Letters
to the Editor

"Work Reworked"—Reworked

Having read the December 2002 note[1] and the three May 2003 Letters to the Editor referring to it,[2] I'm convinced that there's more of pedagogical value to be said about the question "What is the work done in lifting a book (of mass *m*) from the floor onto a table through a vertical distance *h*?"

1. First off, the question is ambiguous in its failure to identify the *agency* that does the work whose amount is sought. Although the questioner evidently seeks the amount of work done by the lifting agent, the question might almost as likely be calling for the *total work* done on the book during its journey from floor to table-top rest — which we all know is zero!

2. In the letter from Richard Mancuso[2] we read (after appropriate typographical shifts, all vertical) "$W_{\text{ext agent}} - W_{\text{gravity}} = \frac{1}{2} m v_f^2 - \frac{1}{2} m v_i^2$" as an expression of the work-energy theorem. It is wrong! The minus sign before W_{gravity} should be a *plus*. (Irrelevant is the fact that W_{gravity} happens to be negative.)

3. The original note's author invites trouble for himself and his students by repeated failure to specify the particular agency that exerts a force, does an amount of work. For example, see **1** above. For another, he perpetrates a disservice in writing[2] "[W]e can write the force on the book as

$$\vec{F} = m(\vec{g} + \vec{a}), \text{....''}$$

"The force on the book" would, in standard usage, normally denote the *total* force on the book; but $\vec{F}$, as used by the author, is the force exerted by the lifting hand only.

4. The equation displayed under point 3 above is *wrong*: With $\vec{g}$ a *down*ward vector, the equation should be corrected to read

$$\vec{F} = m(-\vec{g} + \vec{a}),$$

with $\vec{F}$ properly identified as the force exerted by the lifting agency.

5. But correct though the equation as written in **4** may be, this way of writing it must surely puzzle introductory students. Where, for example, does it come from? What is its basis? If instead we write

$$\vec{F} + m\vec{g} = m\vec{a},$$

students should at once recognize (or be easily reminded) that the (vector) sum of forces exerted by all the agencies influencing a body's motion is equal to its mass times its acceleration.

Nitpicking? Perhaps. But every one of the five points offered reveals a nit that is overripe for picking. Yes, every one of us teachers knows what is *intended* in each of the cases of ambiguity, misnomer, and erroneous sign reversal; for we are (presumably) in solid possession of the material being taught. But what about our students? They can't be expected to read our minds and/or correct us when we write or say something that is wrong or ambiguous or deviant from standard usage or poorly expressed. Physics is hard enough for students to learn without our adding to the difficulties by carelessness in our conveying material to them.

1. R.G. Jordan, "Work reworked," *Phys. Teach*. **40**, 526–527 (Dec. 2002).
2. Jeffrey Wetherhold, Richard Mancuso, and Robin Jordan, letters to the editor, *Phys. Teach*. **41**, 260–261 (May 2003).

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Bell in a Bell Jar – I

The recent article "Improved Bell-in-a-Bell-Jar Demonstration"[1] discusses a method of presenting this popular demonstration that is supposed to overcome some of the problems inherent in the apparatus. Unfortunately, the major problem is said to be "that the sound has difficulty penetrating the thick glass of the bell jar."

This statement, and the comment "that a vacuum cannot conduct sound," implies that sound travels by some conduction mechanism rather than as a wave in a medium.

Sound waves in the audible frequency range travel with relatively low loss in solids such as glass. The reason that not much sound reaches the air outside the bell jar is that much of the energy is reflected at the air-glass boundary because of the large impedance mismatch caused by the greatly different densities and elastic constants of the two media. When I first started teaching, older and wiser faculty members advised me to avoid this demonstration because the decrease in external sound intensity as the air is pumped out of the bell jar is largely due to increasing impedance mismatches, both at the bell-air boundary and at the air-glass boundary, as the air density decreases.

Putting the microphone inside the bell jar may avoid the air-glass impedance mismatch, but it introduces an air-microphone boundary that can lead to misinterpretation because the microphone response to a sound wave with a particular intensity may be quite different at different air densities and pressures.

I am not recommending that this demonstration be abandoned, only that it be postponed until the students are familiar with wave reflections at media interfaces so that the observations can be given an appropriate interpretation.

