THE CHOICE OF CARRIER GAS IN PREPARATIVE GAS CHROMATOGRAPHY

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In analytical gas chromatography with katharometer detection, hydrogen or helium are the best carrier gases. The use of nitrogen results in a considerable loss of sensitivity, and the non-linearity of the detection together with possible peak reversals are additional drawbacks with this gas. In preparative scale gas chromatography, however, gas consumption is an important factor. Helium is ideal, but the price is prohibitive, at least for the majority of institutions. Hydrogen is of course dangerous, although it may be pointed out here that an air–hydrogen mixture only becomes inflammable at hydrogen concentrations of more than 4%. This means that in a fairly large room ($5 \times 6 \times 4$ m) an entire cylinder (± 5 m^3) may be emptied without danger of explosion. Undoubtedly, however, in preparative gas chromatography the use of nitrogen should be reconsidered.

Because of the increased sample loads of preparative gas chromatography the sensitivity of detection is no longer critical. With helium and hydrogen no special problems are encountered.

With nitrogen and katharometer detection, however, the troublesome effect of peak inversion can occur. BOHEMEN AND PURNELL[1] have shown that the signal of a katharometer detector is influenced by several factors. The thermal conductivity factor heats the katharometer when a substance passes and this gives a "positive" deflection. The molar heat capacity of the substances, however, also plays a part and has a cooling effect. If the heat capacity factor is the more important, peak inversion occurs. High gas flow rates, spiral filaments and high temperatures of filament and detector oven favour peak inversion.

With hydrogen and helium, thermal conductivity far outweighs the other factors, but with nitrogen this is not the case and peak inversion can occur easily with this gas. Commercial katharometer blocks are usually designed for analytical purposes and have as small a volume as possible. The use of such a detector block for preparative purposes with nitrogen at high flow rates produces just the conditions where peak inversion is most easily observed. This is for example the case for the Wilkens Autoprep 700 preparative gas chromatographic unit. The chromatograph has also analytical possibilities and in fact the detector block is the same as in analytical chromatographs produced by this firm. Inversion then occurs easily. This seemingly very annoying phenomenon can, however, be guided in such a way that inversion is the normal state of affairs. This is achieved by setting the detector oven at a high temperature (250°) and by using high flow rates and high detector currents. Most

substances then show completely reversed peaks with a strong signal over the whole possible concentration range. All that is necessary then is to switch the polarity of the recorder.

This is for example the procedure to be followed using the instrument mentioned above for all concentrations of acetone, ethyl acetate and benzene, substances for which badly shaped peaks and inversion trouble have been reported frequently in the literature. The highest signal for a reversed peak can be obtained with a nitrogen gas flow of 250 ml and a detector current of 200 mA. The efficiency of the columns is, however, impaired by such a high gas rate using nitrogen and the high katharometer currents considerably shorten the detector block life time. The same detector current will heat a katharometer wire to a much higher temperature in a nitrogen stream than in a hydrogen or helium stream. With more normal conditions *e.g.* gas rate 200 ml and a detector current of 150 mA, the response is only slightly less and the separation is good. This is shown in the chromatogram of Fig. 1 where 500 μl of a mixture of acetone, ethyl acetate and benzene are separated under these conditions on a 6 m glass column of 9 mm diameter filled with chromosorb W with 30 % SE30. The recorder terminals are reversed.

An important point with all detectors is the linearity of the response to sample load. With helium and hydrogen the response of a katharometer detector is linear for very small sample loads and shows decreasing signals for the large samples used in preparative chromatography. The reverse is true for the inverted peaks obtained with nitrogen. For small samples there is no linearity and the response first falls off with increasing sample, while remaining linear for larger sample loads. With a flow rate of 300 ml and 150 mA as bridge current the sensitivity of the detection in hydrogen and nitrogen for large samples is nearly the same.

