzene
55. Bromobenzene
56. *trans*-1,4-Dichloro-2-butene
57. 1,3,5-Trimethylbenzene
58. o-Chlorotoluene
59. p-Chlorotoluene
60. tert-Butylbenzene
61. 1,2,4-Trimethylbenzene
62. Pentachloroethane
63. sec-Butylbenzene
64. p-Isopropyltoluene
65. 1,3-Dichlorobenzene
66. 1,4-Dichlorobenzene-d_4 (I.S.)
67. 1,4-Dichlorobenzene
68. Butylbenzene
69. 1,2-Dichlorobenzene
70. 1,2-Dibromo-3-chloropropane
71. 1,2,4-Trichlorobenzene
72. Hexachlorobutadiene
73. Naphthalene
74. 1,2,3-Trichlorobenzene

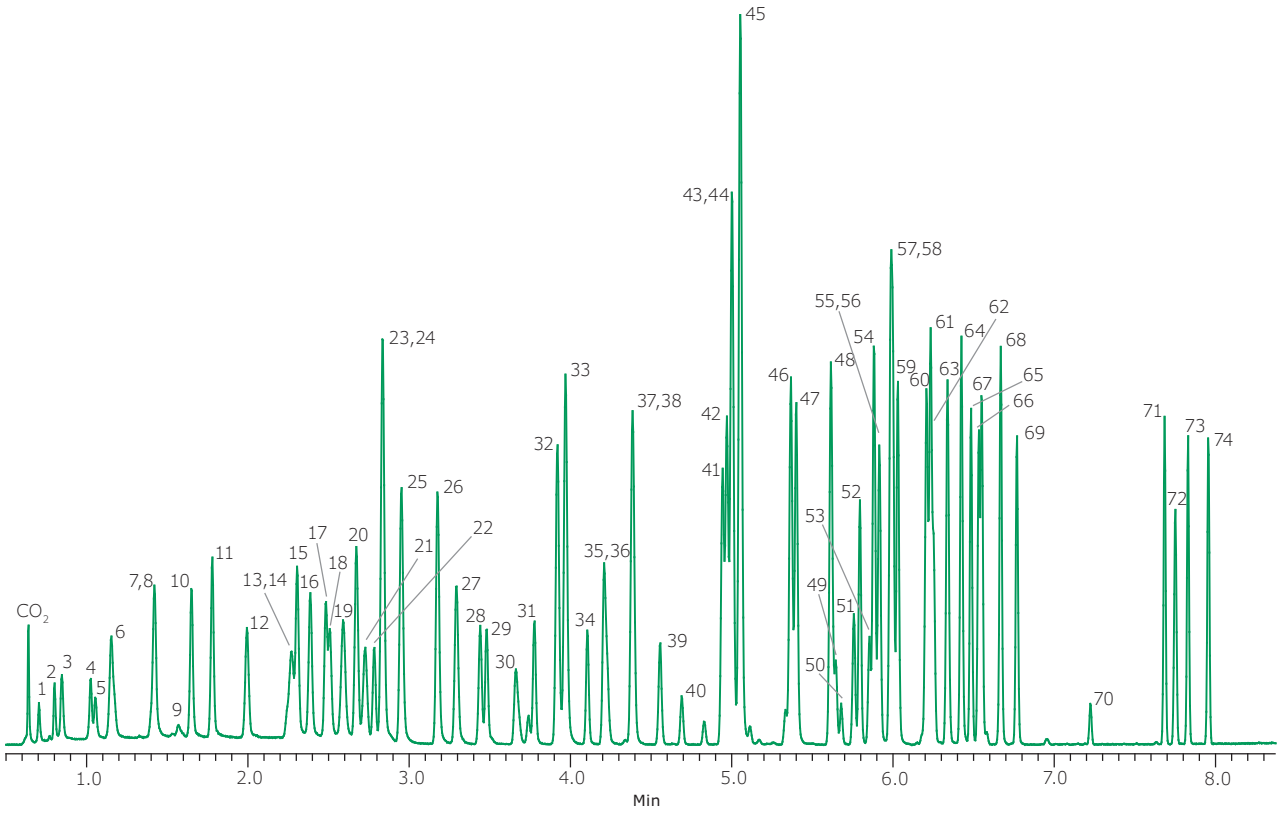


Figure 16. US EPA Method 8270 Semivolatiles on SLB®-5ms (0.18 µm)

Column	SLB®-5ms, 20 m × 0.18 mm I.D., 0.18 µm (**28564-U**)
Oven	40 °C (0.7 min), 55 °C/min to 240 °C, 28 °C/min to 330 °C (2 min)
Inj.	250 °C
MSD interface	330 °C
Scan range	m/z 40 – 450
Carrier gas	helium, 40 cm/sec, constant
Injection	0.5 µL, 10:1 split
Liner	2 mm I.D., fast FocusLiner™ inlet liner with taper (**2879501-U**)
Sample	80-component semivolatile standard at 50 ppm plus 6 internal standards (at 40 ppm) in methylene chloride

1. *N*-Nitrosodimethylamine
2. Pyridine
3. 2-Fluorophenol (surr.)
4. Phenol-d_6 (surr.)
5. Phenol
6. Aniline
7. Bis(2-chloroethyl)ether
8. 2-Chlorophenol-d_4 (surr.)
9. 2-Chlorophenol
10. 1,3-Dichlorobenzene
11. 1,4-Dichlorobenzene
12. 1,4-Dichlorobenzene-d_4 (I.S.)
13. Benzyl alcohol
14. 1,2-Dichlorobenzene-d_4 (surr.)
15. 1,2-Dichlorobenzene
16. 2-Methylphenol
17. Bis(2-chloroisopropyl)ether
18. *N*-Nitroso-di-*n*-propylamine
19. 4-Methylphenol
20. Hexachloroethane
21. Nitrobenzene-d_5 (surr.)
22. Nitrobenzene
23. Isophorone
24. 2-Nitrophenol
25. 2,4-Dimethylphenol
26. Bis(2-chloroethoxy) methane
27. Benzoic acid
28. 2,4-Dichlorophenol
29. 1,2,4-Trichlorobenzene
30. Naphthalene-d_8 (I.S.)
31. Naphthalene
32. 4-Chloroaniline
33. Hexachlorobutadiene
34. 4-Chloro-3-methylphenol
35. 2-Methylnaphthalene
36. Hexachlorocyclopentadiene
37. 2,4,6-Trichlorophenol
38. 2,4,5-Trichlorophenol
39. 2-Fluorobiphenyl (surr.)
40. 2-Chloronaphthalene
41. 2-Nitroaniline
42. Dimethyl phthalate
43. 3-Nitroaniline
44. Acenaphthylene
45. 2,6-Dinitrotoluene
46. Acenaphthene-d_{10} (I.S.)
47. Acenaphthene
48. 2,4-Dinitrophenol
49. 4-Nitrophenol
50. 2,4-Dinitrotoluene
51. Dibenzofuran
52. Diethyl phthalate
53. 4-Chlorophenyl phenyl ether
54. Fluorene
55. 4-Nitroaniline
56. 2-Methyl-4,6-dinitrophenol
57. N-Nitrosodiphenylamine
58. Azobenzene
59. 2,4,6-Tribromophenol (surr.)
60. 4-Bromophenyl phenyl ether
61. Hexachlorobenzene
62. Pentachlorophenol
63. Phenanthrene-d_{10} (I.S.)
64. Phenanthrene
65. Anthracene
66. Carbazole
67. Di-*n*-butyl phthalate
68. Fluoranthene
69. Benzidine
70. Pyrene
71. Terphenyl-d_{14} (surr.)
72. 3,3'-Dimethylbenzidine
73. Butylbenzyl phthalate
74. 3,3'-Dichlorobenzidine
75. Bis(2-ethylhexyl)phthalate
76. Benzo(a)anthracene
77. Chrysene-d_{12} (I.S.)
78. Chrysene
79. Di-*n*-octyl phthalate
80. Benzo(b)fluoranthene
81. Benzo(k)fluoranthene
82. Benzo(a)pyrene
83. Perylene-d_{12} (I.S.)
84. Indeno(1,2,3-cd)pyrene
85. Dibenzo(a,h)anthracene
86. Benzo(g,h,i)perylene

