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REPLY TO "REPAIRING AN ELEMENTARY EXPLANATION OF RADIATION PRESSURE"

Tony Rothman and Stephen Boughn

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REPLY TO “REPAIRING AN ELEMENTARY EXPLANATION OF RADIATION PRESSURE”

We have received several letters from readers making the same suggestion and acknowledge that we hadn't been previously aware of the Halliday, Resnick, and Krane (HRK) argument.¹ We agree that if one includes a damping term on the electrons, then the resultant radiation pressure is nonzero. (This is, after all what the Abraham-Lorentz model does.)

Some models, however, are more transparent than others. For example, if the driving force on the electron is $eE_0 \cos(\omega t)$, then the electron's maximum displacement is $x_{\max} = eE_0/m\omega^2$. Taking an optical laser with $\omega \sim 10^{15} \text{ s}^{-1}$ and a power output of 100 W/cm^2 gives $E_0 \sim 10^4 \text{ V/m}$ and $x_{\max} \sim 10^{-13} \text{ cm}$, approximately the classical radius of the electron. But the

HRK demonstration relies on the Drude model (the one showing that current density is proportional to the electric field), which assumes that the damping arises from collisions between electrons and lattice ions whose spacing is much larger than the size of the electron. Specifically, HRK invoke the drift velocity v_d in their expression for the magnetic force on the electron, $F_B = ev_d B$, but one might question whether the concept of drift velocity is meaningful on length scales much smaller than the lattice spacing. The electrons in the Drude model are usually taken to be subject to a DC field as well as random (thermal) velocities, which are assumed to average to zero; however, a proper treatment takes one beyond freshman physics.

Furthermore, as stated in Mungan's letter,² in the HRK argument the pressure on the system depends on the number of electrons N , which is not a constant associated with light. At this

elementary level, the model only shows that the ratio of the electromagnetic force on the system ($\sim Ne^2 E^2/c$) to the power absorbed by the system ($dU/dt \sim Ne^2 E^2$) is $1/c$, but it does not establish the standard expression for the Poynting flux. To derive the Poynting relation, one must solve Maxwell's equations for the B -field (which is also phase shifted) within the conductor and then integrate over the electron distribution. All of which goes to show, once again, that freshman physics is not always for freshmen.

¹D. Halliday, R. Resnick, and K. S. Krane, *Physics*, 5th ed. (Wiley, New York, 2002), Vol. 2, p. 872.

²Carl E. Mungan, “Repairing an elementary explanation of radiation pressure,” *Am. J. Phys.* **77**(11), 965–965 (2009).

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