Comparing the CO Content of Cigarette Smoke and Auto Exhaust

Measuring Concentrations of a Toxic Vapor Using Gas Chromatography

Dan Jaffe and Laurie Chavasse

Editor's Note: *NSTA has inaugurated* sci*LINKS, a new web-based educational tool that links text resources with instructionally rich Internet resources.* sci*LINKS represents an opportunity to create new pathways for learners and foster professional growth for teachers. NSTA is now incorporating* sci*LINKS into its journals. In this article, sciLINKS logos and code numbers are placed near discussions of key science concepts. Go to the* sci*LINKS website, type the code from the page you are reading, and you will receive a list of websites that further explain these science concepts. These sites are selected by science educators and constantly monitored for good pedagogy, solid science, and timeliness.*

This lab exercise investigates and compares the carbon monoxide content of automobile exhaust and cigarette smoke. The experiment uses gas chromatography with thermal conductivity detection to analyze the percentage by volume concentrations found in cigarette smoke and auto exhaust. Students discover that cigarette smoke has a much higher CO concentration than does the exhaust from a clean, well-maintained vehicle.

Undergraduates often view science classes as boring and unrelated to their world. Environmentally relevant labs that examine familiar pollution sources (e.g., cars and cigarettes), however, provide an important connection between science and students' own experiences. In addition, because students are familiar with cars and cigarettes, they are curious and ready to develop interesting and testable hypotheses about these two objects.

In this paper we report on a lab that compares the carbon monoxide (CO) concentration of car exhaust with cigarette smoke. We have discovered through our experiences teaching the general chemistry course for freshmen at the University of Alaska, where this activity was developed, that students are especially fascinated working on environmental problems that involve cars and/or cigarettes.

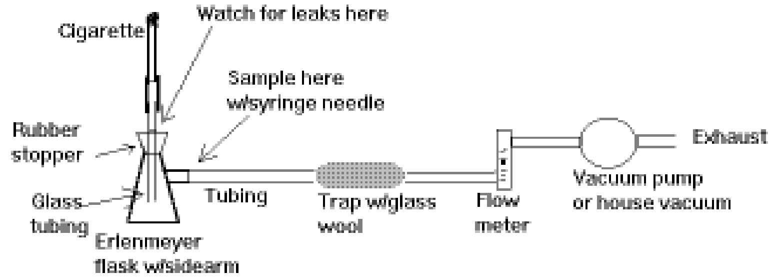
In an earlier report (Jaffe and Herndon 1995), we described a method using gas chromatography with a thermal conductivity detector (GC/TCD) to measure the CO content of auto exhaust. The GC/TCD method for CO has a detection limit of ~0.05% v/v. This is near the level of CO found in the exhaust of a clean, warmed-up, well-maintained vehicle.

In contrast, the CO mixing ratio from a poorly maintained vehicle can be as high as 15% v/v, and is easily detectable by GC/TCD. (Air pollutants are commonly reported as a volumetric "mixing ratio" that is identical to a mole fraction. Thus, 1% v/v refers to a gas mixture where one out of every 100 molecules is CO.)

Cigarette smoke contains an amazing array of gaseous and particulate compounds, including (in approximate order by mass): carbon dioxide, water, carbon monoxide, particulate matter (mostly tar), nicotine, nitrogen oxides, hydrogen cyanide, ammonia, formaldehyde, phenol, and dozens of

Dan Jaffe is a professor of interdisciplinary arts and sciences, adjunct associate professor of atmospheric sciences, and Coordinator for Science, Technology, and the Environment, University of Washington-Bothell 22011-26th Ave SE, Bothell, WA 98021; e-mail: djaffe@u.washington.edu. Laurie Chavasse is an undergraduate student in the department of chemistry and biochemistry, University of Alaska Fairbanks, Fairbanks, AK 99775.

Figure 1: Experimental apparatus for obtaining cigarette smoke sample.



other well-known toxic compounds. Some of these components are present in extremely high concentrations. For example, cigarette smoke contains much higher concentrations of CO than the auto exhaust from a well-maintained vehicle. This concentration of CO would be lethal if inhaled continuously for approximately 30 minutes. Because of the relatively high concentrations of CO in cigarette smoke, it is possible to conduct quantitative measurements using a basic gas chromatograph with thermal conductivity detection.

