Introduction to Measurements

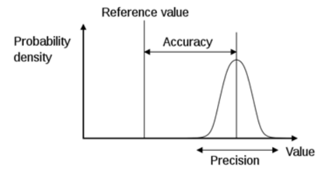
- Typically, we are accustomed to ***counting*** but not ***measuring.***
- Engineers are concerned with distances, elevations, volumes, direction, and weights.
- Fundamental principle of measuring:

No measurement is exact
and the true value is never known

Introduction to Measurements

Accuracy and Precision

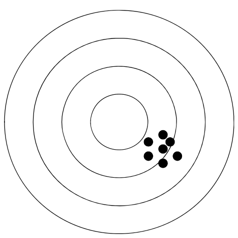
- ***Accuracy*** - degree of perfection obtained in a measurement
- ***Precision*** - the closeness of one measurement to another



Introduction to Measurements

Accuracy and Precision

Target #1

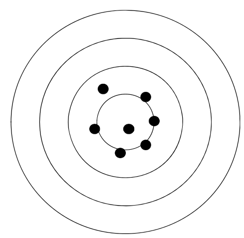


This target grouping is precise

Introduction to Measurements

Accuracy and Precision

Target #2

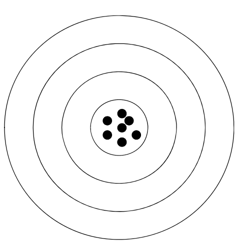


This target grouping is accurate

Introduction to Measurements

Accuracy and Precision

Target #3



This target grouping is accurate and precise

Introduction to Measurements

Accuracy and Precision

Here are a couple of other web sites for additional information in accuracy and precision:

http://www.colorado.edu/geography/gcraft/notes/error/error_f.html

http://en.wikipedia.org/wiki/Accuracy

Introduction to Measurements

Accuracy and Precision

- Better precision does not necessarily mean better accuracy
- In measuring distance, precision is defined as:

$$precision = \frac{\text{error of measurement}}{\text{distance measured}}$$

Introduction to Measurements

Accuracy and Precision

- For example, if a distance of 4,200 ft. is measured and the error is estimated a 0.7 ft., then the precision is:

$$precision = \frac{0.7\text{ ft.}}{4{,}200\text{ ft.}} = \frac{1}{6{,}000}$$

- The objective of surveying is to make measurements that are both ***precise*** and ***accurate***

Introduction to Measurements

Source of Errors

- **Personal Errors** - no surveyor has perfect senses of sight and touch
- **Instrument Errors** - devices cannot be manufactured perfectly, wear and tear, and compatibility with other components
- **Natural Errors** - temperature, wind, moisture, magnetic variation, etc.

Introduction to Measurements

Systematic and Accidental Errors

- **Systematic or Cumulative Errors** - typically stays constant in sign and magnitude
- **Accidental, Compensating, or Random Errors** - the magnitude and direction of the error is beyond the control of the surveyor

Introduction to Measurements

Group Problem

How long is the hallway outside the classroom?

- How did you measure this distance?
- What was your precision?
- What is your accuracy?

Introduction to Measurements

Significant Figures

- Measurements can be precise only to the degree that the measuring instrument is precise.
- The number of significant figures the number of digits you are certain about plus one that is estimated
- For example, what if I tell you go down Central Avenue 1 mile and turn left, what should you do?
- What if I said instead, go down Central Avenue 1.53 miles and turn left. How is that different?

Introduction to Measurements

Significant Figures

- For example you measure a distance with a tape and the point is somewhere between 34.2 ft. and 34.3 ft.

- You estimate the distance as 34.26 ft.

Best guess

- What is the significance of reporting a value of 34.26 ft.

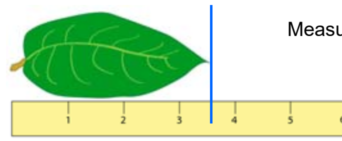
Introduction to Measurements

Significant Figures

- The answer obtained by solving a problem ***cannot*** be more accurate than the information used.

Best guess

Measurement: 3.6



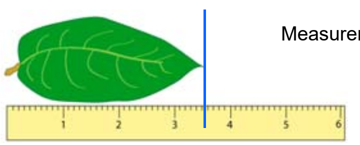
Introduction to Measurements

Significant Figures

- The answer obtained by solving a problem ***cannot*** be more accurate than the information used.

Best guess

Measurement: 3.58



- Why did the number of significant figures change?

