critical constants were found to depend on the molecular mass, $m$, and temperature in a simple manner. The effective critical temperature and effective critical pressure are given by

$$T_c = \frac{T_c^\circ}{1 + \frac{c_1}{mT}} \tag{18}$$

$$P_c = \frac{P_c^\circ}{1 + \frac{c_2}{mT}} \tag{19}$$

where

$$c_1 = 21.8^\circ \text{ K.} \tag{20}$$

$$c_2 = 44.2^\circ \text{ K.} \tag{21}$$

$T_c^\circ$ and $P_c^\circ$ are, respectively, the classical critical temperature and pressure—i.e., the effective critical temperature and pressure in the limit of high temperature. Table III gives $T_c^\circ$ and $P_c^\circ$ for nine quantum gases.

For mixtures containing one or more of the quantum gases, Equations 8 through 12 are used, except that $T_{c_i}$ and $P_{c_i}$ are given by Equations 18 and 19; further, $T_{c_{ij}}$ and $P_{c_{ij}}$ are given by

$$T_{c_{ij}} = \frac{\sqrt{T^\circ_{c_{ii}} T^\circ_{c_{jj}}}\,(1 - k_{ij})}{1 + \frac{c_1}{m_{ij}T}} \tag{22}$$

$$P_{c_{ij}} = \frac{P^\circ_{c_{ij}}}{1 + \frac{c_2}{m_{ij}T}} \tag{23}$$

where

$$P^\circ_{c_{ij}} = \frac{z^\circ_{c_{ij}} R \sqrt{T^\circ_{c_{ii}} T^\circ_{c_{jj}}}\,(1 - k_{ij})}{v^\circ_{c_{ij}}} \tag{24}$$

$$v^{\circ\ 1/3}_{c_{ij}} = \frac{1}{2}\left(v^{\circ\ 1/3}_{c_i} + v^{\circ\ 1/3}_{c_j}\right) \tag{25}$$

$$z^\circ_{c_{ij}} = 0.291 - 0.08\left(\frac{\omega_i + \omega_j}{2}\right) \tag{26}$$

$$\frac{1}{m_{ij}} = \frac{1}{2}\left(\frac{1}{m_i} + \frac{1}{m_j}\right) \tag{27}$$

For all quantum gases, $\Omega_a$ and $\Omega_b$ are, respectively, 0.4278 and 0.0867, and $\omega$(effective) is zero. Values of $v_c^\circ$ for quantum gases are calculated from the relation $v_c^\circ = 0.291RT_c^\circ/P_c^\circ$; they are listed in Table III.

Figure 7 shows experimental and calculated compressibility factors for the two quantum gases, hydrogen (Johnston and White, 1948) and helium (Mann, 1962) at cryogenic temperatures. Calculated results were obtained from the Redlich-Kwong equation using effective critical constants. Good agreement is obtained over the entire temperature and pressure range, including the isotherms very close to the critical. The slightly high compressibility factors near the critical point are due to an inherent limitation of the Redlich-Kwong equation which gives $z_c = 1/3$ for all gases when $\Omega_a = 0.4278$ and $\Omega_b = 0.0867$.

Figure 8 shows experimental and calculated fugacity co-

**Table III. Classical Critical Constants for Quantum Gases**

| | $T_c^\circ$, ° K. | $P_c^\circ$, Atm. | $v_c^\circ$, Cc./Gram Mole |
|---|---|---|---|
| Ne | 45.5 | 26.9 | 40.3 |
| $He^4$ | 10.47 | 6.67 | 37.5 |
| $He^3$ | 10.55 | 5.93 | 42.6 |
| $H_2$ | 43.6 | 20.2 | 51.5 |
| HD | 42.9 | 19.6 | 52.3 |
| HT | 42.3 | 19.1 | 52.9 |
| $D_2$ | 43.6 | 20.1 | 51.8 |
| DT | 43.5 | 20.3 | 51.2 |
| $T_2$ | 43.8 | 20.5 | 51.0 |

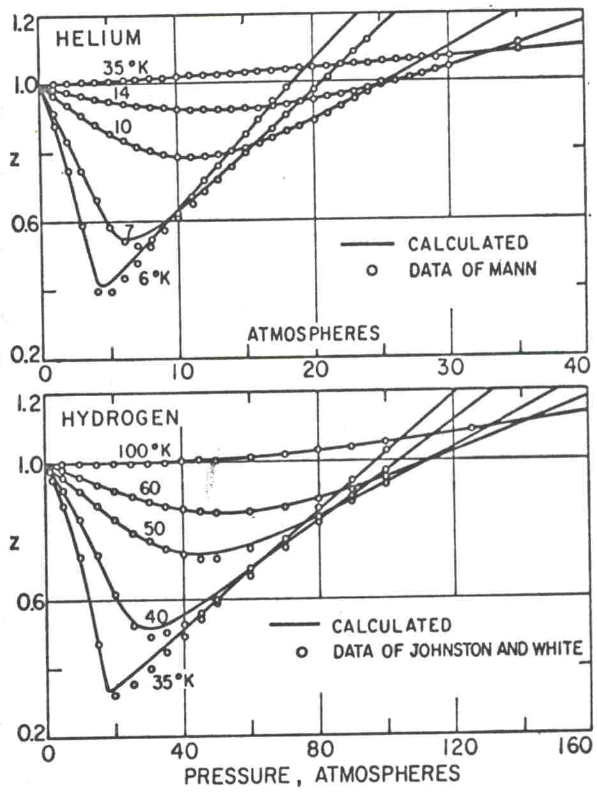


Figure 7. Compressibility factors of helium and hydrogen at low temperatures

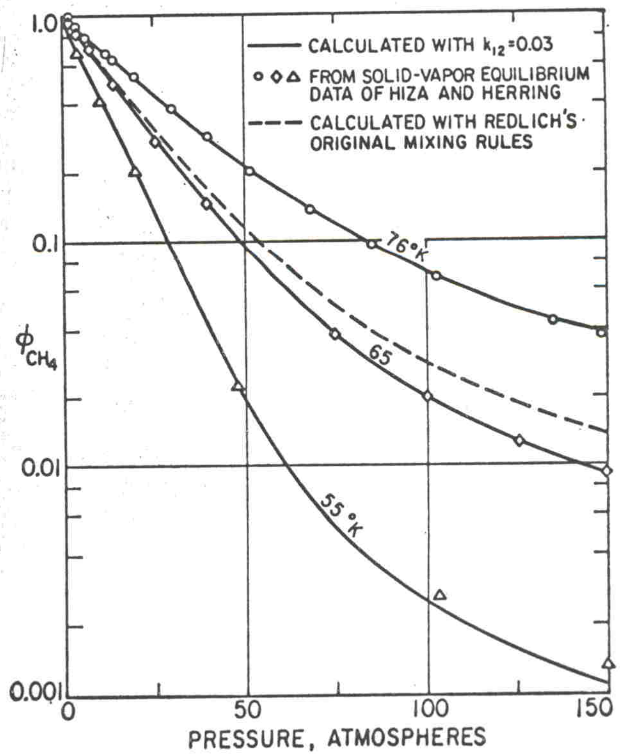


Figure 8. Fugacity coefficients of methane in hydrogen at saturation

$k_{12}$ = 0.03 obtained from second virial coefficient data