Weighing Measurements: The Balance

INTRODUCTION

Chemistry is an experimental science. This means that chemical knowledge must be based on and supported by data collected during carefully controlled chemical experiments. Typical of the data collected in the chemistry laboratory are measurements of such quantities as length, mass, volume, temperature, and time, and observations of physical properties such as color and state of matter. The accurate determination and expression of these fundamental quantities must be mastered if one is to obtain and report meaningful, reliable, and reproducible results. In the first experiment, two instruments for measuring mass are described and used; they are the beam balance and the analytical balance. The second experiment involves the accurate measurement of volume. The third and fourth experiments involve observation of properties of solutions and of changes that occur in chemical reactions.

Weight and Mass

Before considering the instruments, the distinction between the weight and mass of an object should be understood. Mass is a fundamental property of matter. It is a measure of the quantity of material in a substance and has a constant value no matter where it is measured. Weight is not a fundamental property of matter. It is a measure of the gravitational attraction on the object and is related to the mass by the equation

$$w \,=\, mg$$

where g is the acceleration due to gravity. The value of g varies with location. On earth, at sea level, g is equal to 9.80m /sect. Since g is not constant, the weight of an object depends on its location.

In chemical experiments mass is always measured, since data should not depend on location. Balances measure mass by comparing an object of unknown mass with known masses. Since the acceleration due to gravity is exerted equally on all masses at a given location, the mass of the unknown object can be obtained.

Unfortunately, in common practice, chemists do not rigorously maintain the distinction between the terms weight and mass. The use of the balance is termed "weighing," the objects of known mass are called "weights" and the mass of the unknown object is called its "weight."

The basic SI unit of mass is the kilogram. Other common units related to the kilogram are listed below.

Units of Mass
1 kilogram (kg)   = 1,000 grams (g)
1 milligram (mg) =   0.001 g = 10^{-3} g
1 microgram (μg) = 10^{-6} g

Beam Balances

The triple beam balance can measure mass to the nearest tenth of a gram (0.1 g). The quadruple beam balance can measure mass to the nearest one hundredth of a gram (0.01 g). Both balances are useful for measuring large quantities of material or when only approximate amounts of material are required. They are fairly rugged and easy to use. The object to be measured is placed on the pan and the weights are systematically adjusted on the beams until balance is achieved.

For example, the three arms of the triple beam balance are calibrated from 0–100, 0–10, and 0–1.0 grams. First the weight on the 0–100 arm is moved along the beam in 10 gram increments until the increment of weight exceeds the object weight by one unit. The weight is then returned to the next lower value. This procedure is repeated with the weights on the 0–10 gram arm and the 0–1.0 gram arm until the balance point is reached. An object weighing 34.7g would have the weight on the 0–100 g arm set at 30, the weight on the 0–10 g arm set at 4, and the weight on the 0–1.0 g arm set at 0.7 when at balance.

Figure 1-1. Photograph of an Ohaus Model 3600 Beam Balance. Courtesy of Ohaus Scale Corporation.

Analytical Balances

The analytical balance can measure mass to the nearest tenth of a milligram (0.1 mg or 0.0001 g). It is a more sensitive instrument than the beam balance, and is used for measuring small quantities of material or when very accurate weighings are required.

Uncertainty in Measurements

When a measurement is made on an instrument there always exists some uncertainty or error in that measurement. Uncertainties or errors in a measurement are of two types: systematic errors and random errors. Systematic errors are those inherent in the instrument or the method used to make the measurement. They affect all results in the same direction to the same extent. For example, a systematic error would result from incorrect degree markings on a thermometer that caused all temperature readings to be low. This type of error can often be evaluated and suitable corrections can be made to the data.

Random errors occur mainly because of the limitations of the instrument and of the observer in making the measurement. Estimates of correct values are always made in recording measurements from dials, meters, or calibrated glassware. These estimates occur in the last decimal place that the instrument can measure and are always subject to the judgment of the observer. Random errors usually cause the measured value to deviate from the correct value by only small amounts and positive and negative deviations of similar magnitude are equally likely to occur.

There are many ways to designate the uncertainty of a measurement. One which should always be used is to indicate the extent to which the instrument is capable of measuring, e.g., the triple beam balance weighs to 0.1 g, and the analytical balance to 0.0001 g. A reading designated 1.1 g indicates the reading was taken on a triple beam balance and the true weight is probably between 1.0 and 1.2 g (i.e., there is an uncertainty in the last digit of 0.1 g). To record the result as 1.1000 would be meaningless since the .1 is uncertain. The same object weighed on an analytical balance would have its weight reported as 1.1038 g. This indicates its true weight is probably between 1.1037 and 1.1039 g (i.e., there is an uncertainty in the last digit off 0.0001 g). The reading should not be recorded simply as 1.1 g since the. 1 is not uncertain.

Precision and Accuracy

Since errors are present in any measurement it is often necessary to determine the reliability of the data. Two terms used in such an evaluation are precision and accuracy. A series of determinations are precise if there is good agreement among the individual values of the measured quantity. A result is accurate if it agrees well with the true value for that measurement. It is possible for measurements to be accurate but have poor precision (due to large random errors). Alternatively, measurements can be precise but not accurate (due to large systematic errors). The following data taken on an analytical balance illustrate these points.