Introduction to Measurements

Significant Figures

Zeroes between other significant figures ***are*** significant

23.07	1007
4 significant figures	4 significant figures

Introduction to Measurements

Significant Figures

For numbers less than one, zeroes immediately to the right of the decimal place ***are not*** significant

0.0007	0.03401
1 significant figures	4 significant figures

Introduction to Measurements

Significant Figures

Zeroes placed as the end of a decimal number ***are*** significant

0.700	39.030
3 significant figures	5 significant figures

Introduction to Measurements

Significant Figures

36.00620	7 significant figures
10.2	3 significant figures
0.00304	3 significant figures

Introduction to Measurements

Significant Figures

When a number ends with one or more zeros to the left of the decimal, you must indicate the exact number of significant figures.

420,000 How many significant figures?

Introduction to Measurements

Significant Figures

When a number ends with one or more zeros to the left of the decimal, you must indicate the exact number of significant figures.

$4.32\ (10)^5$ 3 significant figures

$4.320\ (10)^5$ 4 significant figures

Introduction to Measurements

Significant Figures - Mathematical Operations

When two numbers are multiplied or divided, the answer should not have more significant figures than those in the factor with the least number of significant figures.

3 significant figures
5 significant figures

$$\frac{3.25 \times 4.6962}{8.1002 \times 6.152} \boxed{= 0.306}$$

5 significant figures
4 significant figures

Introduction to Measurements

Significant Figures - Mathematical Operations

Typically you want to carry more decimal places in the your calculations and round-off the final answer to correct number of significant figures.

3 significant figures
5 significant figures

$$3.25 \times 4.6962 \boxed{= 15.3}$$

Introduction to Measurements

Significant Figures - Mathematical Operations

In addition and subtraction, the final answer should correspond to the column full of significant figures.

$$\begin{array}{r} 3.25 \\ 103.2 \\ +\ 34.662 \\ \hline 141.112 \end{array} \longrightarrow \boxed{141.1}$$

Introduction to Measurements

Significant Figures - Mathematical Operations

- When the answer to a calculation contains too many significant figures, it must be rounded off.
- One way of rounding off involves *underestimating* the answer for five of these digits (0, 1, 2, 3, and 4) and *overestimating* the answer for the other five (5, 6, 7, 8, and 9).

Introduction to Measurements

Significant Figures - Mathematical Operations

This approach to rounding off is summarized as follows:

If the digit is smaller than 5, drop this digit and leave the remaining number unchanged.

Report the following to three significant figures:

1.68497 ➔ 1.68

Introduction to Measurements

Significant Figures - Mathematical Operations

This approach to rounding off is summarized as follows:

If the digit is 5 or larger, drop this digit and add 1 to the preceding digit.

Report the following to three significant figures:

1.24712 ➔ 1.25

Introduction to Measurements

Significant Figures - Mathematical Operations

In addition and subtraction, the final answer should correspond to the column full of significant figures

$$\begin{array}{r} 3.200 \\ 0.4968 \\ +\ 24 \\ \hline 27.6968 \end{array} \longrightarrow \boxed{28}$$

Introduction to Measurements

Significant Figures - Mathematical Operations

When measurements are converted into another set of units, the number of significant figures is preserved.

$$39{,}456\ \text{ft}^2 \longrightarrow \boxed{0.90579\ \text{acres}}$$

Introduction to Measurements

Significant Figures - Mathematical Operations

- There is a nice interactive practice on significant figures on the web at:

  http://www.mrwiggersci.com/chem/Tutorials/Ch2-Interact-Pract-Sig-Figs-Blacksburg.htm

- Some other sites you might want to check out:

  http://en.wikipedia.org/wiki/Significant_figures

  http://www.chem.tamu.edu/class/fyp/mathrev/mr-sigfg.html

Introduction to Measurements

TopHat Problems

Introduction to Measurements

Repeated Measurements of a Single Quantity

- When a single quantity is measured several times or when a series of quantities is measured, random errors tend to accumulate in proportion to the square root of the number of measurements.
- This is called the ***law of compensation***:

$$E_{Total} = \pm E\sqrt{n} \qquad \pm E = \frac{E_{Total}}{\sqrt{n}}$$

Introduction to Measurements

Repeated Measurements of a Single Quantity

If a distance is measured 9 time and the estimated error in each measurement is ±0.05 ft., what is the estimate of the total error?

$$E_{Total} = \pm E\sqrt{n}$$

$$E_{Total} = \pm 0.05 ft\sqrt{9} = \pm 0.15 \text{ ft.}$$

$$\boxed{= \pm 0.2 \text{ ft.}}$$

Introduction to Measurements

Repeated Measurements of a Single Quantity

A surveying crew or party is capable of taping distances with an estimated error of ±0.02 ft. for each 100-ft. distance. Estimate total error if a distance of 2,400 ft. is measured?

$$E_{Total} = \pm E\sqrt{n}$$

$$E_{Total} = \pm 0.02 ft\sqrt{24} = \pm 0.0979..\,ft$$

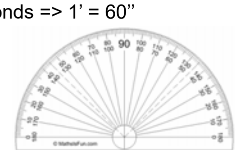
$$\boxed{= \pm 0.1 \text{ft.}}$$

Introduction to Measurements

Repeated Measurements of a Single Quantity

Surveyors typically measure a series of quantities: distance, angles, elevations, etc.