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The Federal Trade Commission (FTC) has developed standard methods for collection of cigarette smoke. The FTC method is intended to approximate a typical smoking pattern and consists of one 35 cm^3 "puff" of two seconds duration, once per minute. Mainstream (MS) smoke is the smoke that is directly inhaled by the smoker whereas sidestream (SS) or secondhand smoke is the smoke that is released to the environment from the burning cigarette. Researchers have measured both SS and MS smoke for many of the toxic constituents in cigarettes (e.g., Guerin 1991; Guerin et al. 1987; Rickert et al. 1984).

For most smoke constituents, the greatest amount is released in the SS smoke, although this result depends on the compound and the type of cigarette. Many cigarette brands have ventilation slits in or near the filter that dilute the concentration of tar, CO, and other compounds in the MS smoke. For particulate matter and CO, the SS/MS mass ratios are typically in the range of 0.4-2 and 2-8, respectively, however, a large amount of variation exists.

Because the quantities and concentrations of the toxic constituents in cigarette smoke are quite high, we concluded that it is possible to quantify these amounts using methods available to undergraduate science students. In developing this laboratory exercise, our goal was to minimize the complexities as much as possible while still maintaining a scientifically valid approach. Therefore, we chose to ignore the differentiation between MS and SS smoke and to focus instead on a total smoke sample obtained by continuously "smoking" the cigarette. Certainly many of the same methods described in this paper could be applied to the MS and SS smoke separately, however, to date we have not done so.

In a separate report (Jaffe et al. 1997), we have described a series of experiments on cigarette smoke that do not require the use of a gas chromatograph, and are thus usable in secondary science classrooms. By utilizing a gas chromatograph, undergraduate science students are able to conduct an experiment that reveals the remarkable finding that cigarette smoke has higher CO concentrations than the exhaust from most cars.

CONDUCTING THE EXPERIMENT

The smoking apparatus is shown in **Figure 1** and **Photos A and B.** In earlier experiments, we inserted the cigarette directly into a one-hole rubber

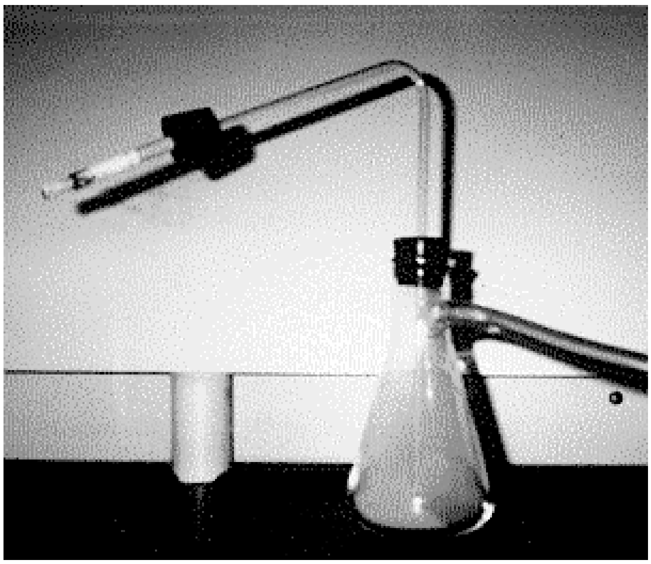


Photo A. Device used to "smoke" cigarette and obtain smoke sample.

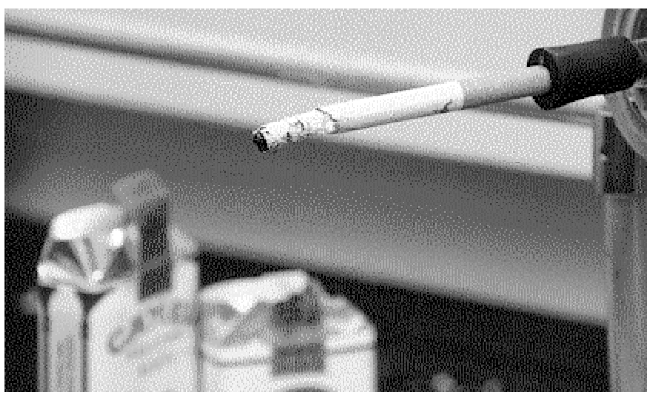


Photo B. Device used to "smoke" cigarette and obtain particulate and tar samples.

