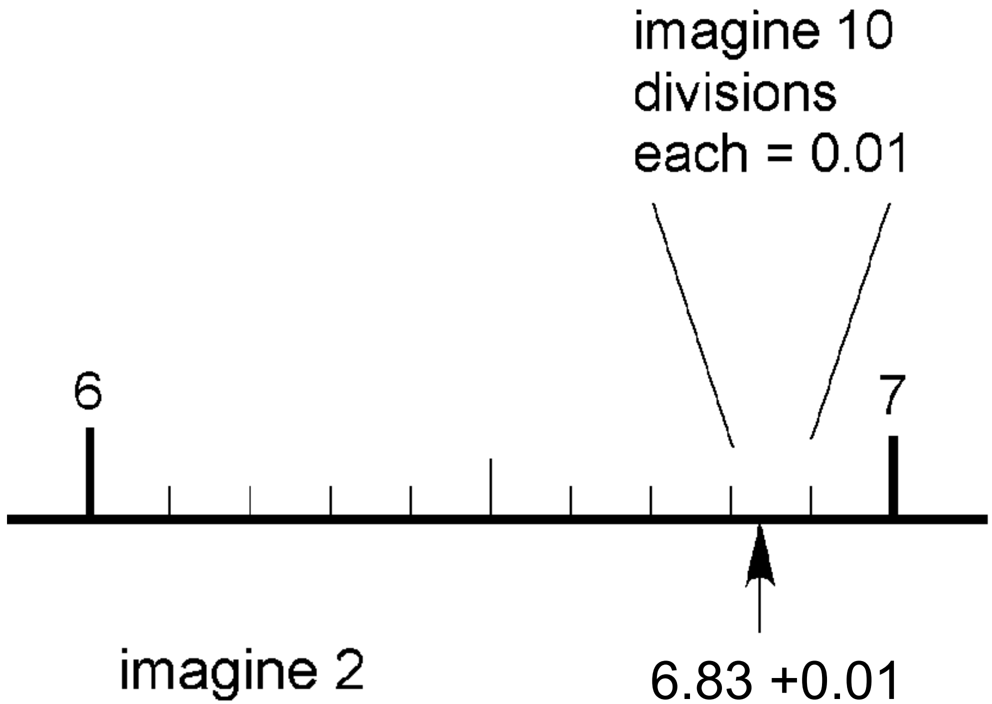
Measurement, Uncertainty and Significant Figures

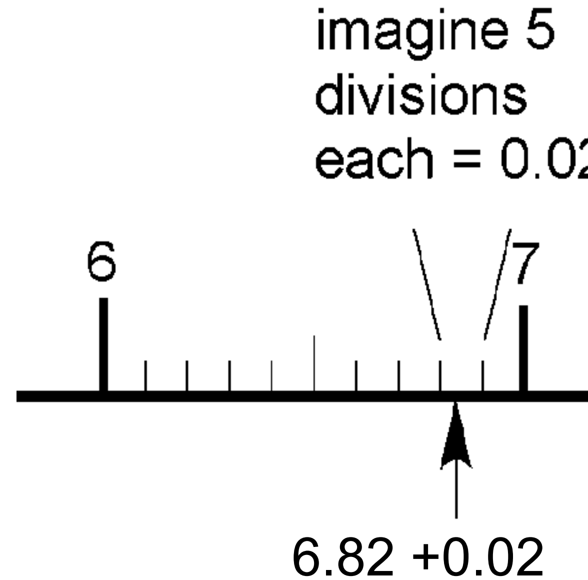
Measurement and Uncertainty

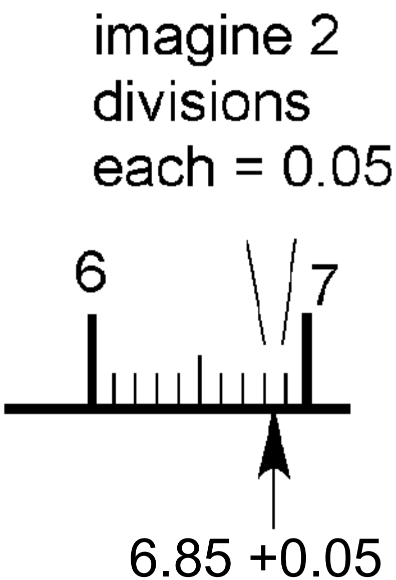
- All measurements have uncertainty because...
  - All measurement involves estimation;
  - The precision of the instruments limits our ability to estimate.