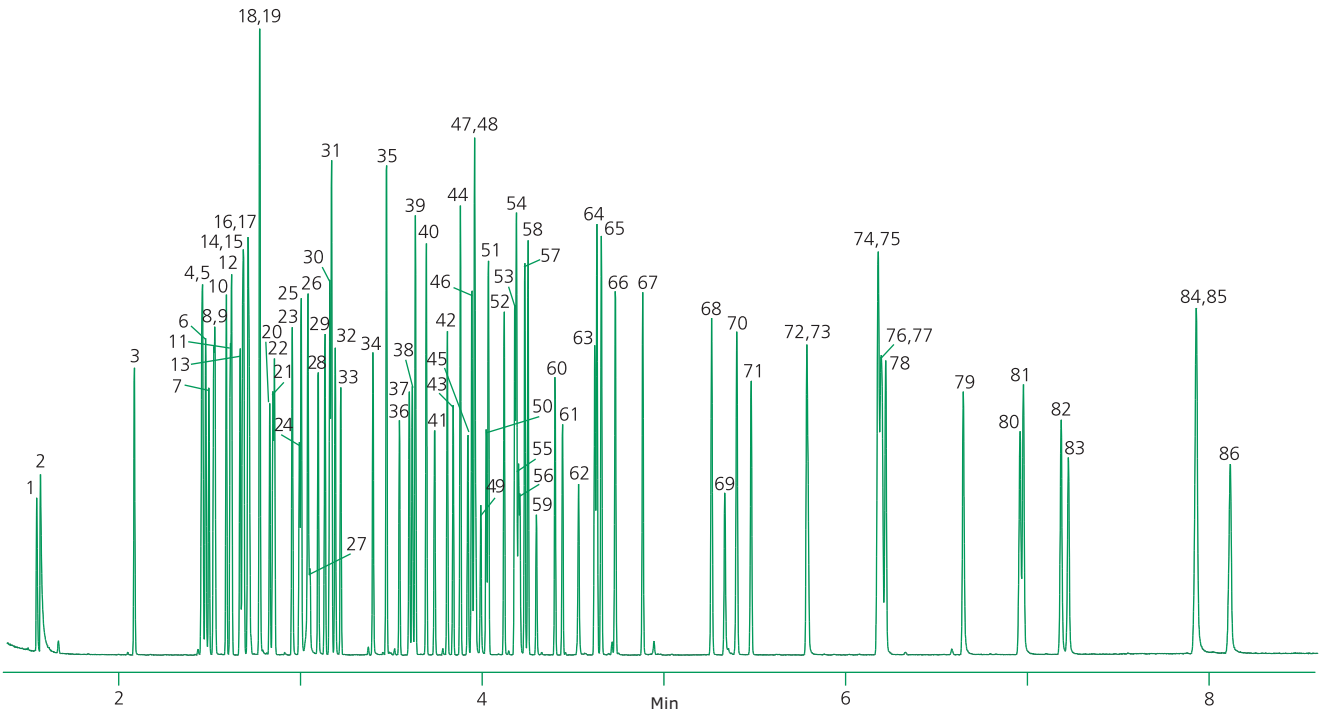


Figure 17. US EPA Method 8270 Semivolatiles on SLB®-5ms (0.36 µm)

Column	SLB®-5ms, 20 m × 0.18 mm I.D., 0.36 µm (**28576-U**)
Oven	50 °C (0.50 min), 28 °C/min to 250 °C, 35 °C/min to 340 °C (5 min)
Inj.	250 °C
MSD interface	340 °C
Scan range	m/z 40 – 450
Carrier gas	helium, 1.4 mL/min constant
Injection	0.50 µL, reduced pressure to 20 psi at injection (0.1 min) (splitter open at 0.75 min)
Liner	2 mm I.D., straight
Sample	80-component semivolatile standard at 50 ppm, plus 6 internal standards (at 40 ppm) in methylene chloride

1. *N*-Nitrosodimethylamine
2. Pyridine
3. 2-Fluorophenol (surr.)
4. Phenol-d_6 (surr.)
5. Phenol
6. Aniline
7. Bis(2-chloroethyl)ether
8. 2-Chlorophenol-d_4 (surr.)
9. 2-Chlorophenol
10. 1,3-Dichlorobenzene
11. 1,4-Dichlorobenzene-d_4 (I.S.)
12. 1,4-Dichlorobenzene
13. Benzyl alcohol
14. 1,2-Dichlorobenzene-d_4 (surr.)
15. 1,2-Dichlorobenzene
16. 2-Methylphenol
17. Bis(2-chloroisopropyl)ether
18. 4-Methylphenol
19. N-Nitroso-di-*n*-propylamine
20. Hexachloroethane
21. Nitrobenzene-d_5 (surr.)
22. Nitrobenzene
23. Isophorone
24. 2-Nitrophenol
25. 2,4-Dimethylphenol
26. Bis(2-chloroethoxy) methane
27. Benzoic acid
28. 2,4-Dichlorophenol
29. 1,2,4-Trichlorobenzene
30. Naphthalene-d_8 (I.S.)
31. Naphthalene
32. 4-Chloroaniline
33. Hexachlorobutadiene
34. 4-Chloro-3-methylphenol
35. 2-Methylnaphthalene
36. Hexachlorocyclopentadiene
37. 2,4,6-Trichlorophenol
38. 2,4,5-Trichlorophenol
39. 2-Fluorobiphenyl (surr.)
40. 2-Chloronaphthalene
41. 2-Nitroaniline
42. Dimethyl phthalate
43. 2,6-Dinitrotoluene
44. Acenaphthylene
45. 3-Nitroaniline
46. Acenaphthene-d_{10} (I.S.)
47. Acenaphthene
48. 2,4-Dinitrophenol
49. 4-Nitrophenol
50. 2,4-Dinitrotoluene
51. Dibenzofuran
52. Diethyl phthalate
53. 4-Chlorophenyl phenyl ether
54. Fluorene
55. 4-Nitroaniline
56. 2-Methyl-4,6-dinitrophenol
57. *N*-Nitrosodiphenylamine
58. Azobenzene
59. 2,4,6-Tribromophenol (surr.)
60. 4-Bromophenyl phenyl ether
61. Hexachlorobenzene
62. Pentachlorophenol
63. Phenanthrene-d10 (I.S.)
64. Phenanthrene
65. Anthracene
66. Carbazole
67. Di-n-butyl phthalate
68. Fluoranthene
69. Benzidine
70. Pyrene
71. Terphenyl-d_{14} (surr.)
72. Butylbenzyl phthalate
73. 3,3'-Dimethylbenzidine
74. Bis(2-ethylhexyl)phthalate
75. 3,3'-Dichlorobenzidine
76. Benzo(a)anthracene
77. Chrysene-d12 (I.S.)
78. Chrysene
79. Di-*n*-octyl phthalate
80. Benzo(b)fluoranthene
81. Benzo(k)fluoranthene
82. Benzo(a)pyrene
83. Perylene-d_{12} (I.S.)
84. Indeno(1,2,3-cd)pyrene
85. 85. Dibenzo(a,h) anthracene
86. 86. Benzo(g,h,i)perylene

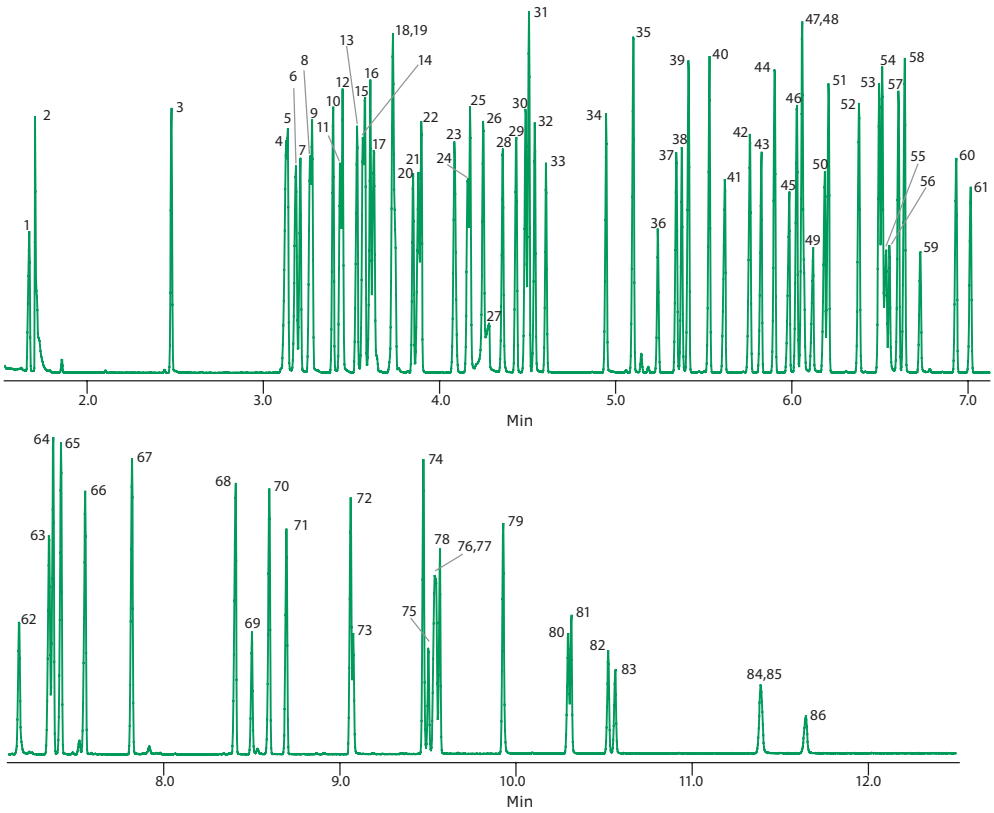


Figure 18. US EPA Method 8081 Organochlorine Pesticides on SLB®-5ms

Column	SLB®-5ms, 15 m × 0.10 mm I.D., 0.10 µm (**28466-U**)
Oven	100 °C, 25 °C/min to 325 °C
Inj.	225 °C
Det.	ECD, 300 °C
Carrier gas	hydrogen, 40 cm/sec constant
Injection	2 µL, splitless (0.75 min)
Liner	4 mm I.D., single taper
Sample	50 ppb of a 22-component chlorinated pesticide standard in n-hexane

1. Tetrachloro-m-xylene (surr.)
2. α-BHC
3. β-BHC
4. γ-BHC
5. δ-BHC
6. Heptachlor
7. Aldrin
8. Heptachlor epoxide
9. γ-Chlordane
10. Endosulfan I
11. α-Chlordane
12. 4,4'-DDE
13. Dieldrin
14. Endrin
15. 4,4'-DDD
16. Endosulfan II
17. Endrin aldehyde
18. 4,4'-DDT
19. Endosulfan sulfate
20. Methoxychlor
21. Endrin ketone
22. Decachlorobiphenyl (surr.)

