Understanding Precision and Accuracy
CHE 353M
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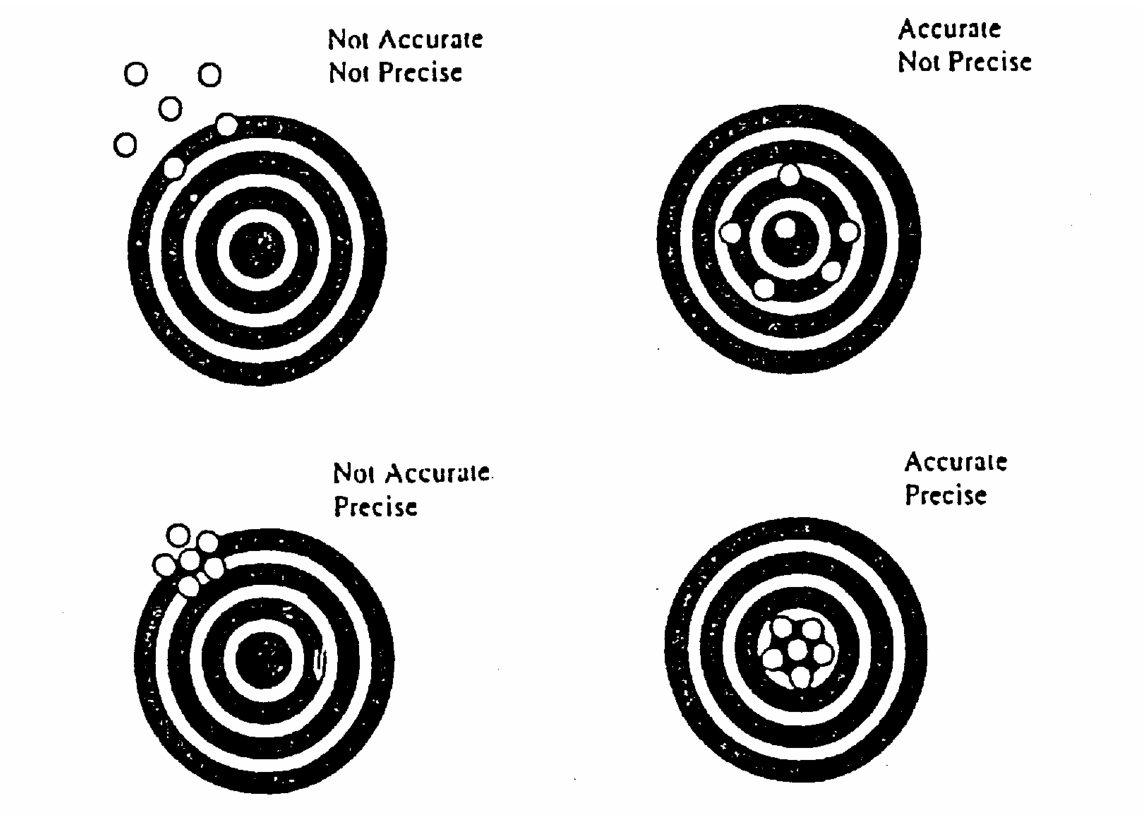
What's the difference between precision and accuracy?

One of the worst things you can do in your lab report is to use the terms precision and accuracy interchangeably! Precision and accuracy are two very different issues as illustrated below:



A measuring device may be remarkably precise, and at the same time, inaccurate. Precision describes the ability of a measuring device to provide the same readings for the same input. However, precision makes no implications about the accuracy of the measuring device. Accuracy describes how close the measured value is to the "true" value as established by some reference standard. You may take a series of readings that are scattered over a range, yet averaged together, they provide an accurate value.

