Problematic Primer

In the January 2005 issue of *TPT*[1] Carl Mungan presented a primer about the work-energy theorem. In a rigorous and sophisticated analysis, he defines and differentiates center-of-mass forces and energy compared with internal forces and energy. Unfortunately, most of my students in an introductory course do not have the sophistication necessary to understand these distinctions.

Mungan provides one example to make the approach more concrete. He proposes that for an assemblage of atoms (for instance in a Frisbee), the kinetic energy is $\frac{1}{2}mv^2 + \frac{1}{2}I\omega^2 + \frac{3}{2}NkT$. The internal energy is stored in atomic vibrations. Mungan assigns a kinetic energy of $\frac{3}{2}kT$ to each atom. However, inextricably al-

lied to each of the three modes of kinetic energy of oscillation is an equal amount of potential energy. For steel, or other high Z material, that would make the energy of each atom equal to $3kT$. But a Frisbee made of steel would be very dangerous. For a Frisbee made largely of carbon, the coefficient of kT should be about 2. Quantum effects reduce the specific heats of low Z materials, but that might be confusing to freshmen. The primer has a peculiar view of rolling friction, one that is common in many introductory texts. Rolling friction is attributed to static friction. If that were the case, we ought to equip our cars with skids rather than wheels, since we all learn that the coefficient of sliding friction is less than that of static friction.

Any discussion of friction should be based on models of what is happening to the microstructure of surfaces. Thus we have sliding friction where molecular bonds are being formed and broken, and where rough spots on one surface are plowing the other surface. As is well known, such friction is independent of velocity over limited ranges and independent of surface area except in cases like skis on snow. Then there is friction between solids and fluids, or between fluids and fluids, which is not velocity independent. We must not confuse these friction phenomena with static friction in which there is no movement and thus no mechanical energy is turned into thermal energy. However, when the sticking is overcome, energy must be expended to pull the object out of the potential wells in which it is trapped. It is an inelastic process.

A cousin of static friction is traction. The former keeps you from moving until you are affected by a threshold force that overcomes the goo that constrains the motion. The latter is a repulsion or compression that keeps you from getting too close to another surface and shoves you away. Since there is never any sticking, no energy is lost. It is an elastic process. It is traction, not static friction, that allows walking and provides the recoil force for circular roiling.

Finally, there is rolling friction. It is real but complicated. Usually its coefficient is less than one-tenth that of dry sliding friction. It is caused by deformation of the wheel or road bed, and the energy loss is absorbed by the wheel (tire) and bed. The complications and analysis are described in the chapter on friction in *Teaching Introductory Physics* by Swartz and Miner.

1. Carl E. Mungan, "A primer on work-energy relationships for introductory physics," *Phys. Teach.* **43**, 10–15 (Jan. 2005).

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Author's Response

The introduction to my paper spells out a particular objective: to clarify the terminology used in standard textbook treatments of work and energy. Although Clifford Swartz describes my analysis as "sophisticated," the equations in my paper (ignoring qualifiers such as subscripts, which have been added to distinguish terms) appear in most introductory texts. I am not changing the established pedagogy but, rather, I am harmonizing it. The examples I chose are therefore purposefully conventional and intentionally use the usual simplified models of friction,[1] springs, and the like. I disagree that "any discussion of friction" needs to be based on detailed models of "the microstructure of surfaces." Teaching proceeds from simpler to richer concepts and levels of approximation.

However, if Swartz (or anyone else) wishes to explore models of specific heat and microscopic views of friction with introductory students, I say go for it! Evidence shows that it can be done: There are field-tested resources such as Chabay & Sherwood's textbook[2] that permit one to do this even in a first physics course.

The bottom line is that it is up to an instructor to decide whether to invest the class time needed to explore work and energy (or any other topic) in rich detail. However, even if one chooses not to do so, it behooves educators to enrich their personal knowledge store about basic textbook concepts. For instance, consider Example 13 in Chapter 6 and Example 5 in Chapter 15 of the popular algebra-based text by Cutnell & Johnson.[3] The first example computes the nonconservative work done on a roller coaster; this is center-of-mass work. The second example calculates the work done by an ideal gas during a quasistatic isothermal expansion; this is particle work. Properly interpreted, neither example is wrong; it is a matter of clearly defining in each context what is meant by the term "work." Based on this enlightened viewpoint, each teacher can then make informed decisions about what to teach and how.

References

1. The simplest view of a rigid, undriven cylinder rolling on a rigid surface is that the friction is static. I am reluctant to describe that as rolling friction. Usually rolling friction is dissipative, while static friction is not.
2. R.W. Chabay and B.A. Sherwood, *Matter & Interactions* (Wiley, New York, 2002). Happily, this particular textbook also answers some of Swartz's desires for more details of specific heats of real materials and the microscopic details of friction.
3. J.D. Cutnell and K.W. Johnson, *Physics*, 4th ed. (Wiley, New York, 1998).

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