A SILLY EXPERIMENT ABOUT CO_2

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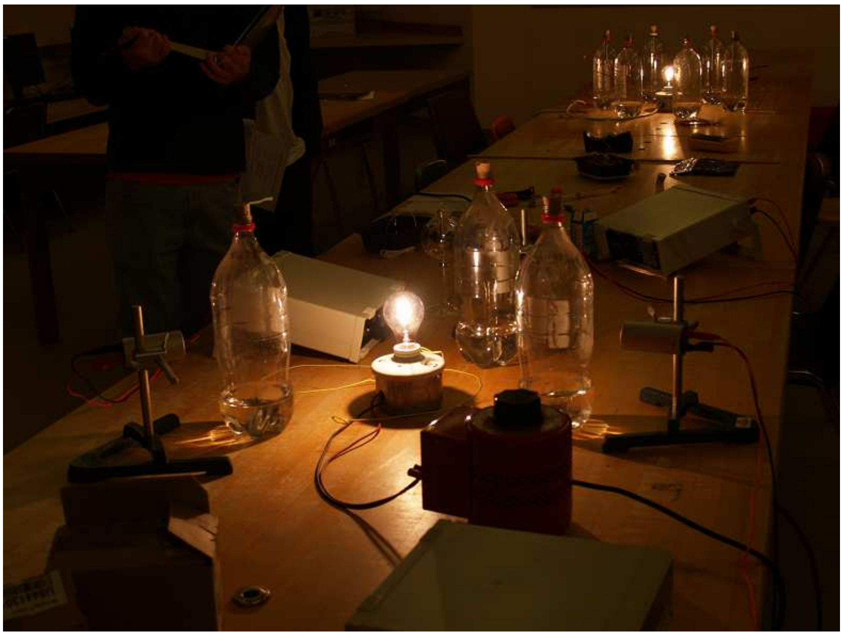

FIGURE 1. Two separate set-ups running at the same time. While it looks like our lab is bathed in mood-lighting this is an illusion. The extremely bright filaments fooled my automatic camera. The room was brightly lit. The nearset set-up uses Moll-type thermopiles, while the distant setup is more like the NOAA description, except with thermocouples replacing lab thermometers.

Are there endless silly or meaningless experiments and demonstrations that one can do with carbon dioxide (CO_2)? We've seen a few on WUWT recently.[1] On Tuesday November 3, 2009, WUWT exposed one endorsed by a major scientific organization under the headline *NOAA*

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[1]See for example: http://wattsupwiththat.com, 2009/11/18/, Climate Craziness of the week.

deletes an inconvenient kids science web page. Indeed, all reference to this page appears now gone at NOAA. But, thanks to the efforts of WUWT, and the help of the way-back machine,[2] selected physics students in three of my courses at LCCC got to try the experiment as someone at NOAA designed it. As it turns out, this experiment is silly for what it attempted to show, but it provides darned good lessons about scientific experiments.

The first group of physics students to get a crack at greenhouse warming in a two liter bottle were from my Physics 1050 course – physics without math. They set the experiment up as closely to the NOAA specifications as possible and made Runs 1 and 2 as I describe below. The algebra based physics course got a stab at it next, then the calculus-based physics class had their try. These classes modified the experiment to get a better picture of what was going on. They performed Runs 3 and 4, respectively.

1. Procedure

The NOAA web-page suggested doing the experiment according to the following recipe.

(1) *Partially fill both bottles with water.* In fact, we filled each with the same amount of water – about two inches worth.
(2) *Add the seltzer tablets to one of the bottles.* We delayed this step until we had the apparatus assembled.
(3) *Suspend the thermometers inside the bottles in such a way that you can measure the temperature of the air and seal the tops with molding clay.* We thought there was little reason for sealing the top completely, so we used a cork stopper with hole large enough to allow gas generated in the bottle to pass out around the thermometer.
(4) *Place the lamp at equal distance between each bottle.* This is the tricky step in this seemingly simple experiment.
(5) *After an hour, measure the temperature of the water in each bottle.* We thought the word "water" was a mistake here because there was no instruction to make the amount of water in each bottle equal, nor any reason the water would be of interest when the thermometers were suspended in air. Accordingly we monitored the temperature of the air to equilibrium at least, which was less than an hour.