The following types of errors affect accuracy, but not precision:

Using the ideal gas law in non-ideal conditions
Incorrect measurement of an orifice diameter that is used in your calculations
A dead-weight tester with weights not corrected for local gravity
A scale that is not zeroed before taking measurements

The following types of errors affect precision:

The random nature of humans reading a gauge differently (parallax effect)
Random fluctuations in a system

Often, it is stated that an instrument must be precise to be accurate. Suppose that an instrument has scattered readings that average out to be the "true" value. This is accurate if you take many readings, but if a user was to read the device once, it is rather improbable that they will happen to read the "true" value. Thus if an instrument has a precision error, it is often deemed inaccurate. This is acceptable as long as one understands that **these terms are not interchangeable**. Precision is a prerequisite for accuracy, but accuracy is not a prerequisite for precision.

Precision

To quantify precision, you must repeatedly sample a dependent variable (y) as a function of a constant independent variable (x). The following equation defines precision for these cases:

$$\text{Precision} = \frac{S_y}{\bar{Y}} \quad (1)$$

For example, suppose you are monitoring the flowrate through a tube with a flowmeter that has a moderate, random fluctuation. Presuming the flow in the tube is constant, you take 10 readings of the flowmeter in 10 second intervals:

Flowmeter reading (cm^3/min)
12.3
12.4
10.9
11.5
12.0
12.1
12.8
11.8
11.9
12.5

Average flowmeter reading: 12.0 cm^3/min
Standard deviation (S_y): 0.543 cm^3/min

Precision: 0.0453

Note that *precision is dimensionless*. This is an important feature in the above definition. By defining precision as a dimensionless quantity, we can compare precision among different systems that may be operating with flowrates on the order of thousands of cm^3/min that have reading errors on the order of hundreds of cm^3/min.

In the event that you only have one sample of the independent variable for each dependent point, you cannot meaningfully define precision. A common mistake for these cases is to use the squared correlation coefficient R^2 as an indicator of precision. However, the R^2 value only tells you how well your experimental data fit a linear trend. By definition, precision should describe the nature of the experimental system and should in no way depend upon equation fitting that is applied independently of the experiment. Notice Eq. 1 does not have any reliance on the equation you fit to the data - it merely describes the statistical scattering of your experimental data.

Accuracy

To discuss accuracy, you must first have a standard you wish to compare to. For example, in the pressure experiment, you will have an instrument (dead weight tester) that is known to generate a precise and accurate pressure. You will then observe the readings of various pressure measuring devices and observe how they compare to the pressures generated by the dead weight tester. The dead weight tester allows you to set pressures in psig. The Validyne variable reluctance transducer has an independent display that reads psig. If the Validyne transducer is perfectly accurate, you would expect a plot of calibrated pressure versus validyne transducer reading to have a slope of one and an intercept of zero. Your calibration equation for the Validyne transducer would be of the form:

$$\text{Calibrated Pressure(psig)} = \text{Validyne Transducer Reading(psig)}$$

The above equation would indicate a perfectly accurate gauge, but of course we know that won’t really happen! A more typical equation might look like:

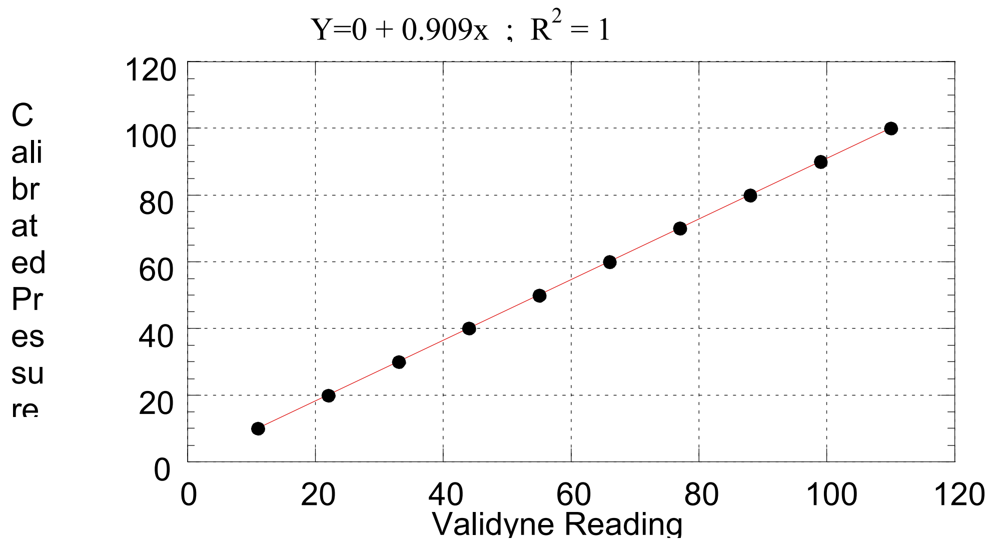
$$\text{Calibrated Pressure(psig)} = (0.997 \times \text{Validyne Transducer Reading(psig)}) - 2.32 \text{ psig}$$