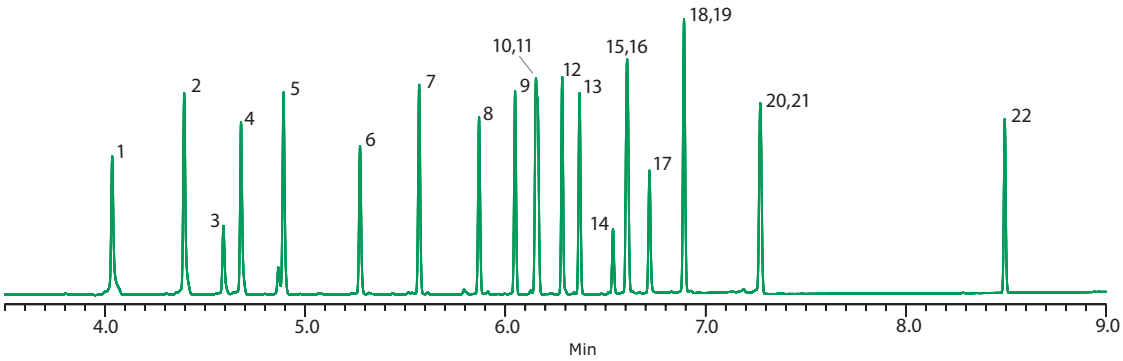


Figure 19. US EPA Method 8081 Organochlorine Pesticides on Equity®-1701

Column	Equity®-1701, 15 m × 0.10 mm I.D., 0.10 µm (2**8343-U**)
Oven	100 °C, 25 °C/min to 280 °C
Inj.	225 °C
Det.	ECD, 300 °C
Carrier gas	hydrogen, 40 cm/sec constant
Injection	2 µL, splitless (0.75 min)
Liner	4 mm I.D., single taper
Sample	50 ppb of a 22-component chlorinated pesticide standard in n-hexane

1. Tetrachloro-m-xylene (surr.)
2. α-BHC
3. β-BHC
4. γ-BHC
5. δ-BHC
6. Heptachlor
7. Aldrin
8. Heptachlor epoxide
9. γ-Chlordane
10. Endosulfan I
11. α-Chlordane
12. 4,4'-DDE
13. Dieldrin
14. Endrin
15. 4,4'-DDD
16. Endosulfan II
17. Endrin aldehyde
18. 4,4'-DDT
19. Endosulfan sulfate
20. Methoxychlor
21. Endrin ketone
22. Decachlorobiphenyl (surr.)

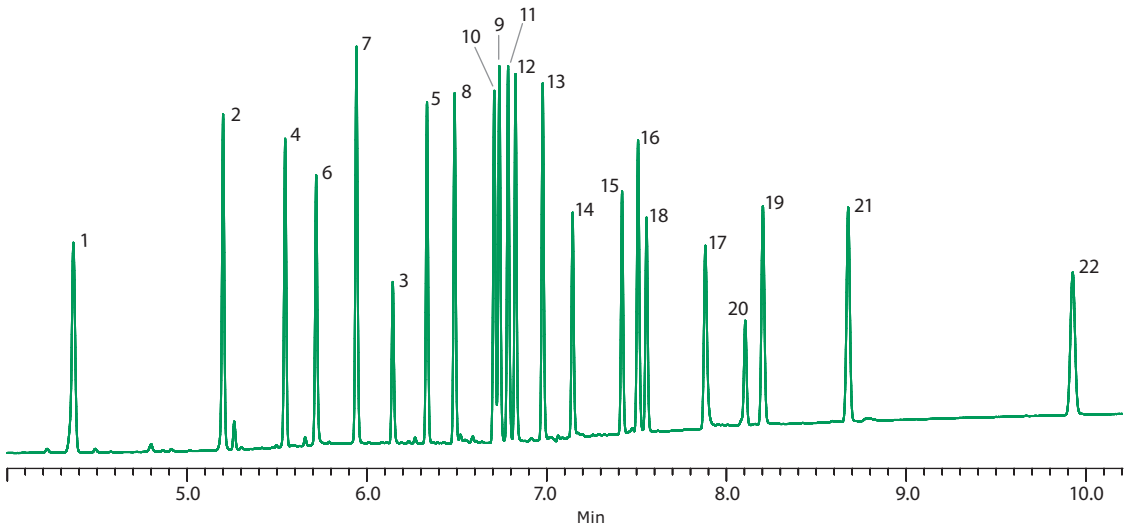


Figure 20. US EPA Method 8082 PCBs as Aroclors on SLB®-5ms

Column	SLB®-5ms, 15 m × 0.10 mm I.D., 0.10 µm (**28466-U**)
Oven	80 °C (0.5 min), 50 °C/min to 200 °C, 35 °C/min to 360 °C (2 min)
Inj.	225 °C
Det.	ECD, 360 °C
Carrier gas	hydrogen, 40 cm/sec constant
Injection	2 µL, splitless (0.75 min)
Liner	4 mm I.D., single taper
Sample	Aroclor standard mix 1 (**46846-U**) diluted to 500 ppb/50 ppb (Aroclors/surrogates) in n-hexane

1. Tetrachloro-*m*-*xylene* (surr.)
2. Aroclor 1016
3. Aroclor 1260
4. Decachlorobiphenyl (surr.)

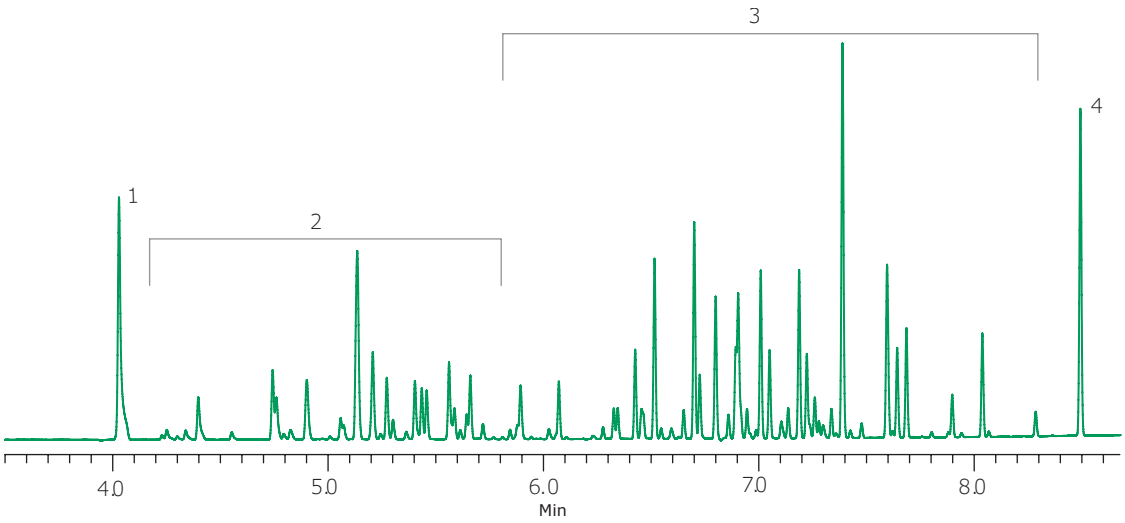


Figure 21. US EPA Method 8082 PCBs as Aroclors on Equity®-1701

Column	Equity®-1701, 15 m × 0.10 mm I.D., 0.10 µm (**28343-U**)
Oven	90 °C, 35 °C/min to 280 °C (3 min)
Inj.	250 °C
Det.	ECD, 280 °C
Carrier gas	hydrogen, 50 cm/sec constant
Injection	2 µL, splitless (0.75 min)
Liner	4 mm I.D., single taper
Sample	Aroclor standard mix 1 (**46846-U**) diluted to 200 ppb/20 ppb (Aroclors/surrogates) in n-hexane