Figure 2. Digitized chromatogram of the 1.0% v/v CO in N_2 calibration standard. The chromatogram. was collected at an attenuation of 4, oven temperature of 75C, He flow rate of 60 ml/minute, detector current of 200 milliamps, an injection volume of 1.0 ml and using a 5 Å molecular sieve column 6' x 1/4" o. d. For these conditions the O_2, N_2 and CO elute at 0.6, 0.9 and 1.8 minutes, respectively. The small amount of O_2 present in this sample was determined to be 0.5% v/v and is due to contamination of the standard during handling (see text).

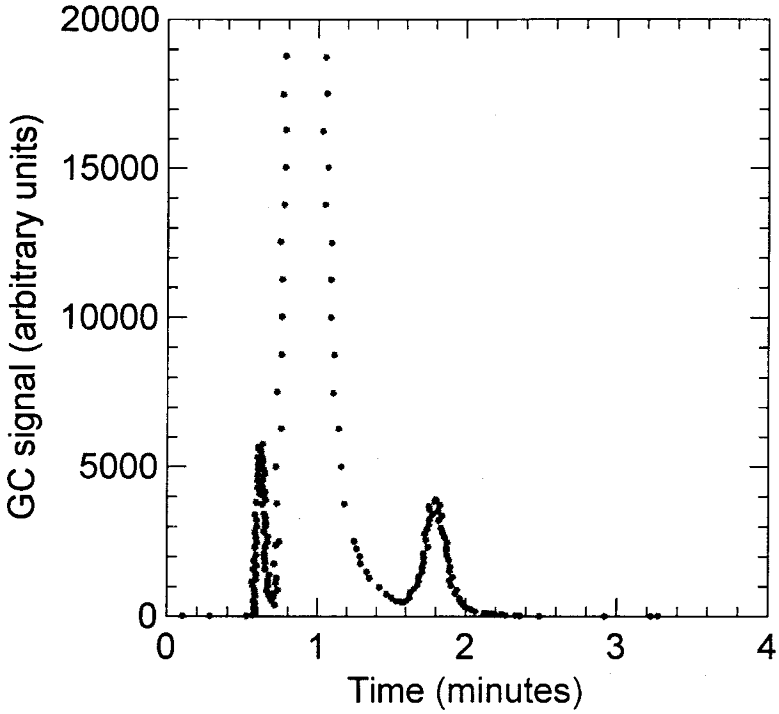
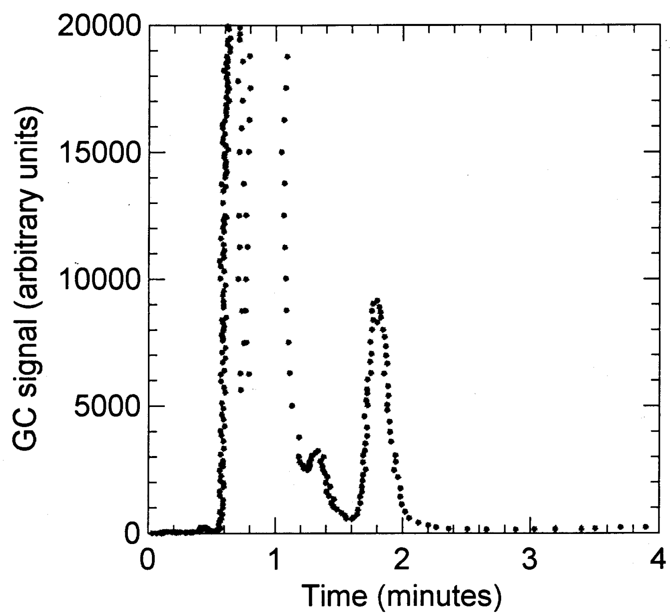


Figure 3. Chromatogram of a sample of cigarette smoke. Conditions are identical to those used for the calibration standard shown in Figure 2. The CO content of this sample was determined to be 2.3% v/v.



stopper in the top of the flasks, but because of leaks we changed this procedure. A more leak-free connection can be made by inserting a piece of glass tubing into the stopper, attaching this piece to Tygon[Tm] tubing, and putting the cigarette into the Tygon[TM] tubing. We used Lucky Strike brand cigarettes as the unfiltered type and Camel Filter 100s as the filtered type.

