Obtaining an Absolute Measurement of Atmospheric Pressure

Introduction

This experiment is an extension of the well-known trick of placing a piece of card over the opening of a container of water and inverting it [3]. Air pressure keeps the card in place. In this case, a ping-pong ball is held in place over the neck of a bottle. Measurements can then be made to determine an absolute value for atmospheric pressure. The idea for this activity comes from The Physics Teacher [1].

p_{atm} : atmospheric pressure (Pa)

p : air pressure inside bottle (Pa)

V : original volume occupied by air in the bottle (m^3)

h : height of water column (m)

ΔV : this is the small increase in the volume occupied by the air in the bottle when it is inverted and water drips out. It is equal to the volume of water that drips out of the bottle. (m^3)

If the ball remains in place after water has dripped out:

$p_{atm} = h\rho g + p$ ....equation (1)

Note that no air enters the bottle, keeping the mass of air in the bottle constant. Hence, Boyle's Law can be applied:

$p_{atm} V = p(V + \Delta V)$ ....equation (2)

Combining equations (1) and (2),

$p_{atm} = h\rho g \dfrac{(V + \Delta V)}{\Delta V}$ ....equation (3)

For our work we used a 500 cm^3 Fisher Brand bottle. If the bottle is inverted over a beaker, the increase in volume occupied by the air can be found by measuring the mass of water collected. Since water has a density of 1 g cm^{-3}, the increase in volume ΔV is easily found. In practice, there will be spillage of water. If the experiment is performed over a paper towel, the increase in mass of both the beaker and the paper towel can be used to determine the increase in volume. Height was measured using a 30 cm ruler. A balance able to read to 0.01 g was used to measure ΔV.

Another approach is to measure h and ΔV for various volumes of air. This is best achieved by filling the bottle to the brim with water, then emptying out the required volume.

If equation 3 is rearranged, we have:

$$h\rho g = p_{atm} \frac{\Delta V}{(V + \Delta V)}$$

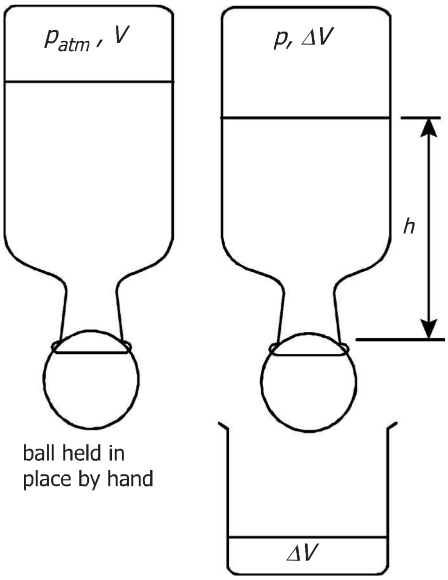

Figure 1 - Basic set-up.

Thus, a graph of $h\rho g$ versus $\dfrac{\Delta V}{(V + \Delta V)}$ should be a straight line through the origin.

The gradient should be p_{atm}.

Results

Raw measurements of atmospheric pressure gave values between 94 kPa and 124 kPa. Using the graphical method, graphs initially displayed a large scatter of points and a gradient equal to 89 kPa, derived using Excel's LINEST function. With practice, 98 kPa was obtained. One of the original graphs is shown below.

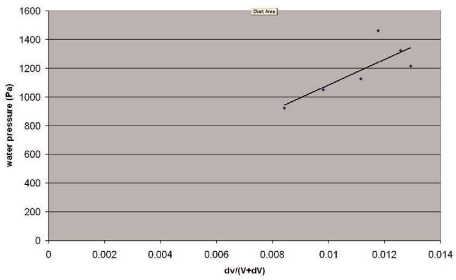

Figure 3 - Example graph.

Evaluation

To achieve any degree of accuracy with this apparatus takes practice and teachers may feel that the time penalty incurred by this is too great. It cannot be introduced at the time that air pressure is taught, as an understanding of Boyle's Law is also essential. A number of pupils will find difficulty in following the derivation of equation (3) above. There are, however, a number of points in favour of carrying out the activity. Firstly, it presents a cognitive challenge. Can students explain why water always drips past the ball whenever the experiment

Figure 2 - Actual equipment.

is done? Are they able to say why more water drips past the ping-pong ball when the volume of water in the bottle is smaller? SQA reports [2] cite that candidates need experience in tackling this sort of non-numerical scenario. The set-up is also a problem solving plus one, requiring the application of more than one physics concept. It could thus be introduced after teaching the gas laws, using the following approach:

Demonstrate the apparatus. Ask students to discuss, in groups, why the ping-pong ball remains in place. Repeat the demonstration using a different volume of air in the bottle. Point out that more water escapes when the volume of water in the bottle is smaller. Students should discuss why this is so. Given the diagrams, they can then derive equations (1) and (2), with the more able going on to combine them to get equation (3). Each group could then measure h and ΔV for a particular volume V. Bearing in mind that practice will be necessary before meaningful measurements can be made, it is unlikely that time would permit every group to measure a range of values for these quantities. Results could thus be pooled if the graphical approach was taken. The experiment could also form part of an Advanced Higher investigation on air pressure.

References

1. The Physics Teacher, Vol. 44, November 2006, P492

2. SQA Higher Physics 2006 Principal Assessor's Report

3. www.ise5-14.org.uk/Prim3/New_Guidelines/Newsletters/38/Under_Pressure.htm