1. Tetrachloro-*m*-xylene (surr.)
2. Aroclor 1016
3. Aroclor 1260
4. Decachlorobiphenyl (surr.)

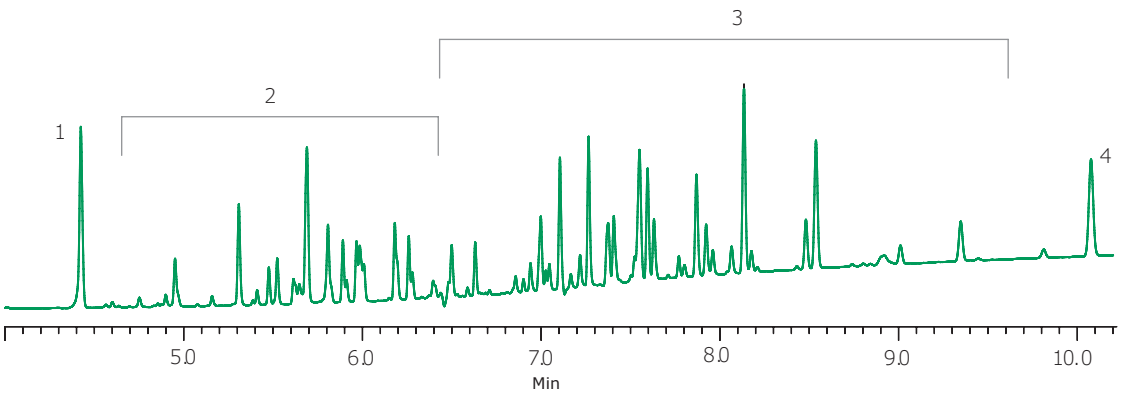


Figure 22. Unleaded Gasoline on Equity®-1

Column	Equity®-1, 15 m × 0.10 mm I.D., 0.10 µm (**28039-U**)
Oven	40 °C (1 min), 45 °C/min to 150 °C (2 min)
Inj.	175 °C
Det.	FID, 175 °C
Carrier gas	hydrogen, 45 cm/sec constant
Injection	0.1 µL, 300:1 split
Liner	2 mm I.D., straight
Sample	unleaded gasoline (refinery standard), neat

1. Isobutane
2. Butane
3. Isopentane
4. Pentane
5. 2,2-Dimethylbutane
6. 2,3-Dimethylbutane
7. 2-Methylpentane
8. 3-Methylpentane
9. Hexane
10. 2,4-Dimethylpentane
11. Benzene
12. 2-Methylhexane
13. 2,3-Dimethylpentane
14. 3-Methylhexane
15. Isooctane
16. Heptane
17. 2,5-Dimethylhexane
18. 2,4-Dimethylhexane
19. 2,3,4-Trimethylpentane
20. Toluene
21. 2,3-Dimethylhexane
22. 2-Methylheptane
23. 3-Methylheptane
24. Octane
25. Ethylbenzene
26. *m-/p*-Xylene
27. *o*-Xylene
28. Nonane
29. iso-Propylbenzene
30. Propylbenzene
31. 1-Methyl-3-ethylbenzene
32. 1-Methyl-4-ethylbenzene
33. 1,3,5-Trimethylbenzene
34. 3,3,4-Trimethylheptane
35. 1-Methyl-2-ethylbenzene
36. 1,2,4-Trimethylbenzene
37. iso-Butylbenzene
38. *sec*-Butylbenzene
39. 1,2,3-Trimethylbenzene
40. Indane
41. 1,3-Diethylbenzene
42. N-Butylbenzene
43. 1,4-Dimethyl-2-ethylbenzene
44. 1,3-Dimethyl-4-ethylbenzene
45. 1,2-Dimethyl-4-ethylbenzene
46. 1,2,4,5-Tetramethylbenzene
47. 1,2,3,5-Tetramethylbenzene
48. Naphthalene
49. 2-Methylnaphthalene
50. 1-Methylnaphthalene
51. Dimethylnaphthalenes

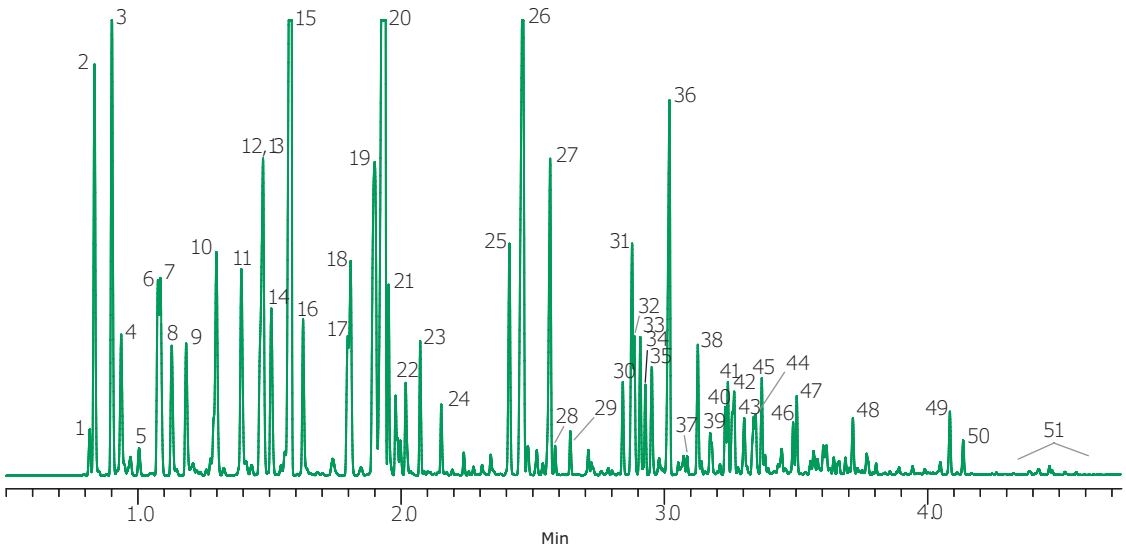
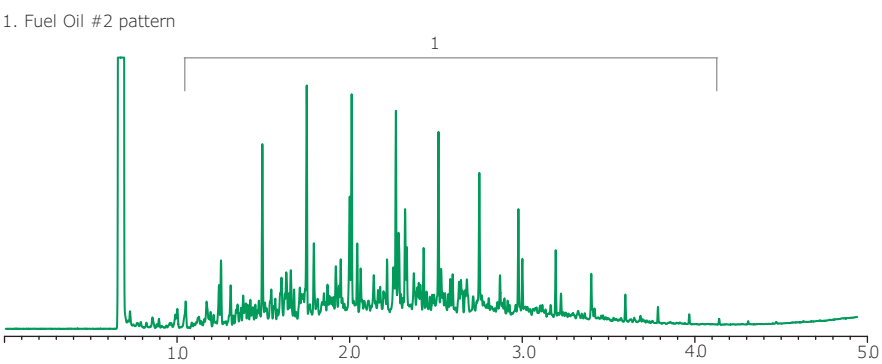
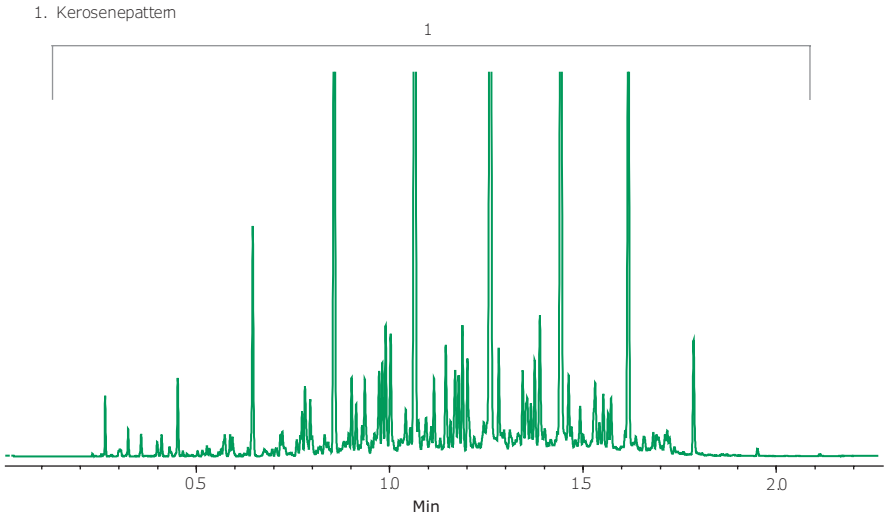


Figure 23. Fuel Oil #2 on Equity®-1



Column	Equity®-1, 15 m × 0.10 mm I.D., 0.10 µm (**28039-U**)
Oven	80 °C, 50 °C/min to 325 °C
Inj.	250 °C
Det.	FID, 350 °C
Carrier gas	hydrogen, 45 cm/sec constant
Injection	0.3 µL, 100:1 split, 0.02 min pre-injection dwell time
Liner	2 mm I.D., straight
Sample	no. 2 fuel oil standard, 20 mg/mL in methanol (**47515-U**)

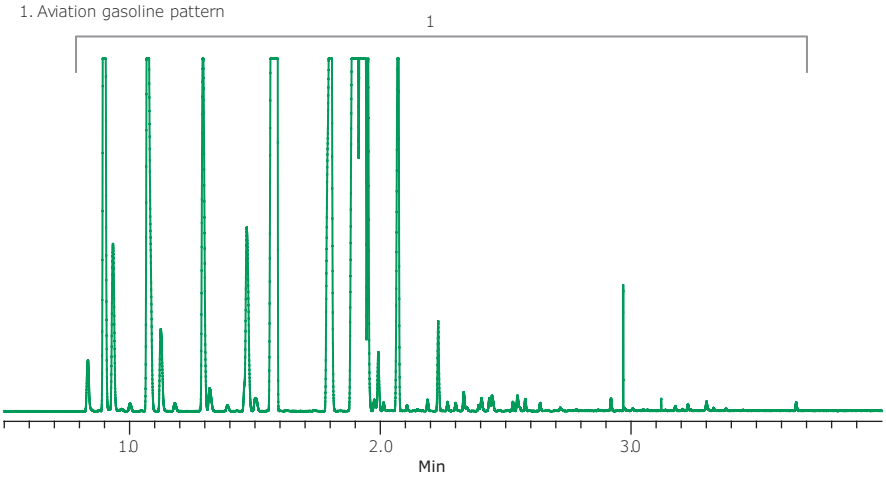
Figure 24. Kerosene on SLB®-5ms



Chromatogram courtesy of Prof. Luigi Mondello (Univ. of Messina, Italy)

