Example Laboratory Report
General Chemistry Laboratory

Stuart Student
Warner Duckworthy (GTF)
September 16, 2002

Determination of the Alcohol Content of Whiskey

Introduction

The concentration of ethanol in alcoholic beverages is generally measured as percent alcohol by volume. However, many alcoholic beverages, such as whiskey and vodka, are not labeled with the percentage of alcohol. Rather, they are labeled with the proof value, which is twice the volume percentage of the alcohol in solution.[1] Thus, 80 proof whiskey contains 40 percent ethanol. In this laboratory experiment, I attempted to experimentally verify that the alcohol content of 80 proof Monarch brand whiskey was 40 percent by volume.

The analysis of alcohol content in this experiment utilizes the density relationship, which relates the quantity of matter to the volume it occupies. The densities of many pure substances are known and tabulated. For example, at 20°C the density of water is 1.00 g/mL and the density of ethanol is 0.789 g/mL[2]. The densities of mixtures, such as whiskey, reflect the components that make up the mixture. For example, the density of a mixture of water and ethanol would be expected to be less than the density of water and more than the density of ethanol. When the density is unknown, it can be determined by weighing a known volume of water on an analytical balance and calculating using the equation: *density = mass/volume*. For this laboratory, a series of ethanol/water solutions were prepared by mixing known volumes of pure ethanol with known volumes of water. Aliquots of each mixture were then weighed and the density of each solution calculated. A plot of density vs. concentration (percent by volume) was prepared and the concentration of the whiskey was determined using the results of a linear regression analysis.

Experimental

30%, 45%, 50%, 60%, 75%, 85%, and 95% ethanol/water solutions were prepared and 5.00 mL aliquots were weighed on balance #12. Table 1 shows the mass and calculated density of each solution.

Table 1: Mass and density of ethanol/water solutions.

% ethanol by volume:	30 %	45%	50%	60%	75%	85%	95%
mass (g):	4.7505	4.470	4.581	4.505	4.280	4.191	4.000
density (g/mL):	0.950	0.894	0.916	0.901	0.856	0.838	0.800

Sample density calculation:

$$density = \frac{mass}{volume} = \frac{4.7505\,g}{5.00\,mL} = 0.950\,{}^{g}\!/_{mL}$$

A 5-mL aliquot of Monarch whiskey was weighed on balance #7 and the density determined:

mass whiskey = 4.710 g

density whiskey = 0.942 g/mL

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A graph (Graph 1) was prepared by plotting solution density vs. percentage by volume ethanol. A linear fit of the data was done using MS Excel. The equation of the best fit line was found to be

$$y = -0.0021x + 1.0124$$

or in other words,

$$density\ of\ the\ solution = (-0.0021)(percentage\ alcohol) + 1.0124$$

The percentage alcohol in whiskey was determined by rearranging this equation and using the calculated density of whiskey:

$$percentage\ alcohol = \frac{density\ of\ the\ solution - 1.0124}{-0.0021}$$

$$= 46\%$$

Discussion/Conclusion

Determination of the concentration of the components of a mixture can often be done utilizing indirect methods. This experiment was performed for the purpose of determining the alcohol content (percentage by volume) of whiskey by measuring its density. Whiskey is a mixture of water, ethanol and various other substances that influence the flavor and color. The densities of pure water and pure ethanol are known, but when the two are combined, the density of the resulting solution is a function of the ratio of the quantities of the two substances. Monarch brand whiskey was determined experimentally to have a density of 0.942 g/mL, which correlated to 46% ethanol by volume. This result contrasts somewhat with the 40% value stated on the bottle.

Before jumping to the conclusion that the bottle had been mislabeled, it is important to consider the many sources of error that were present in the experimental procedure. The first to note is that density is a function of temperature and temperature recordings were not made during this procedure. It was assumed that the temperature remained constant but there may have been some small fluctuations that would contribute to indeterminate error. There was also indeterminate error present due to my use of the volumetric pipets. As this was my fist experience with a pipet, my technique was somewhat imprecise. In particular, the use of the graduated volumetric pipet in the preparation of the known solutions was a challenging experimental technique. Too much ethanol added would cause a density calculation to be low, while too little ethanol added would cause a high density calculation. These two sources of indeterminate error were the primary sources of the scatter in the data, clearly seen in Graph 1.

Table 1 and Graph 1 also reveal that there is a problem with the data recorded for the 45% by volume solution. I am not sure whether the solution was prepared improperly or the density was measured improperly, but the non-linearity of this data point suggests that the measurements should have been repeated if more time had been available. If this point is eliminated, the calculated value for whiskey drops to 44% by volume.

Sources of determinate error in this procedure could be found in the calibration of the pipets and balances. Given the magnitude of the indeterminate error described above, I don't believe that determinate errors in my volume measurements were significant. However, I used different balances to weigh the known solutions and the whiskey sample. Inconsistencies in the

balances would contribute to determinate error that could be eliminated by using the same balance.

There is also a flaw in the basic premise of this experiment. That is, whiskey with a large number of "impurities" was compared to mixtures of pure ethanol and water. Surely the other substances present in whiskey will affect its density to some extent and therefore also affect the percent by volume determination. However, this experiment was still a useful exercise in applying the concept of density to a real world question. The principle of assessing composition by measuring density has wide ranging applications, from establishing the purity of a silver candelabra to determination of the salinity of seawater.

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[1] Miller, G. Tyler; *Chemistry: Principles and Applications*, Wadsworth, Belmont, CA; **1976.**
[2] Petrucci, Ralph; *General Chemistry, 5/e*; Macmillan, N.Y., N.Y.; **1989**.