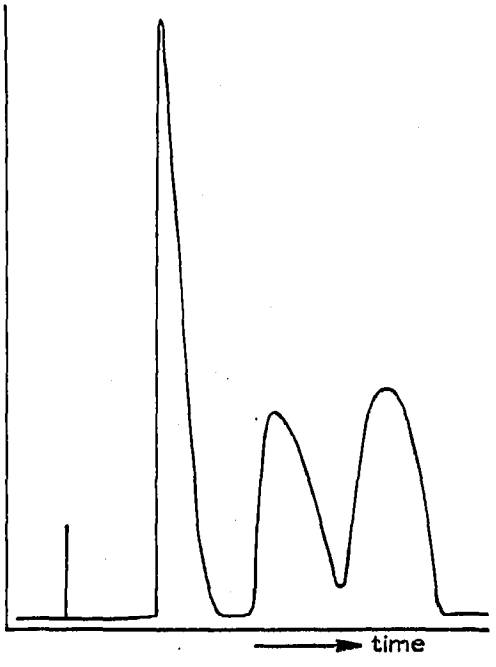

Fig. 1. Separation of acetone, ethyl acetate and benzene (0.5 ml) on 6 m column, diameter 9 mm, 30 % SE30 on Chromosorb W with nitrogen as carrier gas, showing peak inversion over whole concentration range as explained in text.

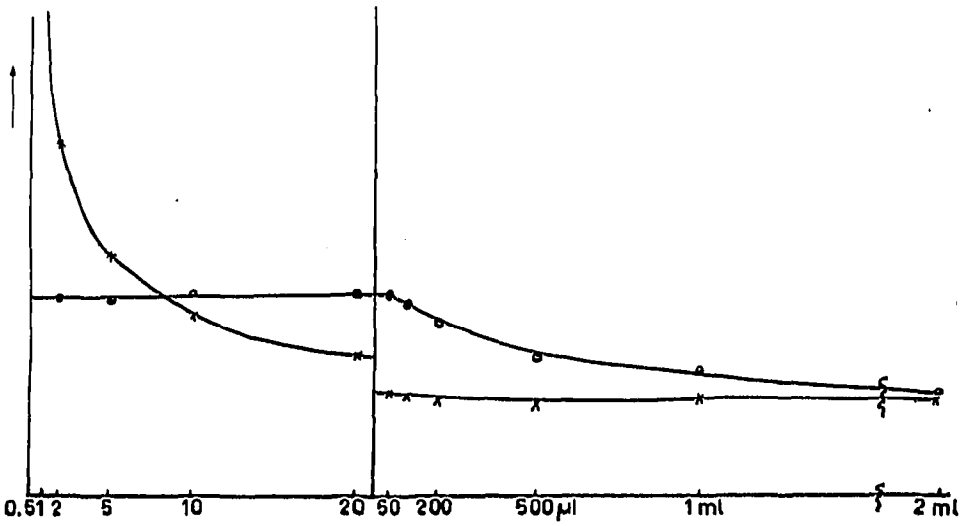

Fig. 2. Response of katharometer detection in hydrogen (⊙ normal peaks) and nitrogen (× inverted peaks) as further explained in text

The linearity discussed above is shown in Fig. 2. To obtain easily readable diagrams, all measured peak surfaces were recalculated as peaks for 2 ml and the sample scale ordinate was compressed for larger sample loads.

The absolute value of the surfaces cannot be compared in Fig. 2, because measurements were obtained on different recorders and with a different flow rate and detector current. The scales were adapted to show that for really large samples the surface area is about the same for the normal peaks in hydrogen and the inverted peaks in nitrogen. For small samples then the inverted peak surface with nitrogen is larger, but the peaks are lower and broader than for the positive peaks obtained with hydrogen. This is a normal result with regard to the higher non-linear response in nitrogen (response is lower at peak maximum) and this is also due to the difference in column efficiency with the two gases for small samples, as will be explained later.

Column efficiency and carrier gas

Column efficiency is defined here as the number of plates calculated from the equation $n = C(V'_R \cdot V_R/W^2)$ where V_R and V'_R are the uncorrected and corrected retention times and W is the band-width. C is a constant and is 18.5 when the band is measured at 10 % of its maximum height[2]. Comparisons of the carrier gases were obtained by chromatographing the same substance under exactly the same conditions. The optimum gas rates for nitrogen and for hydrogen and helium differ slightly, being somewhat lower for nitrogen. Varying the gas rates between 50 and 500 ml makes no difference to the general line of results and conclusions as given below.

