The Vinous Shock: How to Open a Bottle with a Book

MATHEMATICAL CURIOSITIES
By Mark Levi

One evening during my undergraduate days, my fellow math majors and I gathered for a party. We brought along some wine, but quickly realized that there was no corkscrew in the apartment. We could have, of course, just pushed the cork in, but a more experienced friend showed us a better way. Pulling a volume of Lenin's collected works—for this was back in the USSR—from a bookshelf, he placed the tome against the wall, and with a gliding horizontal motion smacked the bottom of the bottle into the book, (see Figure 1). Amazingly, the cork slowly inched out with each repeated impact, to the point where we could pull it out by hand.

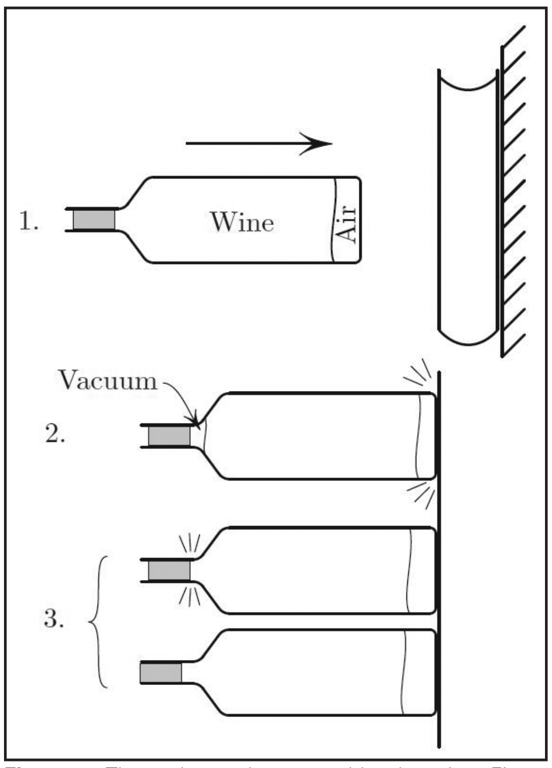

Figure 1. *The cork gets hammered by the wine. Figure courtesy of Mark Levi.*

In an ironic twist, the very economic policies advocated in the book caused the shortage of corkscrews and thus the opus's desecration. This was the only time, I am sure, that the book had a positive impact — pun intended.

Turning from history to science, it is natural to wonder what pushed the cork out. I originally guessed that the cumulative jet was responsible. Such a jet is created if one releases a test tube with water, held vertically, from a few centimeters above a tabletop; as the tube hits the table, a jet of water shoots up and hits the ceiling. Shaped charges utilize the same phenomenon to puncture armor. The velocity of such jets can reach speeds of over $10\,\mathrm{km/sec}$. I initially thought that a similarly-generated jet hit the cork and pushed it out, but later realized that this explanation misses the mark. A much more likely mechanism, shown in Figure 1, consists of three stages:

1. The bottle accelerates towards the book while the wine is driven back; the air thus gathers in the forward position.

2. Upon impact, the wine keeps moving due to inertia, *opening a vacuum bubble* near the cork and compressing the air on the right.

3. The compressed air rebounds the wine back into the cork; the vacuum bubble collapses but the incompressible wine cannot stop instantaneously, thus hitting the cork like a steel hammer.

The cork is thus hammered from the inside out! In other words, the cork acts as a shock absorber, absorbing the shock by inching out a bit. A similar effect of cavitation can damage boat propellers; vacuum bubbles created by rapidly-moving propellers collapse and generate hydraulic shocks, and the propeller's surface may act as a shock absorber, absorbing the shocks by pitting its surface.

We can estimate the distance by which the cork inches out with minimal information. In the final analysis, the kinetic energy imparted by hand to the wine is spent dragging the cork outwards by the distance x to be determined, plus the energy of sloshing waves, etc.:

$$\frac{mv^2}{2} = Fx + E_{\text{other}}.$$

Here, v is the bottle's speed prior to impact, m is the wine's mass, and F is the frictional force needed to drag the cork. Ignoring the last term, we obtain

$$x = \frac{mv^2}{2F};$$

this is an upper bound on the distance that the cork travels, since some energy is wasted as E_{other}. Taking the wine mass as $m = 0.5\,\mathrm{kg}$, the impact speed as $v = 2 \cdot \mathrm{m/sec}$, and the force required to move the cork as $F = 100\,n$, (about 20 pounds), we get

$$x = 1\mathrm{cm}.$$

The net result of the three-stage process is the same as hitting the cork with a hammer of mass m with speed v *from the inside*, assuming that E_{other} is neglected.

Were it not for the cork's ability to absorb the vinous shock, the bottle's neck would likely shatter. I did not get around to confirm this with rigidly-sealed bottles, such as those with beer caps, nor would I recommend doing so to anyone not wearing eye and hand protection.

Mark Levi (levi@math.psu.edu) is a professor of mathematics at the Pennsylvania State University.