THERMAL RECTIFIERS – PHASE AND THERMAL CONDUCTIVITY

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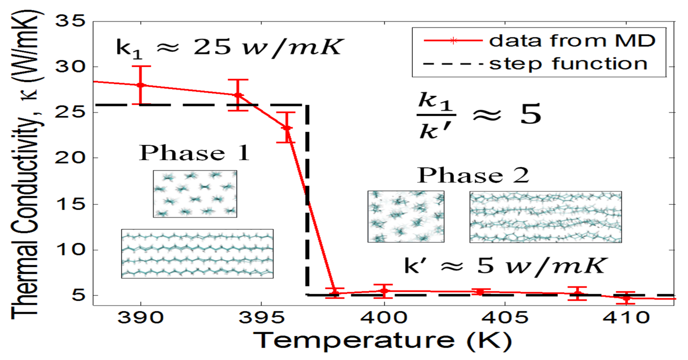
Introduction

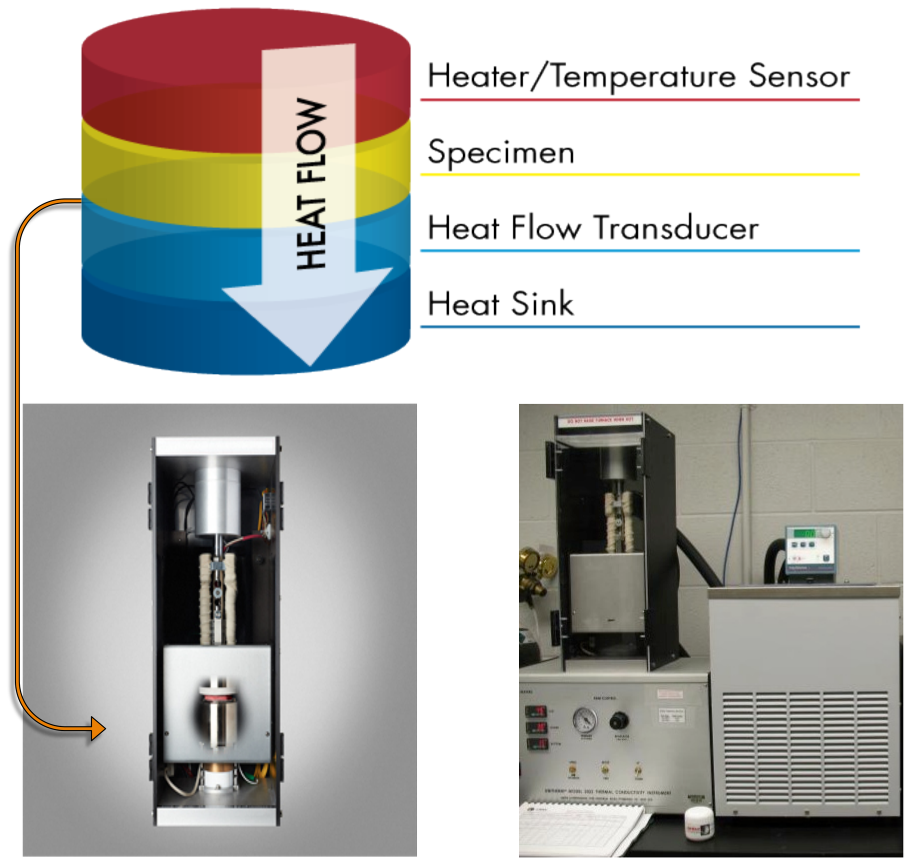
- Thermal conductivity is a material's ability to transfer heat energy
- Most materials in a solid phase are far more conducive than in a liquid phase
- The change in lattice structure creates the difference in thermal conductivity
- A piece-wise-function shows conductivity from one phase to the other
- Observe the conductivity of polyethylene (see below):



- **Hexadecane ($C_{16}H_{34}$)** has a melting point of 291K
- The significant drop in conductivity slows down heat transfer
- This will absorb heat and store it once a phase shift occurs
- It may be possible to construct a bi-layer junction with hexadecane to act as a thermal-rectifier

Materials and Methods

- Find the decrease in the thermal conductivity of hexadecane during its phase shift from solid to liquid
- Use the Unitherm Model 2022 – Thermal Conductivity Instrument
- The 2022 uses the ASTM E1530, which measures thermal conductivity by measuring the temperature difference across the sample along with the output from the heat flux transducer when the thickness is known



Materials and Methods

- At thermal equilibrium, the Fourier heat flow equation applied to the test stack becomes:

$$R_s = F\left[\frac{(T_u - T_l)}{Q}\right] - R_{int}$$

Where:
- R_s = thermal resistance of the sample
- F = heat flow transducer calibration factor
- T_u = upper plate surface temperature
- T_l = lower plate surface temperature
- Q = heat flow transducer output
- R_{int} = interface thermal resistance
- d = thickness of the sample

