

19.1 A trick question. The mean kinetic energy is the same for each case,  $\frac{3}{2}k_{\text{B}}T = 38 \text{ meV}$ .

19.2  $C_p = C_V + R$  and  $C_p = \frac{5}{2}R = 20.785$  (for a gas with only translational modes excited or a monatomic gas; i.e. Ar, He, Ne, Xe),  $C_p = \frac{7}{2}R = 29.099$  (for a gas with translational and rotational modes excited; H<sub>2</sub>, N<sub>2</sub>, O<sub>2</sub>), and  $C_p = 3R = 24.94$  (for solids, such as Al, Au, Cu, Fe, Pb, Ag and Zn).

19.3 Taking the well as a one-dimensional problem,  $dV/dr = 0$  gives a minimum at  $r_0^{n-1} = nA/B$  and one can Taylor expand around the bottom of this well to show that  $V = V_0 + \alpha(r - r_0)^2$  where  $\alpha$  is a constant. The particle can execute simple harmonic motion around the bottom of this well, giving two degrees of freedom (one kinetic, one potential), and so the mean thermal energy is  $2 \times \frac{1}{2}k_{\text{B}}T = k_{\text{B}}T$ .

19.4

$$\langle x_i^2 \rangle = \frac{\int_{-\infty}^{\infty} x_i^2 e^{-\beta\alpha_i x_i^2} dx_i}{\int_{-\infty}^{\infty} e^{-\beta\alpha_i x_i^2} dx_i} = \frac{1}{2\alpha_i\beta}.$$

19.5 Writing  $E = \alpha|x|$ , we have  $dE = \alpha dx$  and  $dx = \alpha^{-1} dE$ . Hence

$$\langle E \rangle = \frac{\int_0^{\infty} E e^{-\beta E} dx}{\int_0^{\infty} e^{-\beta E} dx} = \frac{\int_0^{\infty} E e^{-\beta E} dE}{\int_0^{\infty} e^{-\beta E} dE} = k_{\text{B}}T.$$

19.6 Writing  $E = \alpha|x|^n$ , we have  $dE = n\alpha|x|^{n-1} dx = \frac{nE}{|x|} dx$  and  $dx = \kappa E^{\frac{1}{n}-1} dE$  where  $\kappa$  is a constant. Hence

$$\langle E \rangle = \frac{\int_0^{\infty} E e^{-\beta E} dx}{\int_0^{\infty} e^{-\beta E} dx} = \frac{\int_0^{\infty} E^{\frac{1}{n}} e^{-\beta E} dE}{\int_0^{\infty} E^{\frac{1}{n}-1} e^{-\beta E} dE} = k_{\text{B}}T \frac{\Gamma(1 + \frac{1}{n})}{\Gamma(\frac{1}{n})} = \frac{k_{\text{B}}T}{n}.$$

Note, if  $n = 1$  then the answer is

$$k_{\text{B}}T,$$

in agreement with the previous question. If  $n = 2$  then the answer is

$$\frac{k_{\text{B}}T}{2},$$

in agreement with the equipartition theorem.

19.7  $\ddot{\theta} + (g/\ell)\sin\theta = 0$  and so if  $\theta \ll 1$ , then we have

$$\ddot{\theta} + \omega^2\theta = 0,$$

where  $\omega^2 = g/\ell$  so that the period is  $T = 2\pi/\omega = 2\pi\sqrt{\ell/g}$ . If the angle  $\theta$  deviates from zero, the potential energy increases by

$$\ell(1 - \cos\theta) \approx \ell\theta^2/2,$$

when  $\theta \ll 1$ . Hence the mean P.E. (using equipartition) is

$$\langle mg\ell\theta^2/2 \rangle = \frac{1}{2}k_{\text{B}}T$$

and hence

$$\langle \theta^2 \rangle = \frac{k_{\text{B}}T}{mg\ell}.$$

# Concepts In Thermal Physics Blundell Solutions

**Hussin A.Rothana**



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