and $\lambda_{c,phn}$ is a primary factor in determining K_{phn}. Two types of collisions are important in limiting the phonon mean free path. (Phonon collisions with free electrons and photons are not ordinarily a significant effect.)

Phonon-phonon collisions are dominant at high temperatures, $T \sim \theta_D$. However, only a portion of the phonon-phonon collisions limit the rate of heat transport. If two freely translating phonons collide, energy and momentum are conserved; thus there is no net change in the rate or direction of energy transport. In contrast, when a phonon collides with an optical mode vibration in a molecular crystal (see Unit IIID), the rate and direction of energy transport are altered. Similarly a certain fraction of phonon-phonon collisions involve localized lattice point vibrations (atomic or molecular). Such processes also alter the rate and direction of energy transport. Collectively all of the phonon collisions that affect the rate of phonon transport are called *Umklapp processes*. Partially as a result of the necessity to discriminate between the effective and ineffective phonon-phonon collisions, it is difficult to quantitatively predict the magnitude of the effective mean free path. But on a qualitative basis, eqn. IIIE-13a predicts that it is inversely proportional to the phonon density within the crystal, $\lambda_{c,phn-phn} \propto n^{-1}_{v,phn}$.

Phonon-Lattice Defect Collisions. Imperfections in the crystalline array are present in all but the most perfect single crystals. These imperfections may be due to strain, mechanical working, or lattice distortions in the region of an impurity or simply the grain boundary where two lattice orientations meet. All of these sources limit the phonon mean free path to a constant that is proportional to the defect spacing, $\lambda_{c,phn-def} = \delta L$.

Since we cannot predict the magnitude of $\lambda_{c,phn}$, we are prevented from making a quantitative determination of K_{phn}. However, an understanding of the underlying physical

Ans. 17. From Table IIIE-2, $\sigma^+_{O_2} = 40.9\ (\mathring{A})^2$ and $\sigma^+_{He} = 14.9\ (\mathring{A})^2$. This gives for oxygen at 100 K

$$\mu^*_{O_2}(100\ K) = \frac{2}{3\sigma^+}\left(\frac{MkT}{\pi N_A}\right)^{\frac{1}{2}} = \frac{2}{3 \cdot 40.9 \cdot 10^{-20} m^2}\left[\frac{32.0\ kg/(kg\ mol) \cdot 1.38 \cdot 10^{-23} J/(part\ K) \cdot 100\ K}{\pi \cdot 6.023 \cdot 10^{26} part/(kg\ mol)}\right]^{\frac{1}{2}}$$

$$= 0.787 \cdot 10^{-5} kg/(m\ s)$$

A similar procedure gives the values listed in the table of Ans. 18.

Ans. 18. The values of μ^* predicted in Exer. 17, and listed in the table below, can be readily extended to the evaluation of K^* using Euken's formula. At 100 K, $c^*_{v,O_2} = (5/2)R$. $c^*_{p,O_2} = (5/2+1)R$

$$K^*_{O_2}(100\ K) = \frac{(9\gamma^* - 5)}{4}\mu^* c^*_v = \left(\frac{9 \cdot 1.4 - 5}{4}\right) \cdot 7.87 \cdot 10^{-6} kg/(m\ s) \cdot (5/2) \cdot \left(\frac{8314}{32.0}\right) J/(kg\ K)$$

$$= 9.71 \cdot 10^{-3} W/(m\ K)$$

and

$$P^*_r = \frac{4\gamma^*}{(9\gamma^* - 5)} = \frac{4 \cdot 1.4}{9 \cdot 1.4 - 5} = 0.737.$$

The results for the remaining conditions as well as the values of c^*_v (see Unit IIIC) and μ^* for Exer. 17 are listed in the table.

Substance	T (K)	$\mu^* \cdot 10^5$ [kg/(ms)]	c^*_v [J/(kgK)]	γ^*	$K^* \cdot 10^2$ [W/(mK)]	P^*_r
Oxygen	100	0.787	651	1.40	0.973	0.737
	300	1.73	659	1.39	2.14	0.740
	1000	7.87	831	1.31	11.1	0.771
Helium	100	0.764	3120	1.67	5.98	0.667
	300	1.68	3120	1.67	13.1	0.667
	1000	7.64	3120	1.67	59.8	0.667