Column	SLB®-5ms, 10 m × 0.10 mm I.D., 0.10 µm (**28465-U**)
Oven	40 °C, 80 °C/min to 150 °C, 70 °C/min to 250 °C, 50 °C/min to 320 °C
Inj.	320 °C
Det.	FID, 320 °C
Carrier gas	hydrogen, 85 cm/sec constant
Injection	0.2 µL, 800:1 split
Sample	kerosene

Figure 25. Aviation Gasoline on Equity®-1



Column	Equity®-1, 15 m × 0.10 mm I.D., 0.10 µm (**28039-U**)
Oven	40 °C (1 min), 45 °C/min to 225 °C
Inj.	250 °C
Det.	FID, 250 °C
Carrier gas	hydrogen, 45 cm/sec constant
Injection	0.1 µL, 300:1 split
Liner	2 mm I.D., straight
Sample	Aviation gasoline, neat

Figure 26. PUFA No. 1 Mix (Marine Source) FAMEs on an Omegawax® column

Column	Omegawax® 100, 15 m × 0.10 mm I.D., 0.10 µm (**23399-U**)
Oven	140 °C, 40 °C/min to 280 °C (2 min)
Inj.	250 °C
Det.	FID, 280 °C
Carrier gas	hydrogen, 50 cm/sec constant
Injection	0.2 µL, 200:1 split
Liner	4 mm I.D., split, cup design
Sample	PUFA No. I – Marine Source (47033), diluted to 50 mg/mL in methylene chloride

1. C14:0
2. C16:0
3. C16:1n7
4. C18:1n9
5. C18:1n7
6. C18:2n6
7. C18:3n3
8. C18:4n3
9. C20:1n11
10. C20:1n9
11. C20:1n7
12. C20:4n6
13. C20:4n3
14. C20:5n3
15. C22:1n11
16. C22:1n9
17. C22:5n3
18. C22:6n3

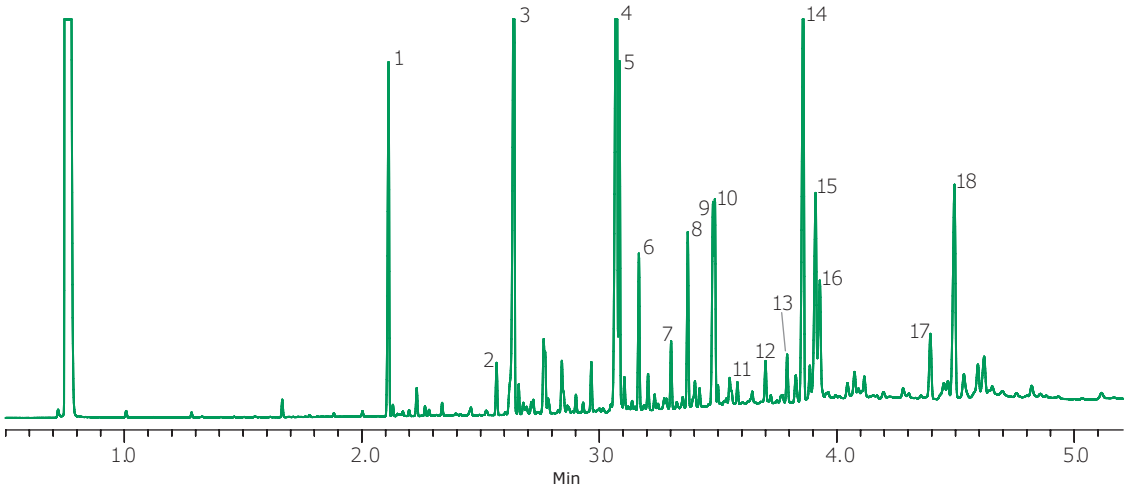


Figure 27. PUFA No. 2 Mix (Animal Source) FAMEs on an Omegawax® column

Column	Omegawax® 100, 15 m × 0.10 mm I.D., 0.10 µm (23399-U)
Oven	140 °C, 40 °C/min to 280 °C (2 min)
Inj.	250 °C
Det.	FID, 280 °C
Carrier gas	hydrogen, 50 cm/sec constant
Injection	0.2 µL, 200:1 split
Liner	4 mm I.D., split, cup design
Sample	PUFA No. II – Animal Source (47015-U), diluted to 50 mg/mL in methylene chloride

1. C16:0
2. C18:0
3. C18:1n9
4. C18:1n7
5. C18:2n6
6. C18:3n6
7. C20:0
8. C20:1n9
9. C20:2n9
10. C20:3n6
11. C20:4n6
12. C20:5n3
13. C22:5n6
14. C22:5n3
15. C22:6n3

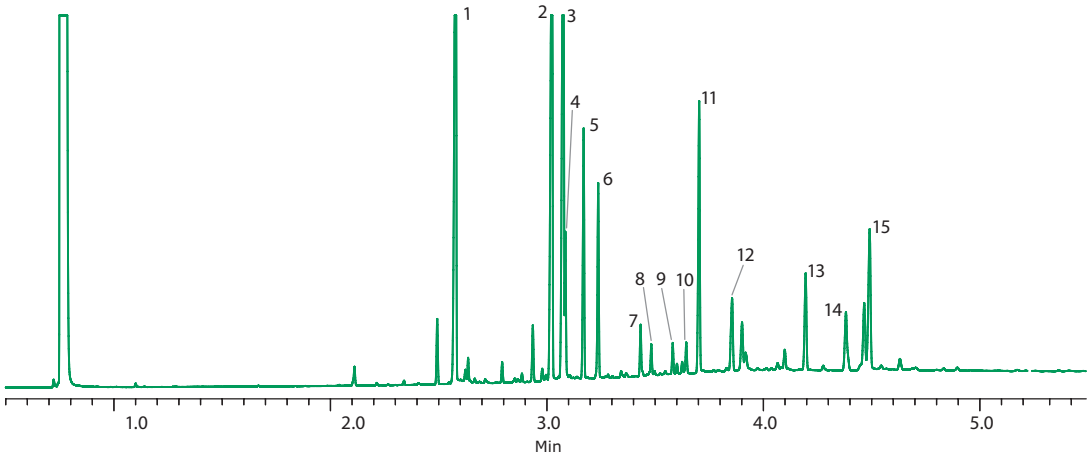


Figure 28. PUFA No. 3 Mix (Menhaden Oil) FAMEs on an Omegawax® column

Column	Omegawax® 100, 15 m × 0.10 mm I.D., 0.10 µm (**23399-U**)
Oven	140 °C, 40 °C/min to 280 °C (2 min)
Inj.	250 °C
Det.	FID, 280 °C
Carrier gas	hydrogen, 50 cm/sec constant
Injection	0.2 µL, 200:1 split
Liner	4 mm I.D., split, cup design
Sample	PUFA No. III – Menhaden Oil (**47085-U**), diluted to 50 mg/mL in methylene chloride

1. C14:0
2. C16:0
3. C16:1n7
4. C16:2n4
5. C16:3n4
6. C16:4n1
7. C18:0
8. C18:1n9
9. C18:1n7
10. C18:2n6
11. C18:3n4
12. C18:3n3
13. C18:4n3
14. C20:1n9
15. C20:4n6
16. C20:4n3
17. C20:5n3
18. C22:5n3
19. C22:6n3

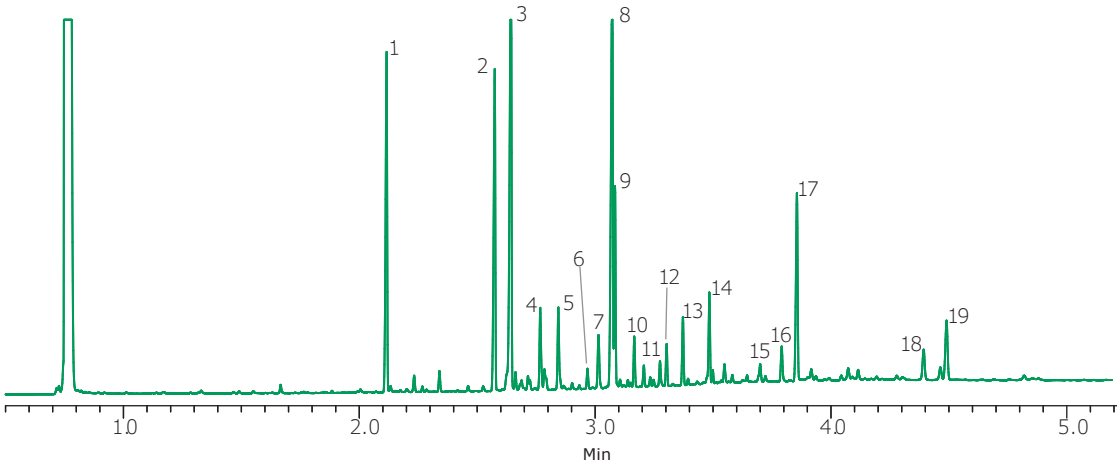


Figure 29. Amino Acids on SLB®-5ms

Column	SLB®-5ms, 20 m x 0.18 mm I.D., 0.18 µm (28564-U)
Oven	100 °C (1 min.), 35 °C/min to 290 °C (3 min), 40 °C/min to 360 °C
Inj. temp.	250 °C
Detector	MSD, scan range m/z 40 – 450
MSD interface	325 °C
Carrier gas	helium, 1 mL/min
Injection	0.5 µL, splitless (1.0 min)
Liner	2 mm I.D., splitless type, straight design
Sample	TBDMS derivatives of amino acids, each approximately 23 µg/mL