[2]The way-back machine still has a copy of this web-page at: http://web.archive.org/web/20060129154229/http://www.srh.noaa.gov/srh/jetstream/atmos/ll_gas.htm

Despite the simplicity of the procedures, we encountered plenty of experiment design issues. These included: 1) the typical lab thermometers have fiducial marks at one-degree interval and so temperature can be read to a resolution of about $0.5°C$ at best,[3] 2) the marks are actually not of uniform size, 3) it is really difficult to get a label completely off a two-liter soda bottle, and so there is a readily available shield or reflector to confound one's results. Finally, there is that deceptively simple step 4; *Place the lamp at equal distance between each bottle.*

FIGURE 2. Thermocouple in a two-liter bottle. Note that the thermocouples are not perfectly vertical, nor are they likely to be perfectly centered. The near thermocouple points away from the lamp and residue from the label shields the thermocouple.

Although a person can purchase clear light bulbs that allow one to see precisely where the filament is, and what geometry it has, there is almost no way to decide what is the exact center of radiation. After all 95% of the radiation leaving the lamp is infrared and invisible. From outside the lamp does radiation appear to come from the filament? Or does the bulb envelope appear as the source? Moreover, even if a person can decide where is the center of radiation, there are a host

[3]Actually it is possible to tell that the liquid in the thermometer is above half way, but below the next fiducial mark. Thus, I suggested students could resolve the least significant digit as .0, .2, .5, .8, respectively.

of other ways to get the set-up wrong. Figures 2 and 3 show some. Students rarely noticed if the thermometer was centered and vertical or if it stayed that way during the course of the experiment – and as one might expect to happen sometimes, thermometers in the CO_2-filled bottle tipped toward the lamp, as Figure 3 shows, while those in the control bottle tipped away like Figure 2.

FIGURE 3. A thermocouple in a two-liter bottle. Note that this thermocouple points toward the lamp, and has a reflector from the residue of the label torn from the bottle.

2. RESULTS

The table below summarizes our research of November 23, 2009. The first experimental run, using ordinary lab thermometers, appeared to detect an increased temperature rise in the CO_2-filled bottle. However, students failed to appreciate at this point that repeating this experiment, no matter how exactly, could arrive at a different outcome. Indeed, Run 2, using six thermocouples read to a temperature resolution of only $1°C$ indicated no average difference in temperature rise, but showed greatest temperature change in some bottles without CO_2.

Run 3, using thermocouples read to better resolution of $0.1°C$, showed the greater average temperature rise to occur in the non-CO_2 bottles. In this case students swapped thermocouples among bottles to make certain no variation was the result of mis-manufacturing of these sensors. We concluded from these results that sufficient replications of properly randomized runs would likely show no detectable difference at temperature resolution typical of equipment in K-14 science labs.

Run 4 made use of Moll-type thermopiles. These devices capture a very broad spectrum of radiation, from far IR through visible, and conveys it to a highly absorptive collector at the base of a conical reflector. A series connection of 17 type-K thermocouples indicates the temperature rise of the absorber. These thermopiles have a sensitivity of $0.28\,mV/\mu W$; a voltage that good quality bench multimeters can read easily. Figure 4 shows one of these devices.

FIGURE 4. A Moll-type thermopile. Picture from Cenco on-line catalog.

In these runs we organized a moll-type thermopile to look at the lamp through our plastic bottles. When the potential of the thermopile became stable we then dropped two selzer tablets in the bottle and monitored the decline in potential until it became stable again. In this manner we managed to avoid all confounding influences except variations in one plastic bottle to another, and possibly extremely small variations in aim of the thermopile. The average decline was $0.095\,mV$. This translates into a typical decline of $0.34\,\mu W$ of radiation power entering the conical collector.

