Guest Editorial

Thermodynamics Is Easy – I've Learned It Many Times

by Harvey S. Leff

As a new 1960s faculty member seeking readable journals, I discovered AAPT. Since then, both *TPT* and *AJP* have provided not only wonderful learning experiences, but also opportunities for publication of my own ruminations on physics and teaching. Those musings have focused mainly on thermodynamics, which has challenged, stimulated, confused, and sometimes tortured me. The late Leslie L. Foldy, a distinguished former colleague, often used the title line to describe thermodynamics. He was inspired by Mark Twain's famous comment about the 'ease' of quitting smoking. Here are some ideas and examples that might help others for whom the title line applies.

What is sometimes not appreciated is that the very essence of thermodynamics, the characteristic that distinguishes it from mechanics, is that invisible energy storage modes of macroscopic matter are important. Indeed, thermodynamics can be defined as the science of energy spreading within and between macroscopic objects. For blocks, inclined planes, and the like encountered in mechanics, internal storage modes are typically ignored. As friction becomes important, *pure* mechanics morphs into thermodynamics, where internal energy storage modes are central.

When a block slides horizontally on a tabletop with friction, both block and table suffer surface deformations. Work is done by table on block, and also by block on table. As their respective internal energies increase, both objects warm up and transfer energy (heat) to the surroundings. The temperature increases of block and table come from *work*, not *heat*, and induce subsequent *heat* processes to the cooler surroundings. The work done on the block is *not* the friction force (μN) times the stopping distance, and the work on the block does *not* equal its kinetic energy change. In actuality, the block's initial kinetic energy becomes internal energy of block, table, and, ultimately, the surroundings.

Another example is an incandescent lamp. When switched on, electric current flows through the filament, and electric *work* causes an increased filament internal energy and temperature. In the steady state, temperature and internal energy remain constant as energy is delivered to the filament via electric work, and energy flows from the filament, mainly by radiation and conduction, at the same rate.

Clausius argued that the first and second laws of thermodynamics focus on energy and entropy respectively. He did not interpret entropy, which has since been related to vague terms such as *disorder.* Here is an energy-based alternative view of entropy:

> Consider a cup of hot coffee that cools to room temperature. The hot coffee and cup transfer energy to the surroundings; i.e., energy spreads *spatially* to microscopic energy storage modes within the air and other materials until temperature equality exists. This spreading over space stops when energy spreading is maximal; i.e., if spreading continued further, the coffee and cup would become cooler than its surroundings. With reasonable postulates, a spreading function can be found, and it turns out to be identical with thermodynamic entropy.

More generally, a system's equilibrium entropy reflects the *temporal* spreading of the system among microstates—an invisible (to us) dance over microstates. For the above block sliding to a stop on a table, the block's initial kinetic energy spreads over the internal microstates of block, table, and surroundings. Increased internal energy brings more temporal spreading over microstates, and increased spreading indicates increased entropy.

Consider a free expansion of a dilute gas, doubling its volume. Here gas particle energies spread over a larger volume, and the volume increase immediately brings the particles' quantized energy levels closer together. In any energy inter-

DOI: 10.1119/1.2432080

val ΔE consistent with *rms* energy fluctuations at temperature T, the number of microstates over which the dance occurs increases. That is, there is more *temporal* spreading and higher entropy after the expansion. Although entropy can be calculated by integrating $dS = dQ_{\mathrm{rev}}/T$ over a reversible path, the latter free expansion is an example of a system's entropy increasing in a real, irreversible process with $Q = 0$ as energy spreading increases.

Pure mechanics can be viewed as a form of constant-entropy reversible thermodynamics. In contrast, for any irreversible thermodynamics process, there is an increase of energy spreading over space, entailing increased energy and/or space, and increased temporal spreading over microstates.

It is a remarkable, fortuitous coincidence that entropy's traditional symbol S can be viewed as shorthand for "Spreading function." Using the interpretation of spreading over *space* and *time*, entropy might become more meaningful to you and your students.

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