1. Alanine
2. Glycine
3. Valine
4. Artifact from derivatization
5. Leucine
6. Isoleucine
7. Proline
8. Asparagine extra derivative
9. Glutamine extra derivative
10. Methionine
11. Serine
12. Threonine
13. Phenylalanine
14. Aspartic acid
15. Hydroxyproline
16. Cysteine
17. Glutamic acid
18. Asparagine
19. Lysine
20. Glutamine
21. Histidine
22. Tyrosine
23. Tryptophan extra derivative
24. Tryptophan
25. Cystine

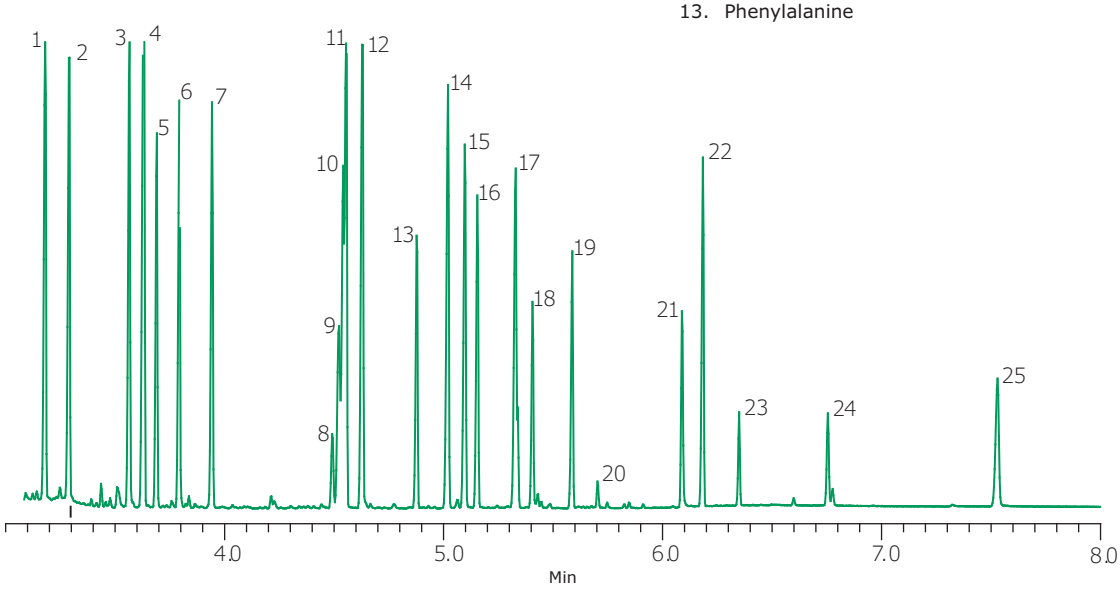


Figure 30. Lemon Essential Oil on SLB®-5ms

Column	SLB®-5ms, 10 m × 0.10 mm I.D., 0.10 µm (28465-U)
Oven	40 °C, 50 °C/min to 320 °C
Inj.	320 °C
Det.	FID, 320 °C
Carrier gas	hydrogen, 81.5 cm/sec constant
Injection	0.4 µL, 300:1 split
Sample	lemon essential oil in hexane

1. Tricyclene
2. α-Thujene
3. α-Pinene
4. Camphene
5. Sabinene
6. β-Pinene
7. Myrcene
8. Octanal
9. α-Phellandrene
10. δ-3-Carene
11. α-Terpinene
12. p-Cymene
13. Limonene
14. (E)-β-Ocimene
15. γ-Terpinene
16. *cis*-Sabinene hydrate
17. Octanol
18. Terpinolene
19. Linalool
20. Nonanal
21. *cis*-Limonene oxide
22. *trans*-Limonene oxide
23. (E)-Myroxide
24. Camphor
25. Citronellal
26. Borneol
27. Terpinen-4-ol
28. α-Terpineol
29. Decanal
30. Citronellol
31. Nerol
32. Neral
33. Carvone
34. Geraniol
35. Geranial
36. Perilla aldehyde
37. Undecanal
38. Methyl geranoate
39. Citronellyl acetate
40. Neryl acetate
41. Linalyl isobutanoate
42. Geranyl acetate
43. 1-Tetradecene
44. Tetradecane
45. (E)-Caryophyllene
46. *trans*-α-Bergamotene
47. β-Bisabolene
48. (Z)-γ – Bisabolene
49. (E)-γ – Bisabolene
50. Norbornanol
51. Campherenol
52. α-Bisabolol

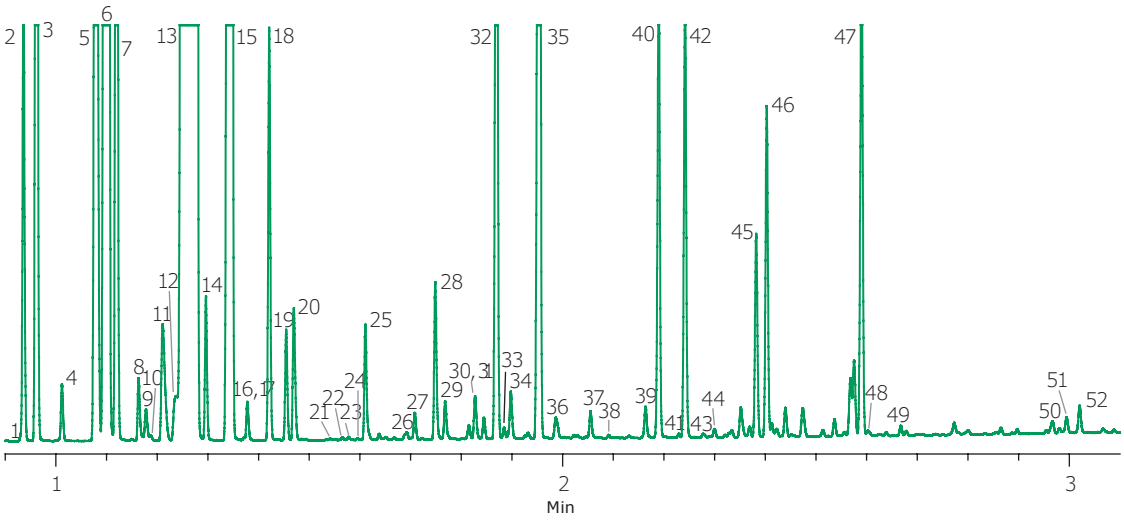


Figure 31. Distilled Lime Essential Oil using an Equity®-1 column

Column	Equity®-1, 15 m × 0.10 mm I.D., 0.10 µm (28039-U)
Oven	75 °C (1 min.), 35 °C/min to 200 °C (1 min)
Inj.	250 °C
Det.	FID, 250 °C
Carrier gas	helium, 45 cm/sec constant
Injection	0.10 µL, 300:1 split
liner	2 mm I.D., straight
Sample	distilled lime oil, neat

1. α-Pinene
2. Camphene
3. β-Pinene
4. Myrcene
5. α-Phellandrene
6. 1,4-Cineole
7. α-Terpinene
8. p-Cymene
9. δ-Limonene
10. γ-Terpinene
11. Terpinolene
12. Linalool
13. α-Fencyl alcohol
14. Terpinen-1-ol
15. β-Terpineol
16. Borneol
17. Terpinen-4-ol
18. α-Terpineol
19. γ-Terpineol
20. Decanal
21. Neral
22. Geranial
23. Neral acetate
24. Geranyl acetate
25. Dodecanal
26. β-Carophyllene
27. *trans*-α-Bergamotene
28. *trans*-α-Farnesene
29. β-Bisabolene

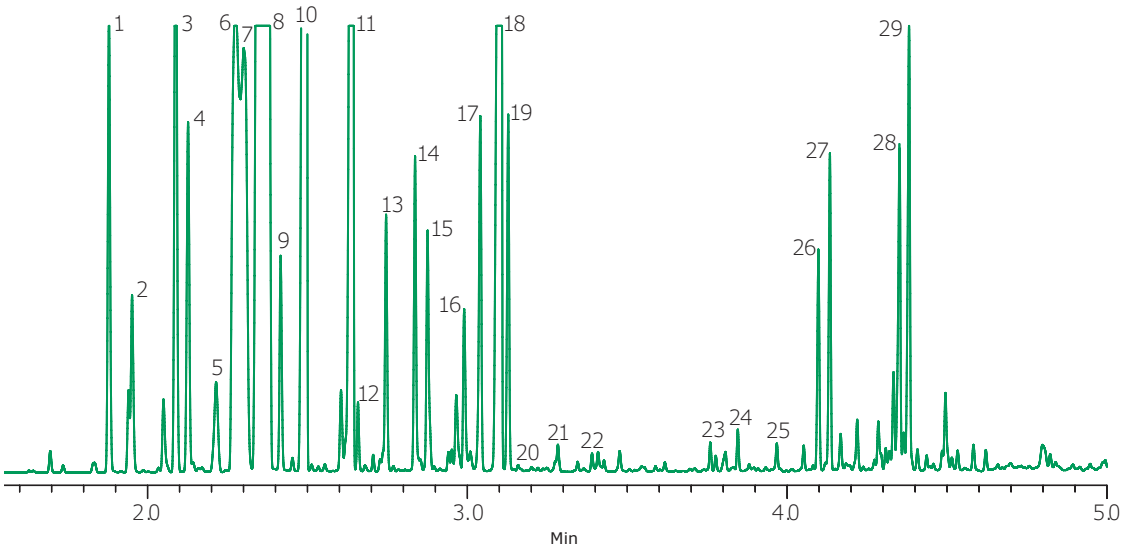


Figure 32. Sweet Orange Essential Oil on SLB®-5ms

Column	SLB®-5ms, 10 m × 0.10 mm I.D., 0.10 µm (28465-U)
Oven	40 °C , 50 °C/min to 320 °C.
Inj.	20 °C
Det.	FID, 320 °C
Carrier gas	hydrogen, 81.5 cm/sec constant
Injection	0.4 µL, 300:1 split
Sample	sweet orange essential oil in hexane