1. Dejun Han, *Phys. Teach.* **41**, 278–279 (May 2003).

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Bell in a Bell Jar – II

I fear the "improvement" of the bell-in-a-bell-jar demonstration [*TPT* **41**, 278–279 (May 2003)] as presented makes things worse, not better. Although bothersome, the attenuation of the sound transmitted through the glass at least can be assumed to be not much affected by evacuation of the bell jar. On the other hand, with the detector inside, the effect could just be that the sound detector stops working or its response changes in a vacuum. This is not just fantasy: A microphone mechanism like an aneroid barometer, depending on the flexing of a membrane over a sealed chamber, would clearly not work (indeed, might be destroyed) in a vacuum. A more serious problem is that the propagation of sound in a gas is not linear with density; it fails only when the mean free path of the residual gas becomes comparable to the dimensions of the container. Also, sound can propagate along the solid supports of the speaker. Improving this demonstration is hard, but since you'd have to prove first that it isn't a feature of the microphone that is responsible for the decreased sound as the chamber is evacuated, the approach proposed in this article has misplaced focus. Incidentally, the same objection applies to the source — does it behave differently in a vacuum? — but here, with an electromagnetically driven speaker this may be less of an issue. Again, it isn't fantasy: Anyone who has been amused with Mickey Mouse speech after inhaling helium knows that the ambient atmosphere has some effect on an oscillating system. The effect of transmission through the glass, which should change little with evacuation of the bell jar, is the least of the worries.

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Bell in a Bell Jar – III

In the May issue of *The Physics Teacher,* Dejun Han described an improvement for the bell-in-a-jar demonstration.[1] He reasoned that sound from the bell must have a hard time getting through the thick glass of the vacuum jar. Rather than insert a student into the jar as a reporter, Han fastened a microphone inside, connected to an external amplifier and speaker.

This seems to be a clever improvement. The traditional system is much used and most physics teachers have observed or performed the experiment, showing that sound cannot travel in a vacuum. Actually, sound travels very well in a vacuum, at least the vacuum produced in these demonstrations. It is difficult, however, to get the sound from the bell into the thin air and then from the thin air into the glass or microphone. The problem is one of impedance matching.

The mean free path of an air molecule at STP is about 10^{-7} m. The mean free path is inversely proportional to the pressure, and so even at 0.1 mm of mercury (the limit of most school mechanical vacuum pumps), the mean free path is only a millimeter. Consequently we can continue to view the air in the jar as a standard gas subject to the standard equations for wave propagation. The speed of sound in air is proportional to the square root of the ratio of pressure to density. Since the pressure is proportional to the density, the speed of sound in air is independent of pressure. However, the *impedance* of a gas is proportional to the square root of the *product* of pressure and density. If we reduce the pressure (and thus the density) in the bell jar by a factor of 10,000, we reduce the impedance by a factor of 10,000. With that impedance mismatch, the vibrations of the bell are not coupled to the air, and if there were sound in the air it would not be coupled to the jar (or microphone).

An easy demonstration of impedance matching is to stretch a rubber band between thumb and forefinger. If you pluck the rubber band, you will hear very little sound. But stretch the band over a drinking glass set on a table, and you have the beginning of a violin. Not a Stradivarius, perhaps, but at least your impedances are beginning to match.

1. Dejun Han, "Improved bell-in-a-bell-jar demonstration," *Phys. Teach.* **41**, 278–279 (May 2003).

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Sun Pillars and Ice Crystals

Dan Quinn contributed a beautiful photograph of a sun pillar, which he correctly attributed to the reflection of sunlight from falling ice crystals.[1] However, the crystals do not necessarily have to be the flat-plate crystals that result in sundogs.[2] Robert Greenler and his collaborators showed that thin-pencil crystals (see Fig. 1), which tend to fall with their long axis approximately horizontal, can also produce sun pillars.[3]

Quinn also posed the question of why the sun pillar has a larger vertical than horizontal extent. This is understood most easily for flat-plate crystals. As Ron Edge explained, these crystals tend to fall with their axes approximately vertical and the

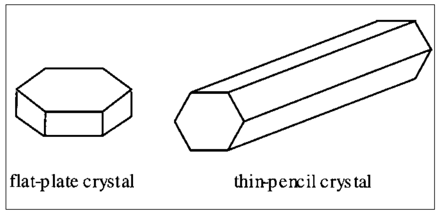

Fig. 1.