With analytical quantities, the efficiency of larger bore columns is much better with hydrogen and helium than with nitrogen. The difference is between 20 and 100 % and varies with column length and grain size of the support material.

With increased sample loads for preparative purposes the efficiency drops sharply as has indeed been long known. It is important that this efficiency decrease is less marked with nitrogen than with hydrogen and helium. This can be concluded from the following diagram showing the plate number *versus* the sample volume at a gas rate of 200 ml/min for the different carrier gases (Fig. 3).

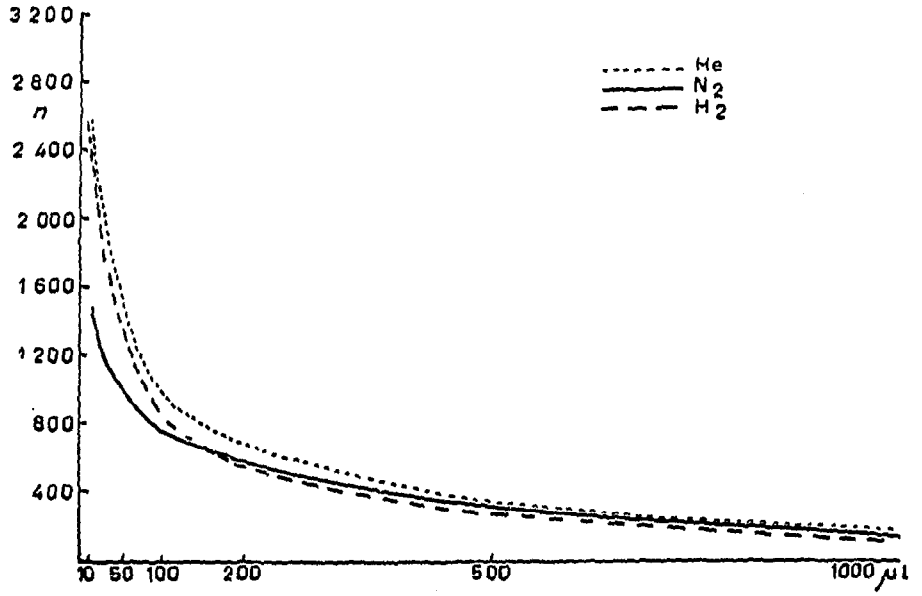

Fig. 3. Plate number of 6 m coiled glass column, diameter 9 mm, as function of sample load of iso-octane with helium, hydrogen and nitrogen as carrier gas.

The same pattern was observed for shorter or longer columns and for a number of different grain sizes of the support.

The conclusion is that for analytical purposes the superiority of helium and hydrogen over nitrogen on large bore columns is unquestionable, but that for preparative quantities there is no very great difference between the three gases from the all-important point of efficiency. It is of course not easy to measure retention times, peak heights and band-widths on the distorted peaks of preparative gas chromatography, and the value of the plate number as a measure of efficiency is questionable in this case. However, in as far as the plate number is an expression of relative band-width, it is useful in this respect. The measured peak heights and band-widths are only proportional to the actual values in the column for linear detection over the whole concentration range of the peak. This in only so for small concentrations and in hydrogen; for all other cases the calculated plate number values must be too low. It is believed, however, that this detection effect is only of minor importance and that the general line of results about the plate number is not influenced by it.

Example of a separation with hydrogen and nitrogen

A separation with hydrogen and nitrogen is shown in the diagrams obtained with decalin (Figs. 4 and 5). The concentration difference at the base and top of the peaks is much greater than could be inferred from the chromatograms. The height of the minimum between the peaks in the separation with nitrogen is reached experimentally with only 1 % of the sample load of the preparative separation, although this height is 12 % of the peak height of *trans*-decalin. This is caused by the sensitivity for small samples in nitrogen as explained in the discussion of Fig. 2. As a result, even when the minimum between two peaks does not reach the base line the recovered substances are purer than would be expected. The substances recovered from the preparative separations of Fig. 4 and 5 by simply switching the collection bottles at the minimum between the two peaks (this means that no waste period was observed)

