

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_2 , N_2 , O_2), 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 α 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 κ 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 θ 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

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