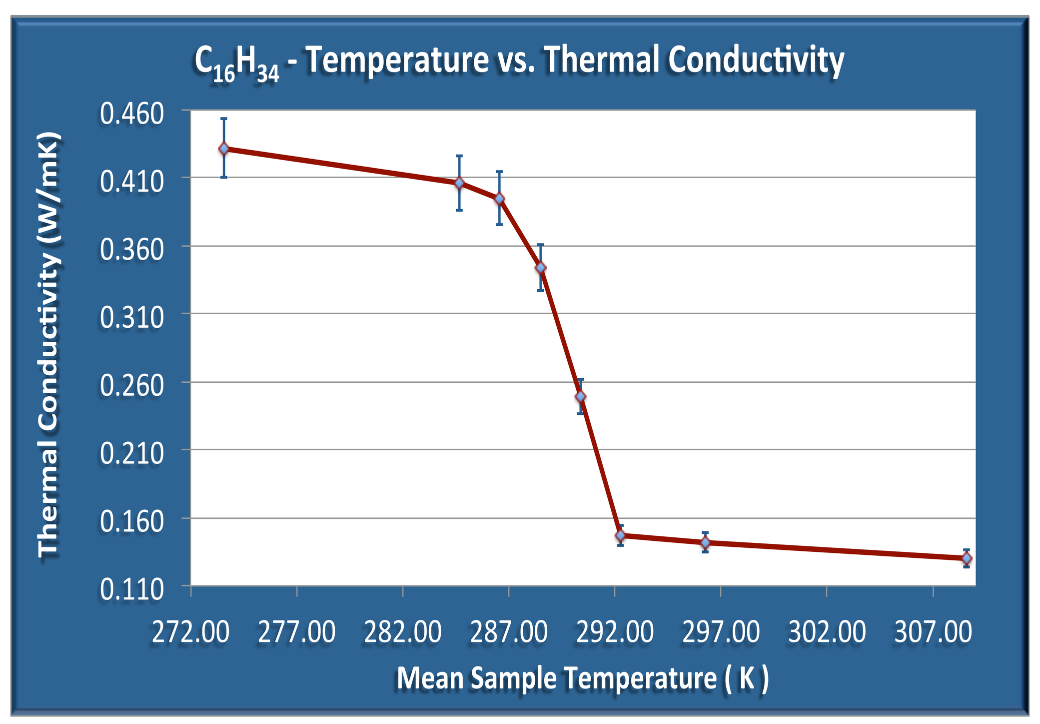
- The sample thermal conductivity, *k*, is calculated from:

$$k = d / R_s$$

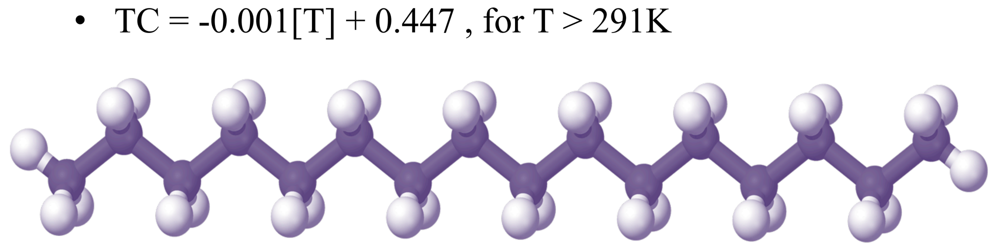
- Calibrate the 2022 using known references such a water, glycerol, and silicone fluid at the temperatures of interest
- Find conductivities at 283, 285, 287, …, 293, 295K
- Find and compare thermal conductivities versus temperatures
- Write piece-wise function to model both sides of phase shifts
- Select the appropriate length of a bi-layer junction such that hexadecane shifts phase and creates rectifier

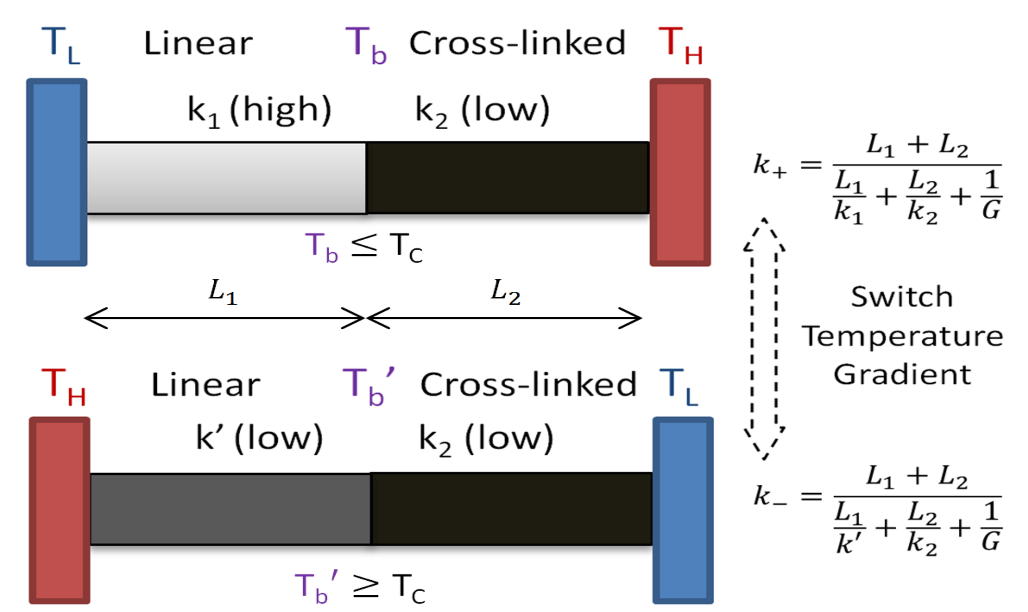
Results

- Temperature-dependent Thermal Conductivity of Hexadecane



- Hexadecane shifts phase at 291K
- Thermal conductivity drops significantly after 291K
- TC = -0.003[T] + 1.169, for T < 291K
- TC = -0.001[T] + 0.447 , for T > 291K

