Students' Ideas in Upper-Level Thermal Physics

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1. Initial [first-day] ideas found among upper-level students, similar or identical to those found among introductory students.

Work

- Many students believe either that “no work” or *positive* work is done on the system during an expansion, rather than negative work.
- Students often fail to recognize that a system loses energy through work done in an expansion, or that a system gains energy through work done in a compression.

Molecular Motion

- Many students believe that molecular kinetic energy can increase or decrease during an *isothermal* process in which an ideal-gas system is heated.

(Introductory students often said that intermolecular collisions lead to net increases in kinetic energy and/or temperature.)

Isothermal Processes

- Most students do not recognize that energy transfers must occur (through heating) in a quasistatic isothermal expansion.

(Students often do not recognize that a thermal reservoir does *not* undergo temperature change even when acquiring energy.)

State Functions

- Students seem comfortable with the state function concept within the context of energy, temperature, and volume, but *not* entropy.

- As do introductory students, upper-level students overgeneralize the state function concept, applying it inappropriately to heat and work.

Net Work and Net Heat Transfer

- Many students believe that heat transfers and/or work done in different processes linking common initial and final states must be equal.
- Students often believe that that net heat transfer in a cyclic process must be zero since $\Delta T = 0$, and that net work done must be zero since $\Delta V = 0$.

2. Ideas found among upper-level students, different from or not probed in introductory students.

Second Law

- In contrast to introductory students, upper-level students are comfortable with the idea of increasing total entropy. However, they share with them the belief that “system” entropy must increase.
- Most upper-level students are initially able to recognize that “perfect heat engines” (i.e., 100% conversion of heat into work) violate the second law, but…
- Most upper-level are initially *unable* to recognize that engines with greater than ideal (“Carnot”) efficiency also violate the second law.

Entropy in Cyclic Processes

- After (special) instruction, most upper-level students recognize impossibility of super-efficient engines, but still have difficulties understanding cyclic-process requirement of $\Delta S = 0$; many also still confused about $\Delta U = 0$.

- On cyclic process questions involving heat engines, most (60%) upper-level students claim that net change in entropy is *not* zero, because they apply $\Delta S = \Sigma Q/T$ even when the process is not reversible; also, they ignore the state-function property of entropy which says $\Delta S = 0$ since initial and final states are identical.

Free Expansion and Equilibrium

- Even after extensive work on free-expansion processes, upper-level students show poor performance (< 50% correct)
  - frequent errors: belief that temperature or internal energy must change, work is done, etc.
  - difficulties with first-law concepts prevented students from realizing that T does not change

- When analyzing changes in available microstates during approach to equilibrium, students often tend to ignore the fact that when equilibrium is reached, changes must cease.

Summary

- Many upper-level students initially share key conceptual difficulties manifested by introductory students
- Certain difficulties persist even after extensive instruction in upper-level courses.