A circle is made up of 360 degrees or 360°
A degree is made up of 60 minutes => 1° = 60 '
A minute is made up of 60 seconds => 1' = 60"



Introduction to Measurements

Repeated Measurements of a Single Quantity

If an angle is measured ten time and the estimated error in each measurement is ±30 seconds, what is the estimate of the total error?

$$E_{Total} = \pm 30''\sqrt{10} = \pm 94.8683...''$$

$$= \pm 95''$$

$$\boxed{= \pm 1'\,35''}$$

Introduction to Measurements

A Series of Unrepeated Measurements

When a series of measurements are made with probable errors of ***E_1, E_2, . . . , E_n***, then the total probable error is

$$E_{Total} = \pm\sqrt{E_1^2 + E_2^2 + \ldots + E_n^2}$$

Introduction to Measurements

A Series of Unrepeated Measurements

What is the probable error for the perimeter of a square tract of land where the probable errors for each side are ±0.09 ft., ± 0.01 ft., ± 0.15 ft., and ± 0.42 ft.

$$E_{Total} = \pm\sqrt{E_1^2 + E_2^2 + \ldots + E_n^2}$$

$$= \pm\sqrt{(0.0\bar{9}\,\text{ft.})^2 + (0.0\bar{1}\,\text{ft.})^2 + (0.\bar{1}\bar{5}\,\text{ft.})^2 + (0.\bar{4}\bar{2}\,\text{ft.})^2}$$

$$= \pm\sqrt{0.008\,\text{ft}^2 + 0.0001\text{ft}^2 + 0.023\,\text{ft}^2 + 0.18\,\text{ft}^2}$$

$$= \pm\sqrt{0.21\,\text{ft}^2} = \pm 0.4583\ldots\text{ft.} \quad \boxed{= \pm 0.46\,\text{ft.}}$$

Introduction to Measurements

A Series of Unrepeated Measurements

Estimate the total error is the estimated error per 100 ft. is ±0.04 ft. and the measurements are 654.3, 987.8, and 2,241.1 ft.

$$E_1 = \pm E\sqrt{n}$$

$$E_1 = \pm 0.0\bar{4}\,\text{ft.}\sqrt{6.543} = \pm 0.\bar{1}023\ldots\text{ft.}$$

$$\boxed{\pm 0.1\text{ft.}}$$

Introduction to Measurements

A Series of Unrepeated Measurements

Estimate the total error is the estimated error per 100 ft. is ±0.04 ft. and the measurements are 654.3, 987.8, and 2,241.1 ft.

$$E_2 = \pm E\sqrt{n}$$

$$E_2 = \pm 0.0\bar{4}\,\text{ft.}\sqrt{9.878} = \pm 0.\bar{1}257\ldots\text{ft.}$$

$$\boxed{\pm 0.1\text{ft.}}$$

Introduction to Measurements

A Series of Unrepeated Measurements

Estimate the total error is the estimated error per 100 ft. is ±0.04 ft. and the measurements are 654.3, 987.8, and 2,241.1 ft.

$$E_3 = \pm E\sqrt{n}$$

$$E_3 = \pm 0.0\bar{4}\,\text{ft.}\sqrt{22.411} = \pm 0.\bar{1}894\ldots\text{ft.}$$

$$\boxed{\pm 0.2\,\text{ft.}}$$

Introduction to Measurements

A Series of Unrepeated Measurements

Estimate the total error is the estimated error per 100 ft. is ±0.04 ft. and the measurements are 654.3, 987.8, and 2,241.1 ft.

$$E_{Total} = \pm\sqrt{E_1^2 + E_2^2 + E_3^2}$$

$$= \pm\sqrt{(0.1\text{ft.})^2 + (0.1\text{ft.})^2 + (0.2\,\text{ft.})^2}$$

$$= \pm\sqrt{0.01\text{ft}^2 + 0.01\text{ft}^2 + 0.04\,\text{ft}^2}$$

$$= \pm\sqrt{0.06\,\text{ft}^2} = \pm 0.2449\ldots\text{ft.} \quad \boxed{= \pm 0.2\,\text{ft.}}$$

Introduction to Measurements

TopHat Problems

Introduction to Measurements

Any Questions?