To begin the experiment, insert the cigarette into the tubing, turn the vacuum on, and adjust the flow rate to 0.5-1.0 liter per minute. Then light the cigarette and, after waiting at least one minute, insert a syringe directly into the tubing and withdraw a gas sample.

It is important that the Erlenmeyer flask be the smallest size available since a large Erlenmeyer will cause dilution and result in lower CO concentrations until the cigarette smoke has completely flushed the flask (about two flushing times).

For cars, we collected exhaust samples directly into sandwich-sized "zipper-type" bags. In our earlier versions of this lab we used a small vacuum pump, but later found that this was unnecessary. The plastic bag should be flushed with exhaust, filled, and then quickly sealed.

Based on our earlier work (Jaffe and Herndon 1995), it is best to conduct the GC-TCD analysis on the same day as the samples are collected, although this is not absolutely necessary. A sample of the exhaust for injection into the GC-TCD can be obtained by inserting a syringe needle through the plastic bag. A resealable sample port can be made on the plastic bags with two pieces of transparent tape, one on top of the other.

For the experiments described here, we used a GOW MAC 150 Series gas chromatograph with thermal conductivity detector. The column was a 1/4" o.d. by 6' molecular sieve (5A) column, and the oven temperature was set to 70-75° C. We used the detector current 200 mA, helium as the carrier gas, and set the column flow rate to 60 ml/min. We recommend that the column be baked out at elevated temperature prior to each class use. Inject a 1.0 ml aliquot of the standard, car exhaust, and cigarette smoke samples into the gas chromatogram. For our freshmen chemistry classes we use inexpensive plastic syringes to inject the samples into the GC.

The standard sample that we use is a small compressed gas cylinder containing 1% v/v CO in N_2. This piece of equipment is the only item needed for the lab that is not usually available in most undergraduate labs. It can be bought for under $100 by special ordering it from, for example, Scott Specialty Gases in Freemont, CA.

A convenient way to provide the standard sample for students is by filling one or two of the "zipper type" bags. The students can then sample the standard in the exact same manner as the exhaust. This method also guards against an accidental release of the lecture bottle standard.

Our previous work (Jaffe and Herndon 1995) has shown that the CO response on the TCD is linear. Therefore, for simplicity and economy sake we use only a single point calibration with the standard, although it would be a straightforward exercise to produce multiple concentration standards by appropriately diluting the standard with clean air.

Results

Figure 2 shows a chromatogram of the CO standard. Since the TCD has a relatively low sensitivity, compared with other GC detectors, you will detect only the major components in each sample, including N_2, O_2, and CO. Since the main components of air are N_2 and O_2 and the standard contains little or no O_2, it is relatively easy to identify which peak is which. A small O_2 peak is sometimes present in the standard chromatogram (see Figure 2), which is probably due to our imperfect transfer of the standard to the plastic bags. Water and CO_2 are apparently retained by the column and do not appear in the chromatogram as identifiable peaks. For these conditions, the retention times for O_2, N_2, and CO are 0.74, 1.0, and 1.8 minutes, respectively.

Table 1. Cigarette and car exhaust data obtained by students at the University of Alaska.

	Exhaust From Warm Car	Nonfilter Cigarette	Filter Cigarette
Mean	0.24	2.4	2.8
S.D.	0.26	0.4	0.6
Range	bdl*-0.82	1.8-2.9	1.6-3.7
N	16	4	10

By comparing the height of the O_2 peak in the standard with the O_2 peak in air (20% v/v), it is possible to estimate the amount of contamination in the calibration standard. For the chromatogram shown in Figure 2, we estimate that the O_2 content is less than 0.5% v/v, which represents an insignificant dilution of the calibration standard by ambient air.

Figure 3 shows a chromatogram of the cigarette smoke sample. It shows O_2, N_2, CO, and a fourth unidentified peak that appears as a small peak on the tail of the N_2 peak. Other compounds that might be detected in the exhaust and cigarette smoke samples are H_2 (exhaust), NO (exhaust or cigarettes), HCN (cigarette), acetaldehyde, benzene, or other hydrocarbons (exhaust or cigarettes). Keep in mind that even in an extremely polluted urban environment where CO mixing ratios often exceed 10 parts per million by volume (ppmv), this number is many orders of magnitude less than the exhaust mixing ratios (%) and is well below what is possible to detect with the TCD. In general, chromatograms obtained from the exhaust samples appear identical to the cigarette smoke samples, but with varying amounts of CO.