Weighings of a Sample on an Analytical Balance		
Data	Series #1 1.0025 g 1.0026 g 1.0024 g	Series #2 1.0094 g 1.0040 g 1.0001 g	Series #3 1.0047 g 1.0047 g 1.0044 g
Average	1.0025 g	1.0045 g	1.0046 g
True Weight	1.0046 g	1.0046 g	1.0046 g
Precision	Good	Poor	Good
Accuracy	Poor	Good	good

Average Values

Since results are always affected by random errors it is often necessary to report one "best" value for a measurement. An average of several determinations is usually calculated for this purpose. An average reduces the effect of random errors since each of the determinations has an equal probability of being greater or smaller than the true value. The greater the number of determinations, the better the average obtained.

Significant Figures

Previous discussion indicated that measurements must be recorded to the extent justified by the instrument used in making the observation. This indicates the uncertainty in the measurement. The digits used in recording data are often referred to as significant figures. In a recorded number, all digits are significant except zeros used only to locate the decimal point. For example, 1.2 contains 2 significant figures while 1.2000 contains 5 and 0.00012 contains 2.

The relationship between the number of significant figures used to express a measurement and the accuracy of the instrument used to obtain the measurements is illustrated by the following examples. A weight recorded using a triple beam balance could be 12.7 g (3 significant figures) or 133.1 g (4 significant figures-uncertainty still in the first decimal place). A weighing on an analytical balance could be 2.4000 g (5 significant figures-uncertainty in the fourth decimal place) or 24.6320 g (6 significant figures-uncertainty in the fourth decimal place) or 0.0123 g (3 significant figures—uncertainty still in the fourth decimal place).

Often the result of an experiment is obtained from a series of calculations using collected data. The calculated result must also indicate the uncertainty in the collected data. This uncertainty is noted by recording the result of the calculations to the proper number of significant figures.

Two "rules of thumb" help determine how many significant figures to record in a calculated result. (1) In multiplication or division the result should not contain more significant figures than the measurement with the fewest number of significant digits, e.g., 12.3/3.2 (3 and 2 significant figures respectively) = 3.8 (2 significant figures).

In addition or subtraction the result cannot be more precise than the least precise measurement, e.g., 1.200 g + 4.1 g = 5.3 g, (2 significant figures). Since one of the weights is only known to the nearest tenth of a gram it would be incorrect to express the sum to more than the nearest tenth of a gram.

PROCEDURE

NOTE: Balances and other instruments used in this laboratory are delicate and costly. The instructions for their use should be closely followed.

1. Obtain a set of unknown objects to be weighed from the instructor. Record the unknown number on the data sheet.
2. Weigh the metal rod and the vial containing sodium chloride on the triple beam balance. Record the weights to the correct number of significant digits on the data sheet. See the instructor if the pointer does not come to rest on the scale when the balance is empty or if other questions arise.
3. When an instrument is available the instructor will review the proper operation of the analytical balance. See the directions below.

4. Weigh the metal rod and the small metal wire on the analytical balance. Record the weights to the correct number of significant digits. Repeat the weighing of the same metal wire two more times.

5. Weigh a piece of weighing paper on the analytical balance and record the weight to the correct number of significant figures.

6. Transfer about 0.5 g of the sodium chloride from the vial to the weighing paper. Weigh the weighing paper with the sodium chloride. Record this weight to the correct number of significant figures.

7. Determine the weight of the sodium chloride transferred from the vial.

8. Have the instructor check your results before leaving the laboratory.

Directions for Use of the Analytical Balance

A. If the balance is OFF:
　　1. Press the On/Of button to turn the balance on.
　　2. The balance runs through a self-test which ends with a readout of 0.0000 g.
　　3. The appearance of the weight unit "g" indicates the balance is ready for use.

B. If the balance is already ON:
　　1. Press the TARE button to zero the balance so that the readout displays 0.0000 g. The appearance of the weight unit "g" indicates the balance is ready for use.
　　2. Place the object to be weighed on the balance pan and close the balance doors.

　　CAUTION: Never place chemical samples directly on balance pan. Always use weighing paper, a watch glass, or a small beaker.

　　3. The appearance of the weight unit "g" indicates the weighing operation is complete. Read and record the weight of the object.
　　4. Remove the object from the balance.
　　5. It is NOT necessary to turn the balance OFF after each weighing. It should only be turned OFF at the end of the lab period.

Lab 1: WEIGHING MEASUREMENTS: THE BALANCE

Name_____

Section _____

Unknown number of metal rod_____

Unknown Number of metal wire_____

I. DATA

	Weight	Number of Significant Figures
Triple beam balance	XXXXXXXXXXXXXXXXXXX	XXXXXXXXXXXXX
Metal rod		
Vial + sodium chloride		
Analytical balance	XXXXXXXXXXXXXXXXXX	XXXXXXXXXXXX
Metal rod		
Metal wire: Trial 1		
Trial 2		
Trial 3		
Weighing paper + sodium chloride		
Weighing paper		

II. RESULTS

Average weight of metal wire		
Weight of sodium chloride sample removed from vial		

III. Show Sample calculations:

IV. QUESTIONS

1. Which balance should be used to

    a. weigh approximately 10 g of NaCl?

    b. weigh 10.1032 g of NaCl? c. weigh 10.1 g of NaCl?

2. a.   Calculate the average obtained from the following weighings of the same object.

    10.4375 g, 10.4381 g, 10.4373 g, 10.4376 g

    b.   Comment on the precision and accuracy of these results if the true weight is 10.4376 g.