1. α-Thujene
2. α-Pinene
3. Camphene
4. Sabinene
5. β-Pinene
6. Myrcene
7. Octanal
8. α-Phellandrene
9. δ-3-Carene
10. α-Terpinene
11. p-Cymene
12. Limonene
13. (E)-β-Ocimene
14. γ-Terpinene
15. Octanol
16. Terpinolene
17. Linalool
18. Nonanal
19. *cis*-Limonene oxide
20. *trans*-Limonene oxide
21. Citronellal
22. Terpinen-4-ol
23. α-Terpineol
24. Decanal
25. Neral
26. 2-(E)-Decenal
27. Geranial
28. Perilla aldehyde
29. Perilla alcohol
30. Undecanal
31. Neryl acetate
32. α-Copaene
33. Geranyl acetate
34. β-Cubebene + β-Elemene
35. Dodecanal
36. (E)-Caryophyllene
37. β-Copaene
38. *cis*-β-Farnesene
39. α-Humulene
40. Germacrene D
41. Valencene
42. Bicyclogermacrene
43. δ-Cadinene
44. Unknown

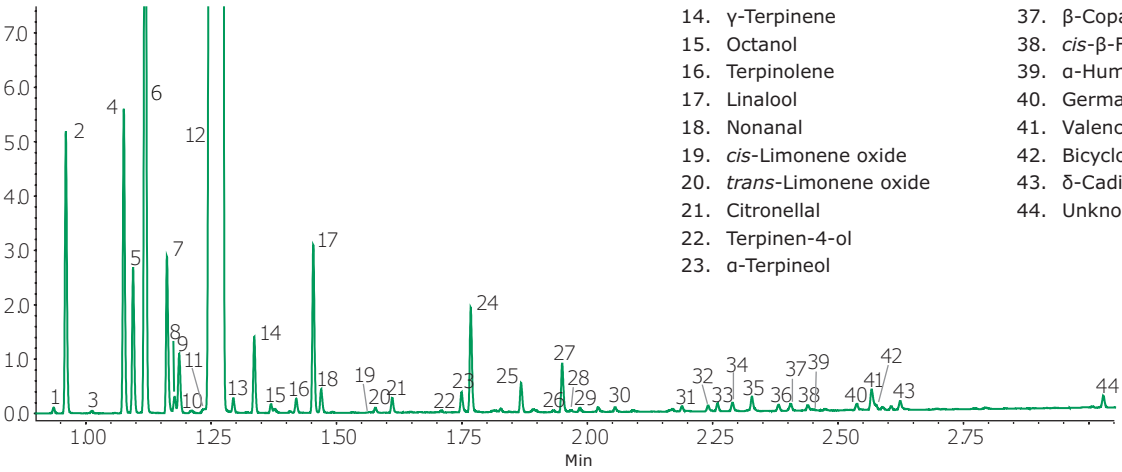


Figure 33. Allergens in Commercial Perfume on SLB®-5ms

Column	SLB®-5ms, 10 m × 0.10 mm I.D., 0.10 µm (**28465-U**)
Oven	40 °C , 50 °C/min to 320 °C
Inj.	320 °C
Det.	FID, 320 °C
Carrier gas	hydrogen, 81.5 cm/sec constant
Injection	0.2 µL, 500:1 split
Sample	neat perfume

1. Limonene
2. Linalool
3. Citronellol
4. Neral
5. Geranial
6. Hydroxycitronellal
7. Cinnamyl alcohol
8. Eugenol
9. Coumarin
10. α-Isomethylionone
11. Hexyl cinnamylaldehyde

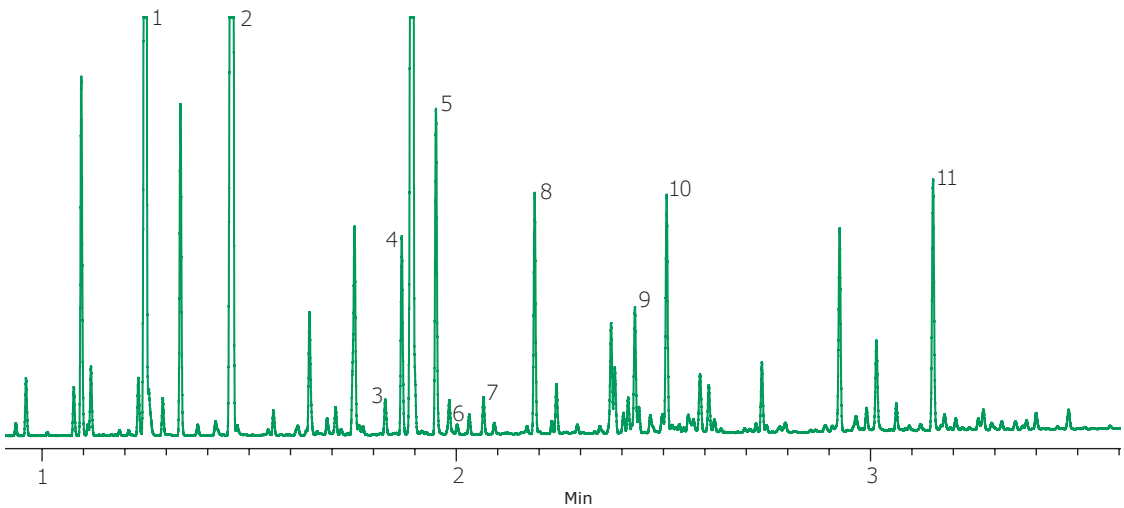


Figure 34. Bacterial Acid Methyl Esters (BAMEs) using an Equity®-1 column

Column	Equity®-1, 15 m × 0.10 mm I.D., 0.10 µm (28039-U)
Oven	175 °C, 30 °C/min to 275 °C (1 min)
Inj.	280 °C
Det.	FID, 280 °C
Carrier gas	hydrogen, 45 cm/sec constant
Injection	0.5 µL, split 200:1
Sample	Bacterial Acid Methyl Ester (BAME) Mix (**47080-U**)

1. Methyl 2-hydroxydecanoate (2-OH C10:0)
2. Methyl undecanoate (C11:0)
3. Methyl dodecanoate (C12:0)
4. Methyl 2-hydroxydodecanoate (2-OH C12:0)
5. Methyl 3-hydroxydodecanoate (3-OH C12:0)
6. Methyl tridecanoate (C13:0)
7. Methyl tetradecanoate (C14:0)
8. Methyl 2-hydroxytetradecanoate (2-OH C14:0)
9. Methyl 3-hydroxytetradecanoate (3-OH C14:0)
10. Methyl pentadecanoate (C15:0)
11. Methyl 13-methyltetradecanoate (iC15:0)
12. Methyl 12-methyltetradecanoate (a-C15:0)
13. Methyl hexadecanoate (C16:0)
14. Methyl 14-methylpentadecanoate (iC16:0)
15. Methyl 2-hydroxyhexadeanoate (2-OH C16:0)
16. Methyl *cis*-9-hexadecenoate (C16:19)
17. Methyl heptadecanoate (C17:0)
18. Methyl 15-methylhexadecanoate (iC17:0)
19. Methyl *cis*-9,10-methylenehexadecanoate (C17:0D)
20. Methyl octadecanoate (C18:0)
21. Methyl *cis*-9-octadecenoate (C18:19)
22. Methyl *trans*-9-octadecenoate (C18:19) & Methyl *cis*-11-octadecenoate (C18:111)
23. Methyl *cis*-9,12-octadecadienoate (C18:29,12)
24. Methyl nonadecanoate (C19:0)
25. Methyl *cis*-9,10-methyleneoctadecanoate (C19:0D)
26. Methyl eicosanoate (C20:0)

