A simple distillation is incapable of significant purification if the boiling points of the components are too close. When the difference in boiling points is less than \(100^\circ \text{C}\), a modification is necessary, namely insertion of a fractionating column between the distilling flask and three-way adapter (Figure 5.37a).

![Fractionating column](image)

**Figure 5.37:** a) Fractional distillation setup, b) Zoom in of fractionating column during distillation, with condensation dripping from the glass indentations.

The distillate of a simple distillation is always enriched in the lower boiling compound. As previously discussed, the simple distillation of a \(75 \text{ mol\%} \) ethylbenzene/\(25 \text{ mol\%} \) \(p\)-cymene mixture resulted in a distillate that was \(90 \text{ mol\%} \) ethylbenzene (ethylbenzene had the lower boiling point). Imagine if a subsequent distillation were performed on the \(90 \text{ mol\%} \) solution: the distillate of that process would contain an even higher percentage of ethylbenzene.

A fractionating column essentially allows for many successive distillations to take place at once, without dismantling the apparatus. A fractionating column contains indentations (a Vireux column, Figure 5.37) or a packing material with lots of surface area. The vapors temporarily condense on these surfaces (see Figure 5.37b) and the heat of the distillation allows those pools of liquid to vaporize again. Every vaporization-condensation event (called a “theoretical plate”) is similar to a simple distillation, and each event enriches the distillate in the lower boiling component.

The concepts of a fractional distillation can be shown through a distillation curve. In the distillation of an equimolar mixture of compounds A + B (which is described by the distillation curve in Figure 5.38), one vaporization-condensation event is represented in Figure 5.38 by following points a to b to c. This process represents one theoretical plate, and would produce a distillate that is \(81\%\) A and \(19\%\) B. A second vaporization-condensation event is represented in Figure 5.38 by following points c to d to e, and would produce a distillate that is \(96\%\) A and \(4\%\) B.
A 50%/50% mixture of two components whose boiling points differ by only 20-30°C would require at least three theoretical plates to obtain a distillate with >95% purity. In practice, fractional distillations still often produce mixtures. The best chance of obtaining purity via fractional distillation is when there is very little impurity to begin with.