Another mechanical parameter

First volume:

\[ V(T, p, N, m) = \frac{Nk_B T}{p} \]

whence

\[ \frac{\partial V}{\partial m}_{T,p,N} = 0 \]

Then entropy:

\[ S(E, V, N, m) = k_B N \left[ \frac{3}{2} \ln \left( \frac{4\pi mEV^{2/3}}{3h^2 N^{5/3}} \right) + \frac{5}{2} \right] \]

but use

\[ E = \frac{3}{2} Nk_B T \quad \text{and} \quad V = \frac{Nk_B T}{p} \]

to write

\[ S(T, p, N, m) = k_B N \left[ \frac{3}{2} \ln \left( \frac{2\pi m^{5/3} k_B T^{5/3}}{3h^2 p^{2/3}} \right) + \frac{5}{2} \right] \].

In other words (abusing the notation to allow the logarithm of a variable with dimensions),

\[ S(T, p, N, m) = k_B N \left[ \frac{3}{2} \ln(m) + \text{stuff independent of } m \right] \]

whence

\[ \frac{\partial S}{\partial m}_{T,p,N} = \frac{3}{2} Nk_B N \frac{1}{m} \]

Experiment: Compare \( V(T, p, N, m) \) and \( S(T, p, N, m) \) for a series of (nearly) ideal monatomic gases such as He, Ne, Ar, Kr, Xe that differ in mass.