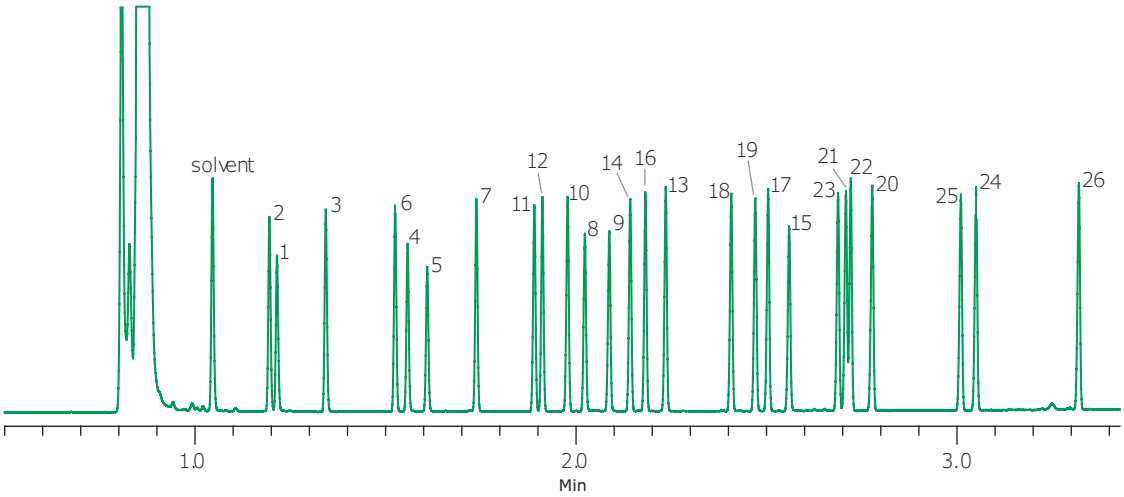
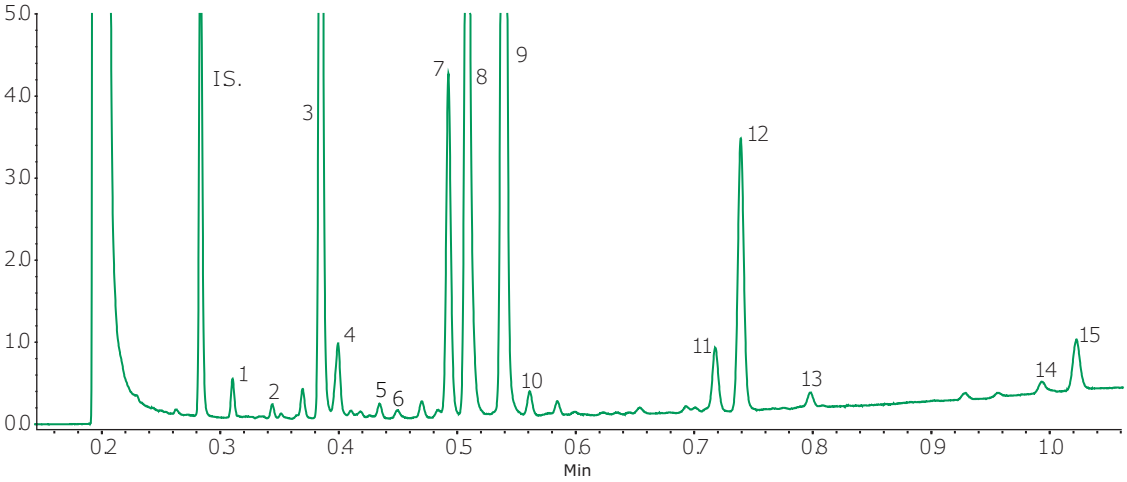


Figure 35. FAMEs in Plasma on SUPELCOWAX® 10

Column	SUPELCOWAX® 10, 10 m × 0.10 mm I.D., 0.10 µm (**25026-U**)
Oven	220 °C, 60 °C/min to 280 °C (1 min)
Inj.	280 °C
Det.	FID, 280 °C
Carrier gas	hydrogen, 120 cm/sec
Injection	0.5 µL, 30:1 split
Sample	plasma FAMEs in hexane

1. IS C13:0
2. C14:0
3. C15:0
4. C16:0
5. C16:1n7
6. C17:0
7. C16:3n4
8. C18:0
9. C18:1n9
10. C18:2n6
11. C18:3n3
12. C20:3n6
13. C20:4n6
14. C20:5n3
15. C22:5n3
16. C22:6n3



Ordering Information

Analytical GC chemists are continually striving to reduce analysis times, because shorter analysis times increase sample throughput, which translates to the completion of more runs per shift. However, any decrease in analysis time must not diminish the resolution necessary to adequately resolve peaks of interest, or to identify specific elution patterns. Applying the Principles of Fast GC to any application can achieve both objectives. Table 5 lists the catalog numbers of our special purpose, ionic liquid, and general purpose Fast GC columns.

Table 5. Fast GC Columns

Chemistry	I.D. (mm)	df (µm)	Length (m)	β Value	Cat. No.
Special Purpose Fast GC Columns					
SLB®-5ms	0.10	0.10	10	250	**28465-U**
SLB®-5ms	0.10	0.10	15	250	**28466-U**
SLB®-5ms	0.18	0.18	20	250	**28564-U**
SLB®-5ms	0.18	0.30	30	150	**28575-U**
SLB®-5ms	0.18	0.36	20	125	**28576-U**
SPB®-624	0.18	1.00	20	45	**28662-U**
VOCOL®	0.18	1.00	20	45	**28463-U**
Equity®-1701	0.10	0.10	15	250	**28343-U**
Omegawax®	0.10	0.10	15	250	**23399-U**
SP®-2560	0.18	0.14	75	321	**23348-U**
Ionic Liquid Fast GC Columns					
SLB®-IL59	0.10	0.08	15	313	**28880-U**
SLB®-IL60	0.10	0.08	15	313	**29503-U**
SLB®-IL60	0.18	0.14	20	313	**29504-U**
SLB®-IL61	0.10	0.08	15	313	**29484-U**
SLB®-IL76	0.10	0.08	15	313	**28909-U**
SLB®-IL82	0.10	0.08	15	313	**29477-U**
SLB®-IL100	0.10	0.08	15	313	**28882-U**
SLB®-IL100	0.18	0.14	20	313	**28883-U**
SLB®-IL111	0.10	0.08	15	313	**28925-U**
General Purpose Fast GC Columns					
Equity®-1	0.10	0.10	15	250	**28039-U**
Equity®-5	0.10	0.10	15	250	**28083-U**
SUPELCOWAX® 10	0.10	0.10	5	250	**25025-U**
SUPELCOWAX® 10	0.10	0.10	10	250	**25026-U**
SUPELCOWAX® 10	0.10	0.10	15	250	**24343**

Our Fast GC webpage contains over 75 Fast GC chromatograms spanning several industries and applications. For this and additional information, visit **SigmaAldrich.com/fastgc**

GC workflow solutions to streamline your GC analyses

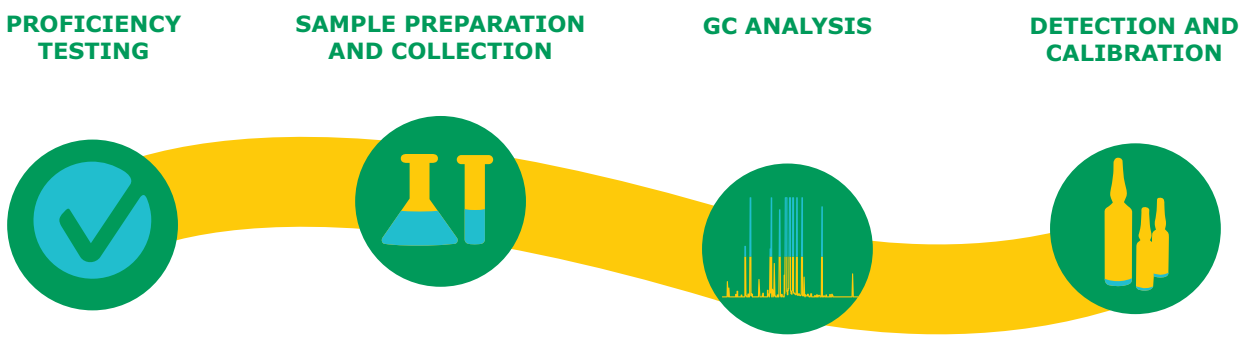
Our complete GC workflow solutions can help you to optimize your fast GC workflow by increasing sample throughput without compromising on resolution.

Whether you use ECD, FID, TCD, MS or another detector—our range of GC columns, solvents, standards & accessories offers a dedicated quality for your specific application and detection method.

Ensure accurate and reliable results while supporting laboratory regulatory requirements with our comprehensive portfolio of solutions for the entire GC workflow

- Proficiency testing
- Sample collection and preparation products: SPE, purge & traps, water, air sampling etc.
- GC products for analysis: columns, solvents and accessories
- Detection and calibration: certified reference materials and standards, matrix materials etc.

Visit **SigmaAldrich.com/gc** to discover how we can help you to streamline your analyses, whatever your sample matrix



Supelco®

Analytical Products

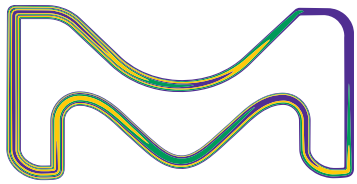
Merck KGaA
Frankfurter Strasse 250
64293 Darmstadt, Germany

SigmaAldrich.com/GC

To place an order or receive technical assistance

Order/Customer Service: **SigmaAldrich.com/order**
Technical Service: **SigmaAldrich.com/techservice**
Safety-related Information: **SigmaAldrich.com/safetycenter**

SigmaAldrich.com/GC



Lit. No. MK_BR4748EN Ver. 1.0
2019 - 25100
04/2020