- When reporting a measured value,
  - Include all certain digits and **ONE** estimated digit.
  - All certain digits plus one estimated digit are called **significant digits** or **significant figures.**

Reading Scales



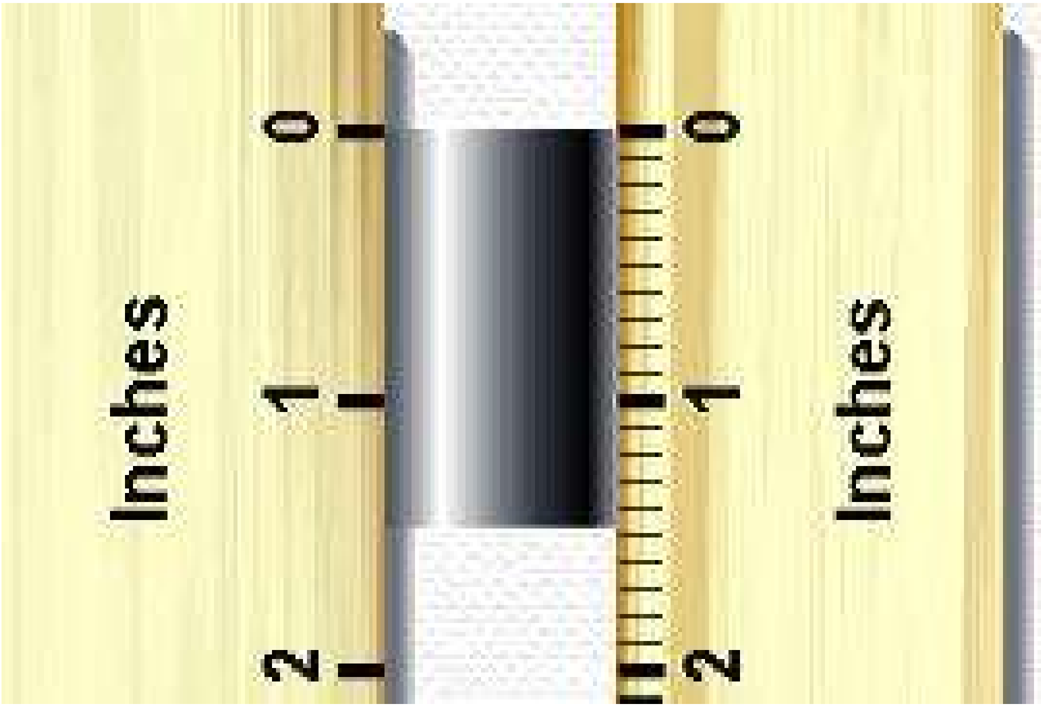




Uncertainty – Limit of precision of the reading (based on the precision of the scale and your ability to estimate the final digit).

How long is it?

(1)



Left:

1.4 in ±0.1 in

Right:

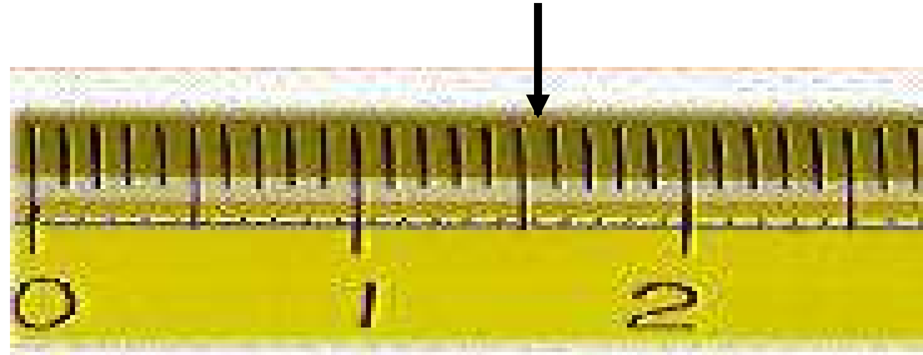
1.47 in ±0.01 in

- For each of the rulers, give the correct length measurement for the steel pellet. Indicate uncertainty by adding ±.

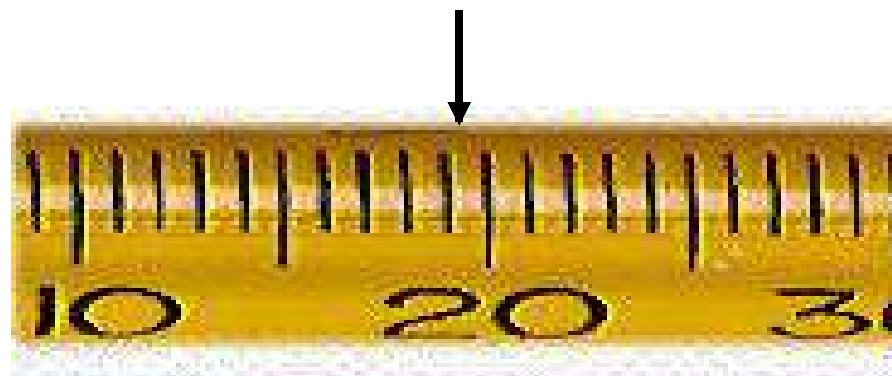
Read thermometers in °C

(2)

30.0 °C ± 0.1 °C



(3) 1.55 °C ± 0.05 °C



(4) 19.3 °C ± 0.1 °C

Reading Graduated Cylinders

- **Use the BOTTOM of the <u>meniscus</u>** (the curved interface between air and liquid) as a point of reference in making measurements of volume in a graduated cylinder, pipet, or buret.
- In reading any scale, your line of sight should be perpendicular to the scale to avoid 'parallax' reading errors.