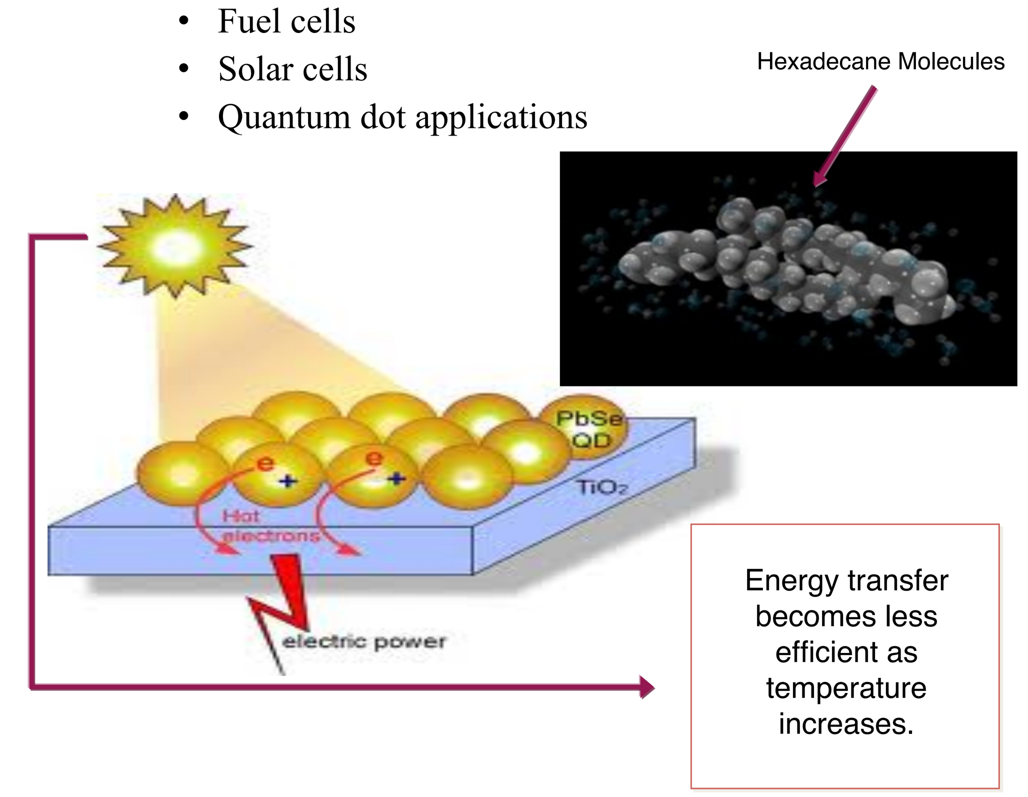




- Construct a bi-layer junction – thermal rectifier
- Junction transfers heat energy to link
- Link absorbs heat energy via conduction
- Link temperature increase causes phase shift
  - Solid to liquid
- Temperature-dependent thermal conductivity drops
- Hexadecane not as conducive once thermal switch is thrown
- Change in thermal conductivity creates one-way heat flux
- Heat energy is transferred across one-way junction
- Heat energy is trapped in liquid hexadecane
- Rectification is optimized when:

$$\frac{k_1}{L_1 G} + \frac{k_1 L_2}{k_2 L_1} = \left(\frac{k_1}{k'}\right)^{0.5}$$

- Thermal storage has many applications
  - Fuel cells
  - Solar cells
  - Quantum dot applications



- Develop STEM-based PBL lesson plan for Algebra II / Physics Hybrid course at South Bend New Tech High School

Conclusions

The data shows that Hexadecane's thermal conductivity, k, is temperature dependent and decreases significantly after a phase transition from solid to liquid. This drop in conductivity is due to differences in molecular structure.

While still in progress, a bi-layer junction could be constructed by using the properties of hexadecane to create a thermal rectifier – one-way heat flux transfer mechanism.

Lastly, the author is charged with the task to present real discovery and new knowledge from post-secondary academia, and transfer that knowledge to a secondary environment. This goal can be accomplished via a Science, Technology, Engineering, and Mathematics [STEM] based lesson in a Project Based Learning [PBL] hybrid course of Algebra II / Physics offered at South Bend New Tech High School. The unit will cover topics such as linear functions, linear regression, piece-wise functions, proportions, metric conversions, conduction, radiation, convection, and heat energy transfer.

Literature cited

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