$$\theta_E = \frac{h\nu_E}{k}$$

The property relationships for vibration are listed in Table IIIC-1.[10]

[10]Notice that these expressions for the properties of *solids* are written in terms of the universal *gas* constant. The parameter is a physical constant of nature, $\bar{R} = N_A k$. It appears in property relationships for all three phases. In that sense the name gas constant is unfortunate.

Ans. 8. The required values are obtained by substitution into eqns. IIID-7, 8, 9, and 10. $[k/hc = 69.49\ m^{-1}K^{-1},\ (k/hc)^3 = 3.356 \cdot 10^5 m^{-3}K^{-3}]$

$$n_v(300\ K) = 2.404 \cdot 8\pi \cdot 3.356 \cdot 10^5 m^{-3}K^{-3}(300)^3K^3 = 5.472 \cdot 10^{14}\ \text{photons}/m^3$$

$$u_v(300\ K) = \frac{8\pi^5 \cdot 1.38 \cdot 10^{-23} J/(\text{part K}) \cdot 3.356 \cdot 10^5 m^{-3}K^{-3} \cdot (300)^4K^4}{15} = 6.126 \cdot 10^{-6} J/m^3$$

$$s_v(300\ K) = \frac{4u_v(300\ K)}{3T} \quad \frac{4 \cdot 6.126 \cdot 10^{-6} J/m^3}{3 \cdot 300\ K} = 2.720 \cdot 10^{-8} J/(m^3K)$$

$$p(300\ K) = \frac{u_v(300\ K)}{3} = \frac{6.126 \cdot 10^{-6} J/m^3}{3} = 2.042 \cdot 10^{-11}\ \text{bar}$$

Photon properties at other temperatures are found similarly. We summarize.

T(K)	$n_v(pht/m^3)$	$u_v(J/m^3)$	$s_v[(J/(m^3K)]$	p(bar)
300	$5.47 \cdot 10^{14}$	$6.13 \cdot 10^{-6}$	$2.72 \cdot 10^{-8}$	$2.04 \cdot 10^{-11}$
3000	$5.47 \cdot 10^{17}$	$6.13 \cdot 10^{-2}$	$2.72 \cdot 10^{-5}$	$2.04 \cdot 10^{-7}$
30,000	$5.47 \cdot 10^{20}$	$6.13 \cdot 10^{2}$	$2.72 \cdot 10^{-2}$	$2.04 \cdot 10^{-3}$

Ans. 9. The condition of equal photon and particle densities is specified by

$$n_{v,pht} = 8\pi \cdot 2.404 \left(\frac{k}{hc}\right)^3 T^3 = n_{v,mol} = \frac{p}{kT} \quad \text{or} \quad p = 8\pi \cdot 2.404 \frac{(kT)^4}{(hc)^3}$$

Thus at 300 K, using the results of Exer. 8, we find

$$p = kT \cdot n_{v,pht} = 1.380 \cdot 10^{-23} J/(\text{part K}) \cdot 300\ K \cdot 2.03 \cdot 10^7 pht/m^3 \cdot 10^{-5} bar\ m^2/N$$
$$= 2.26 \cdot 10^{-11} bar$$

The translational energy per molecule is (3/2) kT. Thus the equal energy density condition is specified by

$$u_{v,pht} = \frac{8\pi^5 k^4}{15(hc)^3} T^4 = n_{v,mol} \frac{3}{2} kT = \frac{3}{2} p$$

Thus at 300 K

$$p = \frac{2}{3} u_{v,pht} = \frac{2}{3} \cdot 6.13 \cdot 10^{-6} J/m^3 \cdot 10^{-5} bar/p_a = 4.09 \cdot 10^{-11} bar$$

To summarize, the gas pressures needed to have equal molecular and photon densities at 300, 3000, and 30,000 K are $2.26 \cdot 10^{-11}$, $2.26 \cdot 10^{-7}$, and $2.26 \cdot 10^{-3}$bars. The gas pressures needed to have the translational component of internal energy equal the photon component at 300, 3000, and 30,000 K are $4.09 \cdot 10^{-11}$, $4.09 \cdot 10^{-7}$, and $4.09 \cdot 10^{-3}$ bars.