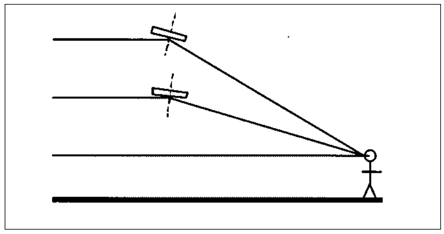

Fig. 2. The formation of the sun pillar at sunrise or sunset when the incoming rays are horizontal.

reflecting surfaces approximately horizontal. Figure 2 shows how ice crystals farther above the Sun must be tilted farther to reflect light toward an observer. The axes of ice crystals to the right or left of the observer (into or out of the plane shown in Fig. 2) must have greater tilts in order to contribute to the pillar since they must also redirect the light in the horizontal direction. However, flat-plate crystals are not likely to be tilted very far.

Unfortunately, it is difficult to tell which type of ice crystals formed the sun pillar in the photograph. Greenler notes that "the shapes do not differ greatly when the Sun is near the horizon."[3] Also, there are no other effects visible in the picture to offer clues about the crystals. For example, sundogs would be evidence that flat-plate crystals were present in the atmosphere.

1. Dan Quinn, "Photo of the Month," *Phys. Teach.* **41**, 304 (May 2003).
2. Ron Edge, "Sundogs, ice crystals, and Bernoulli," *Phys. Teach.* **40**, 522 (Dec. 2002).
3. Robert Greenler, *Rainbows, Halos and Glories* (Cambridge, 1980), pp. 65–74.

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Grazing Incidence Reflection and X-ray Images

To Hasan Fakhruddin's interesting article about grazing incidence ("Specular Reflection from a Rough Surface" [*Phys. Teach.* **41**, 206–207 (April 2003)], I can add that NASA's Chandra X-ray Observatory is now making high-resolution x-ray images of celestial objects using the same technique. Four nested cylindrical mirrors are used, since the area of any one mirror that is exposed to incoming radiation is small at low angles of incidence. See http://chandra.harvard.edu for the fascinating results.

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Comments on Determination of Absolute Zero

The March 2003 issue (Vol. 41, No. 3) was a fascinating one, and I would like in particular to compliment Prof. Eugene Hecht on his paper "On Morphing Neutrinos and Why They Must Have Mass" (pp. 164–168). It made the mass question and the matter of neutrino oscillation reasonably clear to me for the first time. I also found Dragia Trifonov Ivanov's paper "Experimental Determination of Absolute Zero Temperature" (pp. 172–175) both useful and interesting. It presents an elegant shortcut to obtaining this value, in contrast to the more lengthy and pedestrian procedure described in my laboratory textbook.[1]

Nevertheless, I would like to add one small comment. Professor Ivanov's description of the isobaric measurement process (p. 174) says that after the measurement at boiling-water temperature, the gas-containing flask is inverted in ice water and the tap in the attached tube opened so that atmospheric pressure forces water into the flask as the contained gas contracts. The author then states, "The process [of water being drawn into the flask] continues until the air pressure in the flask is equal to the atmospheric pressure." This, of course, will only be true if the flask is held so that the water levels inside the flask and outside it in the beaker are the same. After all, the beaker and flask as shown in Fig. 6 (p. 175) form a rudimentary water manometer, so that with atmospheric pressure on the water surface in the beaker, the pressure in the flask will only be atmospheric if the levels match. The author may well have considered this point to be too obvious to mention, but I thought I might call attention to it, especially as the matching of levels is not obvious in Fig. 6. I also wondered if an effect of the water's vapor pressure should be considered, but I noted that for the high-temperature measurement there is no water in the flask, and for the low temperature one the vapor pressure would surely be negligible. Certainly Ivanov's amazingly accurate results attest to the excellence of this method, so that my compliments go to this author also.

1. Dean S. Edmonds Jr ., *Cioffari's Experiments in College Physics*, 10th ed. (Houghton Mifflin, Boston, 1997), pp. 155–165.

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Correction: "Some Simple Black-Hole Thermodynamics" [*Phys. Teach.* **41**(5), 299–301 (2003)]

The expression for the area of the event horizon in paragraph 3 should be $A = 4\pi R^2$. Paragraph 6, beginning at the top of page 300, should read "Stefan-Boltzmann" and the expression for σ should have a c^2 in the denominator. Neither of the formula typos affect any of the expressions that follow them. My thanks to the reader who pointed these out.

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