An Extension of the Imploding Can Demonstration

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In this paper we address some fascinating aspects of the well-known, simple demonstration of a collapsing can. An Internet search on “collapsing can” or “imploding can” gives more than 700 hits. Because physics and physics teaching journals have not given a corresponding amount of attention to this experiment, we decided to make our own contribution to the literature. We show that a careful study of the crushing can experiment introduces a very wide range of conceptual and practical topics in classical thermodynamics. We especially suggest a simple experimental extension that allows much more information on the physical behavior of the imploding can to be easily obtained.

The Classic Demonstration

The open end of a metal (soda, beer, oil) can is placed over a pan of boiling water, and the can becomes filled with water vapor. The top (open end) of the can is then quickly immersed in a shallow pan of cold water. Immediately the can collapses, producing an audible sound. This phenomenon and its physical interpretation are well-known components of classical “kitchen experiments.” The sudden collapse is evidently due to an abrupt decrease in pressure within the can.

The physical processes involved in this phenomenon are relatively simple and yet require the use of many important concepts in classical thermodynamics. First, one must understand the filling of the can with water vapor. With the can placed over the pot of boiling water, vapor enters through the opening. Water vapor is less dense than air, and the former gradually replaces the latter so that eventually the can becomes hot and filled with vapor. In the next step, the rapid cooling of the can results in a dramatic decrease in the vapor pressure of the H₂O contained and some of the vapor inside condenses. Since the volume of the condensed water is much smaller than that of the original vapor, and since the opening of the can is now effectively sealed, there is a sudden drop in pressure within the can.

A Different Perspective

Now let’s examine a simple “secondary” experiment to better clarify the actual mechanisms involved in the crushing of the can. The central point is the difference between gas cooling and gas condensation. If a can is filled with heated air and then rapidly cooled, the resulting pressure decrease within the can would not be sufficient to cause it to implode. A simple experiment can be used to elucidate the relevant concepts in a quantitative way. We start with a small glass or polyethylene (PET) bottle containing only air at 100°C. This may be easily (and very carefully) done by heating the dry, “empty” bottle and the air inside with a hair dryer. A second, identical bottle is filled with water vapor as described above (we use a PASCO steam generator TD-8556A). At this point we have two identical bottles containing equal volumes of different gases (air, water vapor) both at about 100°C. In the second step of our experiment, we do the same as for the soda can, i.e., we rapidly immerse the open ends of the bottles in a shallow pan of cold water. The behavior is very different in the two cases. In the vapor-filled
bottle the water rises to a much greater height than in the air-filled one (compare Figs. 1 and 2). Why? And why don’t the bottles collapse as the soda can does?

In the first bottle, the air is cooled due to heat loss to the cold water through the bottle opening (the plastic or glass bottle is a poor heat conductor). The gas volume decreases and the water level rises. A simple calculation shows that the ideal gas law is approximately satisfied. In our experiment (see Fig. 1) the initial volume and temperature are $V_i = 660 \pm 5$ ml and $T_i = 370 \pm 5$ K, respectively (the relatively large uncertainty in $T_i$ is due to the nonuniform temperature in the bottle). After cooling we measured $T_f = 294 \pm 1$ K and $V_f = 535 \pm 5$ ml. Using the perfect gas equation, assuming isobaric conditions, we predict that $V_i / V_f = T_i / T_f$. Our ratio of the measured volumes is $0.81 \pm 0.01$, while the temperature ratio is $0.79 \pm 0.03$. So, in this first experiment we simply observe the cooling of air at constant pressure, which causes a volume reduction consistent with the ideal gas law.

In the vapor-filled bottle, the temperature reduction is again caused by heat loss through the bottle opening, but now the water rises to fill essentially the whole bottle (Fig. 2). The bottle doesn’t implode as the can does because glass (or PET) is a poor thermal conductor compared to the steel or aluminum of which the can is made. Therefore, the temperature drop for the can is much more rapid than for the bottle. The faster pressure drop in the can results in an implosion, whereas in the bottle one simply sees a large rise in the water level. One could say that the bottle experiment is a “slow-motion” rendition of the collapsing can.

It is possible to estimate the amount of gas condensed in this experiment and also the pressure reduction within the can. We find (Fig. 2) that the final volume occupied by the H$_2$O gas is $15 \pm 2$ ml, where again the initial volume was $660 \pm 5$ ml. This means that a volume of $645 \pm 5$ ml of vapor gets condensed. In our laboratory the atmospheric pressure was $9.66 \times 10^4$ Pa. Since the condensation happens very rapidly, the temperature can be considered constant at the (initial) observed value, $370 \pm 5$ K. These figures allow us to compute the mass of water condensed: $n = \frac{PV}{RT} = 0.0202 \pm 0.0007$ mol, or $m = 0.36 \pm 0.01$ g.

Concerning the pressure drop in the vapor-filled can, we consider that an instant before the big crunch the can and its contents cool down to a certain (non-equilibrium) temperature. By comparing the vapor pressure of water at $294$ K and $370$ K, we estimate that the relative pressure reduction is more than 95%. This implies that almost the totality of the atmospheric pressure acts to crush the can!

**Conclusions**

The imploding can demonstration may be used to address a number of concepts in classical thermodynamics. An easy extension of the experiment allows
physical details of the observed phenomena to be studied quantitatively.

References
1. For some nice pictures, movies, and comments on this experiment, just browse the Internet! To start with, try with the following addresses: http://www.steve
spangler science.com/experiment/00000043,
http://phun.physics.virginia.edu/demos/drum.html, and
3. Alternatively, one can use a hot plate or a Bunsen burner to heat a can containing a small amount of water. As the water is brought to a boil, the can fills with vapor.
4. Safety goggles should be worn and a shield should be placed between the lecture table and the class. If a glass bottle is used (PET bottles work well but tend to become distorted and unusable after their first hot bath!), it should be wrapped with transparent tape, to prevent flying shrapnel.

PACS codes: 01.40.gb, 01.50.My, 05.20.Dd, 51.30.+i

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