Dec 3: Get Whiteboards and Clickers
VPython version of bar chart

N = 500, N1 = 300, N2 = 200, q = 100

N = 500, N1 = 250, N2 = 250, q = 100

N = 500, N1 = 100, N2 = 400, q = 100

N = 500, N1 = 400, N2 = 100, q = 100
How do we handle huge numbers?

\[ S = k \ln(\text{# of ways}) \]

\[ k = 1.38 \times 10^{-23} \text{ J/K} \]
Second Law of Thermodynamics

\[ S = S_1 + S_2 \]

\[ \frac{dS}{dq_1} = 0 \]

Increase entropy \( q_2 \) to top peak

Define temperature

\[ T = \frac{\Delta S}{\Delta E} \]

\[ 0 = \frac{dS}{dq_1} = \frac{dS_1}{dq_1} + \frac{dS_2}{dq_1} \]

\[ q_1 = 100 - q_1 \]

\[ dq_2 = -dq_1 \]

\[ \frac{dS_1}{dq_1} - \frac{dS_2}{dq_2} = 0 \]
Q1

A system of 300 oscillators contains 100 quanta of energy. What is the physical meaning of this model?

A) one atom oscillating in 300 dimensions
B) 300 atoms, each in the 100th energy level
C) 300 atoms with 100 joules of energy distributed among them
D) 100 atoms with 300 joules of energy distributed among them

E) 100 atoms with $100\hbar\sqrt{\frac{k}{m}}$ joules of energy among them
Q2

Which arrangement is most probable?

A) A  
B) B  
C) C  
D) D  
E) They’re equally probable
Q3

| Inside an insulated container two aluminum blocks, 1 kg and 2 kg, have been in contact for a long time. What physical property is the same for the two blocks? | A) the mass  
B) the temperature  
C) the volume  
D) the thermal energy  
E) the weight |
Q4

The slope of a graph of entropy vs. energy (dS/dE) in a metal block is related to the temperature of the block. From the graph of entropy for two blocks in contact, we see that the block with the larger slope tends to gain energy from the block with the smaller slope. Therefore, which of these statements is true?

A) Big dS/dE means high temperature
B) Small dS/dE means high temperature

\[ \frac{dS}{dE} = \frac{1}{T} \]
Q5

There is thermal transfer of energy of 5000 J into a system. The entropy of the system increases by 50 J/K. What is the approximate temperature of the system?

\[ \frac{\Delta S}{\Delta E} = \frac{1}{T} \implies T = \frac{\Delta E}{\Delta S} \]

\[ = \frac{5000 J}{50 J/K} = 100 K \]

A) 5000 K  
B) 100 K  
C) 50 K  
D) 0.01 K  
E) 0.0002 K
Q6

Consider a 3 kg block of aluminum. One mole of aluminum has a mass of 27 grams (0.027 kg). From Young's modulus we determined that the stiffness of the interatomic bond is 16 N/m, but in the Einstein model the $x, y,$ and $z$ oscillations each involve 2 half-length springs, so the effective stiffness is $64 \, \text{N/m}$. $\hbar = 1.05 \times 10^{-34} \, \text{J} \cdot \text{s}$;

$1 \, \text{mol} = 6 \times 10^{23} \, \text{atoms}$

What is the energy in joules of one quantum of energy?

A) $1.62 \times 10^{-34} \, \text{J}$
B) $4.85 \times 10^{-34} \, \text{J}$
C) $5.11 \times 10^{-33} \, \text{J}$
D) $1.25 \times 10^{-22} \, \text{J}$
E) $3.96 \times 10^{-21} \, \text{J}$

\[
E = \hbar \omega = \hbar \sqrt{\frac{k}{m}}
= \hbar \sqrt{\frac{k}{M/NA}}
\]
Figure 11.21 The number of ways of distributing 1000 quanta between two blocks containing 3000 and 2000 oscillators, respectively.
Figure 11.27 Entropy vs. number of quanta of energy in system 1.
Figure 11.28 Location of the initial and final states of the two-block system on a plot of entropy vs. number of energy quanta in system 1.
What's this thing called quanta?

3 kg of Al  \[ 27.9 \text{ m/s} \]  \[ k_0 = 16 \text{ N/m} \]

1 quantum of energy

\[ E = 3.96 \times 10^{-21} \text{ J} \]

\[ \Delta E = h \nu = h \sqrt{\frac{k}{\nu}} \]

\[ = 1.05 \times 10^{-34} \sqrt{\frac{4 \times 16}{0.27/6 \times 10^3}} \text{ J} \]
\[ = 3.96 \times 10^{-21} \text{ J} \]
100 atoms

\[ \frac{\Delta E}{\Delta T} = C \]  heat capacity

Heat capacity/atom

\[ C = \frac{\Delta E}{\Delta T} \div \text{atoms} \]