Cornell University

Department of Physics

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# Basic Training in Condensed Matter Theory, Spring 2007

## Teaser # 10

(Due Wednesday, March 28)

Recall the standard argument for the behavior of the specific heat of an insulating or semiconducting crystal at low temperatures. It goes something like this:

> At low temperatures, only the lowest energy excitations contribute, in this case the *acoustic* phonons. There are three acoustic phonon branches, one for each continuous symmetry of the crystal, each with a linear dispersion relation, $\omega = ck$. Roughly speaking, only those modes with energy $\hbar\omega < k_B T$ are significantly excited so only modes in a volume of phase space scaling as $T^3$ are relevant. These excited modes each have roughly the classical energy content, $\frac{1}{2}k_B T$. Thus, the thermal energy of the insulator scales as $T^3 \cdot T = T^4$ and the specific heat scales as the derivative of this, $T^3$.

This week's teaser is to think through how this argument changes for a semiconducting carbon nanotube as $T \to 0$. How many acoustic phonon branches would there be now? What dispersion relations will the branches have? What will be the final scaling of the specific heat?

**Hint:** Consider temperatures low enough that vibrational modes traveling around the circumference of the tube ("$m \neq 0$" modes) are frozen out so that the tube, effectively, behaves like a one-dimensional elastic medium.

| **Your answer:** | **Answer from class:** |
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