The CO peak height for the 1% standard varies from day to day, but typically has a height of 4-5 cm on the chart recorder at an attenuation of 2. The CO peak height for a well-performing, warmed-up vehicle will be much less than the standard under these conditions, although for a cold vehicle much greater exhaust CO mixing ratios are observed (Jaffe and Herndon 1995). It is a simple matter to convert these peak heights to CO mixing ratios using:

CO (unknown) = CO (standard) * Peak height (unknown)/Peak height (standard).

A summary of the cigarette smoke and car exhaust data is given in **Table 1.**

Discussion

The range of cigarette smoke concentrations that we have found (1.6-3.7% (v/v)) is comparable to the range reported (1.5-5.5% (v/v)) in other studies (Godish 1985).

Cigarettes clearly emit much higher concentrations of CO than most cars. In fact, all of the cigarette measurements we made gave CO mixing ratios of greater than 1.0%, which is interesting considering that this level is the usual "passing" value for cars on annual emission tests. Of the cars we tested in this experiment none exceeded the 1.0% level, although we have seen higher values from other vehicles we have tested.

The filtered and unfiltered cigarettes yielded similar CO data. At a 95% confidence level the data from the two types of cigarettes cannot be distinguished. This is in contrast to the data on tar and other particulates that show filtered cigarettes yielding much lower amounts of tar.

This relatively simple experiment lends itself to inquiry and hypothesis testing because students are already familiar with the basic principles behind the internal combustion engine and many of them probably know quite a bit about smoking patterns. In our Chem 106 course (second semester of general chemistry attended mostly by freshmen) this lab generates the most enthusiasm of any of the labs the students complete during the semester.

The visual nature of this experiment also provides strong evidence to a population that is most at risk of becoming smokers. In collecting the CO samples, a noticeable pattern of dense smoke appears in the Erlenmeyer flask. In addition, the tar that accumulates in the flask, tubing, and glass wool trap are powerful visual and olfactory indications of the true nature of inhaled cigarette smoke. (Because of the tar we recommend that the equipment used in this lab be dedicated to this experiment.)

Since students can see that inhaled smoke contains similar or more carbon monoxide than in car exhaust, this experiment offers an immediate "real-world" significance attached to the measured levels of the toxin. This evidence leads to the question: why isn't smoking immediately lethal? The answer lies in the fact that smokers do not inhale continuously on cigarettes. Nonetheless, serious health implications result from this high level of CO in cigarette smoke because of the bonding of CO to hemoglobin. Between two and five percent of smokers' hemoglobin is tied up with CO and, therefore, unavailable for O_2 transport.

This basic experiment can be broadened to test a wide range of interesting and relevant hypotheses. For example, a partial list might include:

- ▲ Is more CO released in mainstream or sidestream smoke?
- ▲ What factors increase the production of CO in cigarette smoke? (e.g., flow rate, humidity, combustion at reduced pressure/high altitude)
- ▲ Why do cold or poorly tuned vehicles generate much more CO during combustion, as compared to a warm, well-tuned vehicle?
- ▲ Why do cigarettes produce a greater CO concentration compared to a well-tuned car?
- ▲ Finally, it is possible to combine the GC measurements of CO in cigarette smoke with mass measurements of the tar content using a filtration technique we have developed. It is also possible to use less accurate, but simpler, colorometric indicator tubes to measure the CO mixing ratios in cigarette smoke or exhaust. Both of these projects are suitable for secondary science classes and are described in a separate report (Jaffe et al. 1997).

Internet resources:

- ▲ FDA home page on Children and Tobacco: *http://www.fda.gov/opacom/campaigns/tobacco.html*
- ▲ CDC's Tobacco Information and Prevention home page (TIPS): *http://www.cdc.gov/nccdphp/osh/*
- ▲ EPA home page on Indoor Air Quality and Secondhand Smoke: *http://www.epa.gov/docs/iedweb00/index.html* ❑

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