5. (4 points) Back in the days before the hard-charging, marathon-running Bob Gavin (a physical chemist!) served as President of Macalester, science faculty spent leisurely summers, not on research, but on developing new lab experiments and lecture demonstrations. About 1980, Emil Slowinski worked on a gas chromatography experiment and got the following chromatogram:

```
\begin{align*}
    \text{time (min)} & \quad t_1 \quad t_2 \quad t_3 \quad t_4 \\
    \text{mv} & \uparrow
\end{align*}
```

Draw an operational amplifier-based circuit that would allow the “retention times” ($t_1, t_2, t_3,$ and $t_4$) to be determined more accurately.

Draw an operational amplifier-based circuit that would allow the “retention times” ($t_1, t_2, t_3,$ and $t_4$) to be determined more accurately.

6. (12 points) Consider the substances Cl$_2$(g), HCl(g), and Kr(g).

(a) Rank order their dielectric constants, and justify your ordering. (Note: There is not necessarily one “right” ordering—I will grade on the quality of your chemical reasoning.)

```
\begin{align*}
\text{\(\varepsilon(\text{H-ce}) > \varepsilon(\text{Cl}_2) > \varepsilon(\text{Kr})\)} & \quad -2 \text{ Kr is not polarizable} \\
\uparrow & \quad \text{polar} \quad \text{non-polar} \quad \text{non-polar} \\
\downarrow & \quad \text{linear} \quad \text{linear} \quad \text{spherical} \\
\text{or} & \quad \varepsilon(\text{H-ce}) > \varepsilon(\text{Kr}) > \varepsilon(\text{Cl}_2) \\
\uparrow & \quad \text{non-polar} \quad \text{more electrons} \quad \text{more polarizable(?)}
\end{align*}
```

(b) Imagine three discharge tubes, each containing one of the above substances. If all three tubes are running at the same temperature, the lines from which source would you expect to suffer the least from Doppler broadening? Explain your choice.

Doppler broadening is proportional to the mean speed of the gas: \(\Delta \lambda_{\text{Dop}} \sim u \sim \sqrt{1/m}\)

so the heaviest gas, Kr, will have the lowest \(\Delta \lambda_{\text{Dop}}\).