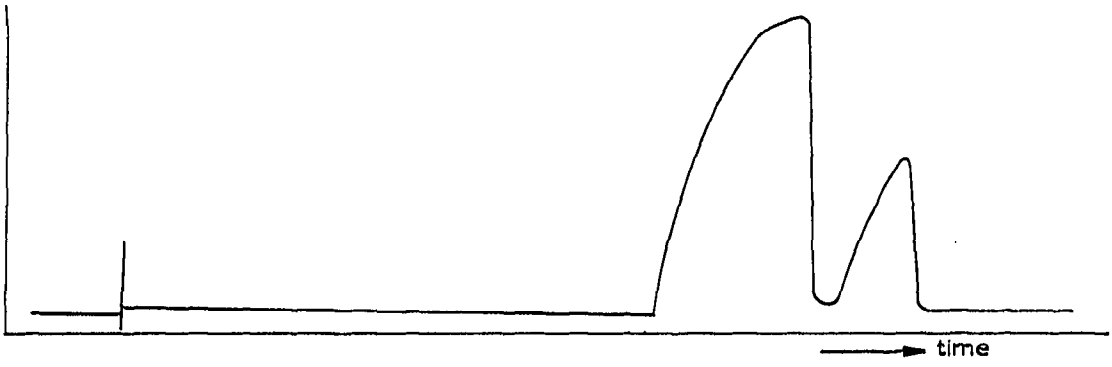

Fig. 4. Separation of 0.5 ml decalin (*trans* and *cis*) on 6 m coiled glass column, diameter 9 mm, filled with 30 % SE30 on Chromosorb P with hydrogen as carrier gas.

were analysed by ordinary gas chromatography. No trace of *cis*-contamination of *trans*-decalin or *vice versa* could be detected with katharometer detectors. On a flame ionisation instrument with a capillary column, less than 0.5 % *cis*-decalin was found in the *trans*-decalin from the separation with nitrogen; the other substances were pure. This is indeed surprising considering the tracing shown in Fig. 5 obtained with nitrogen.

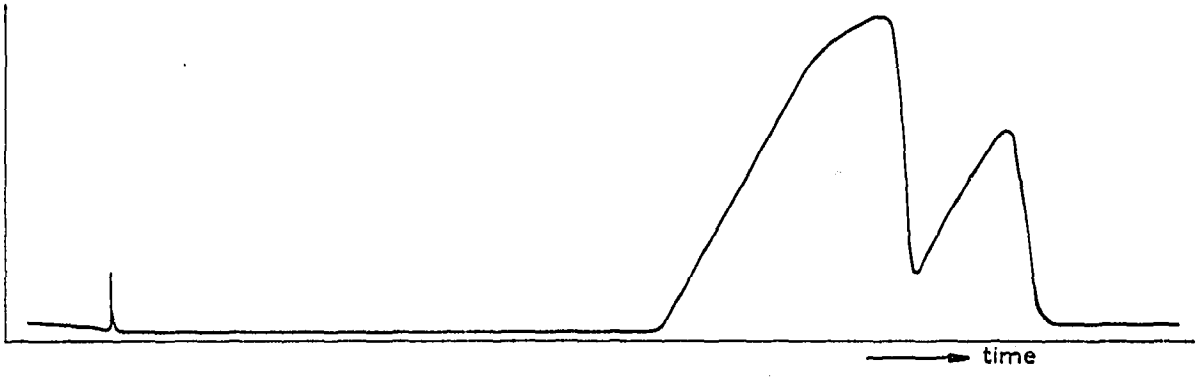

Fig. 5. The same as in Fig. 4 but with nitrogen as carrier gas. The inverted peaks become normal after switching the polarity of the recorder terminals.

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SUMMARY

Helium and hydrogen as carrier gases are more suitable than nitrogen for preparative gas chromatography. Having regard, however, to the high price of helium and the danger of hydrogen, nitrogen may be preferred. For small analytical sample loads on large bore columns helium and hydrogen are far superior to nitrogen, but for larger sample loads this difference is not so great. The separations obtained with nitrogen are much better than indicated by the recorded chromatograms because of the non-linearity of the detection.

REFERENCES

[1] I. BOHEMEN AND J. H. PURNELL, *J. Appl. Chem. (London)*, 8 (1958) 433.
[2] M. VERZELE AND F. ALDERWEIRELDT, *Bull. Soc. Chim. Belges*, 66 (1957) 570.