3. Discussion

The presence of CO_2 in a plastic bottle reduced radiation collected by a thermopile looking through that bottle. But what radiation is reduced, and what causes the reduction? We are pretty sure that visible light isn't reduced as there is no visible difference between bottles with CO_2 and those without. Thus, the difference is likely in the infrared

(IR) part of the spectrum. CO_2, as we have heard interminably for the past 25 years, absorbs certain bands of IR radiation, most notably in the IR near 2, 3 and 4 micrometers wavelength, and in longwave bands between 13 to 17 micrometers wavelength. At thermal equilibrium CO_2 will radiate in these same wavelength bands as much power as it absorbs. The radiated radiation does not travel in the same direction as the absorbed radiation was traveling, however. It is radiated uniformly in all directions. In the case of our experiment this leads to a small decrease in power reaching the Moll-type thermopile.

Applying this to the case of a simple Earth atmosphere, containing nothing but CO_2 and having no weather, leads one to conclude that longwave radiation leaving the top of Earth's atmosphere will decline in magnitude slightly. This decrease in longwave power traveling away from the surface forces the Earth's surface temperature to rise slightly in order to maintain its thermal equilibrium. This is the "greenhouse effect" in its pure form.

Run 1 Thermometers			
Bottle	Initial T	Final T	ΔT
1 (air)	21	21.8	0.8
2 (air)	21	21.8	0.8
3 (CO_2)	21	22.5	1.5
Run 2 Thermocouples			
Bottle	Initial T	Final T	ΔT
1 (air)	23	25	2
2 (air)	23	24	1
3 (air)	23	25	2
4 (CO_2)	23	24	1
5 (CO_2)	23	25	2
6 (CO_2)	24	26	2
Run 3 Thermocouples			
Bottle	Initial T	Final T	ΔT
1 (air)	21.3	25.0	3.7
2 (air)	21.6	25.0	3.4
3 (air)	21.2	25.2	4.0
4 (CO_2)	21.3	24.7	3.4
5 (CO_2)	22.0	25.1	3.1
6 (CO_2)	21.6	24.8	3.2
Run 4 Moll Thermopiles			
Bottle	Initial mV	Final mV	ΔmV
1 (air-> CO_2)	4.93	4.79	-0.14
2 (air-> CO_2)	4.93	4.85	-0.08
3 (air-> CO_2)	4.84	4.78	-0.06
4 (air-> CO_2)	6.56	6.46	-0.10

TABLE 1. Various runs of our experiment. Thermometers run showed the expected enhanced ΔT of the CO_2-filled bottle. First run with thermocouples, though, showed no average difference, but was fraught with confounding influences. Temperatures were displayed at the whole number resolution because of the digital readout. Run 3 thermocouples read with a digital display having $0.1°C$ resolution and showed the largest effect in bottle with no CO_2. Thermopiles were read with a bench DMM having $10\,\mu V$ resolution.

4. Conclusions

When this experiment is set-up according to the prescription on the NOAA webpage it is quite possible to get a difference of temperature of $1\,^{\circ}C$ between or among thermometers even if none of them contain any CO_2. A properly randomized experiment will likely result in no discernable difference among thermometer readings irrespective of CO_2 in bottle or not. The issue is one of not enough magnitude of effect to resolve on typical lab thermometers.

An instrument as sensitive as a Moll-type thermopile can detect a small difference in radiation passing through bottles filled with CO_2 as compared to an identical bottle not filled. The amount of IR power redirected by a two-liter, CO_2-filled bottle appears to be about $100\mu W/m^2$.

The most important result of this experiment is how it shows students so many issues of experiment design. First, there is the issue of how difficult temperature measurments are to make accurately. Students are quite surprised at this. They are equally surprised that seemingly identical temperature sensors will not measure indentically. Second, there is also the difficulty of proving conclusively that A causes B when the experiment includes confounding factors. This is an important lesson about the value of skepticism in climate change research, observations, and publicity. If X, Y, and Z cause B just as readily as does A, then what allows one to claim A causes B?