The extent to which the slope deviates from one and the intercept deviates from zero are indicators of the Validyne transducer’s accuracy. This technique may be applied to any case where you have a reference standard and you are comparing a test sample with the same units as the reference standard.

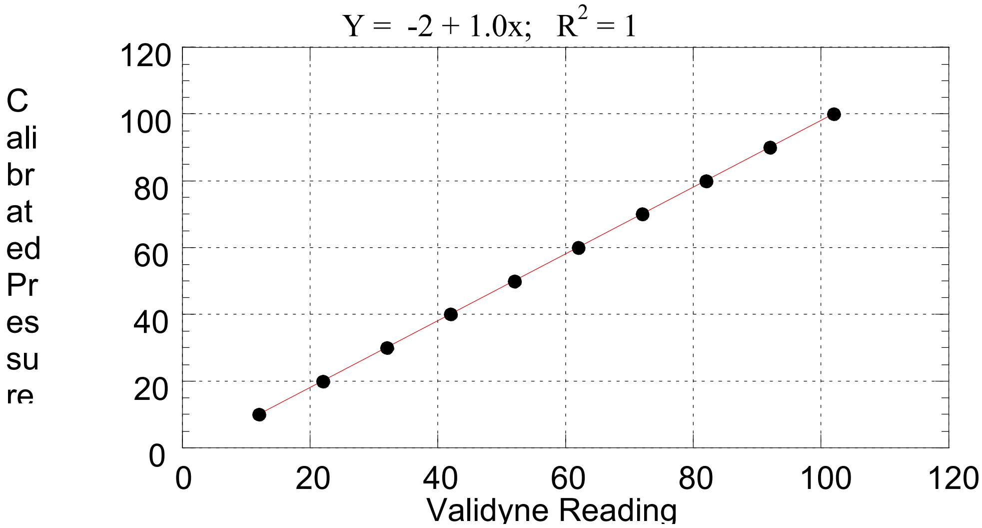
Suppose that you were looking at the calibration equation for a transducer that did not read in units of pressure, but instead read in mV. To apply the above arguments, you would have to know a theoretical relationship between mV and psig that is a universal constant independent of your particular experimental system. Unfortunately, such information is not always available. In these cases, you cannot draw conclusions about the accuracy of your data relative to the standard.

Again, you may be inclined to use the correlation coefficient as an indicator of accuracy. But the following two plots should convince you that in some cases, you may have a remarkably linear trend with a perfect correlation coefficient yet the data is highly inaccurate. For example, adjusting the zeroing control on the Validyne display unit will shift all readings by an equal amount. Even though the transducer has a very linear response to pressure, the intercept would be shifted resulting in an inaccurate gauge, yet a data set with a very high R^2.

Inaccurate - but R^2 = 1 and intercept = 0. Slope not equal to one.



Inaccurate - but R^2 = 1 and slope = 1. Intercept not equal to zero.



The moral of the story is to be cautious in the conclusions you draw based on the R^2 correlation coefficient. It is completely acceptable to draw conclusions about how well your data correlates with a linear fit. Sometimes, this may be of interest to you. For example, a fundamental assumption with many pressure transducers is that you will see a linear voltage response to changes in pressure. This is something you will test using the R^2 value when you do the pressure experiment. However, this does not prove that the transducer is precise - nor does it prove that the transducer is accurate. Be sure to understand that precision and accuracy are very different issues and are not interchangeable with each other, or the squared correlation coefficient.