5.73 mL $\pm$ 0.01 mL (5)

(6)

3.0 mL ± 0.1 mL

(7)

0.35 mL ± 0.01 mL

Measured Values vs. Numbers

- Science is based on measurement
  - All measurements have
    - Magnitude
    - Units
    - Uncertainty
- Mathematics is based on numbers
  - Exact numbers are obtained by
    - Definition
    - Counting

No Naked Numbers in Science!!!

Counting numbers

- **Numbers obtained by counting have no uncertainty** unless the count is very large.
  - For example, the word *'sesquipedalian'* has 14 letters. You can count them.
  - "14 letters" is not a measurement, since that would imply that we were uncertain about the count in the ones place.
  - 14 is an exact number here.

Counting numbers

- **Very large counts often do have some uncertainty** in them, because of inherent flaws in the counting process or because the count fluctuates.
  - For example, the number of human beings in Arizona would be considered a measurement because *it can not be determined exactly at the present time*.

Numbers from definitions

- **Numbers obtained from definitions have no uncertainty** unless they have been rounded off.
  - For example, a foot is exactly 12 inches. The 12 *is not uncertain at all*.
  - A foot is also exactly 30.48 centimeters from the definition of the centimeter. The 8 in 30.48 *is not uncertain at all*.
  - But if you say 1 foot is 30.5 centimeters, you've rounded off the definition and *the rounded digit is uncertain*.

Practice

- **Which of the following quantities can be determined exactly? (Select all that are NOT measurements.)**
  1. The number of light switches in the room you're sitting in now
  2. The number of ounces in one pound
  3. The number of stars in the sky
  4. The number of inches per meter
  5. The number of red blood cells in exactly one quart of blood

Significant Figures/Digits

- All reported measurements should include **ONE** and only one **estimated digit**.
- All the certain digits plus the one estimated digit are called **significant digits**.

Example: A sample of liquid has a measured volume of 23.01 mL.

1. Which digits are certain and which digit is estimated?

2,3,0 are certain; 1 is estimated

2. How many significant digits does the measurement have?

4

3. How far apart are the closest markings on the cylinder, in mL?

0.1 mL

Significant Figures Practice

Consider the following measurements. The estimated digit is in red:

Measurement Number of Significant Digits Distance Between Markings on Measuring Device

142.**7** g __ __ g

10**3** nm __ __ nm

2.9979**8** x 10^8 m __ ________ m

Significant Figures Practice

Consider the following measurements. The estimated digit is in red:

Measurement	Number of Significant Digits	Distance Between Markings on Measuring Device
142.**7** g	4	1 g
10**3** nm	3	10 nm
2.9979**8** x 10^8 m	6	0.0001 x 10^8 m

Counting Significant Digits

- Consider a sample has a measured mass of *124.1 g*.

  124.1 g can also be expressed as *0.1241 kg*

  – By expressing the measurement in different units, is the estimated digit changed? No.

  – Should these two values have the same number of sig. fig.? Yes.

  – Moving the decimal place doesn't change the fact that this measurement has ***4*** significant figures.

Counting Significant Digits

- Suppose a mass is given as 127 ng.
  - That's 0.127 μg, or 0.000127 mg, or 0.000000127 g.
  - These are all just different ways of writing the same measurement. So all have the same number of significant digits: ***3***.

Should the leading zeros be counted as sig. fig.?

Leading zeros are not counted as sig. fig. because they are place holders (holding where the decimal is).

Counting Significant Digits

- **Determine the number of significant digits in the following series of numbers:**

  0.000341 kg = 0.341 g = 341 mg

  12 µg = 0.000012 g = 0.000000012 kg

  0.01061 Mg = 10.61 kg = 10610 g

Is the last zero in 10610 g significant?

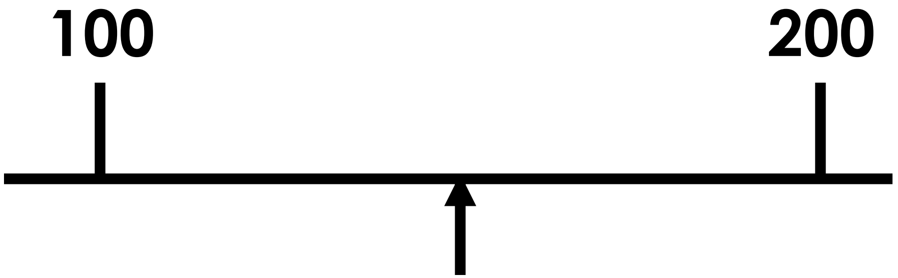
No, because 10610 should only have 4 sig. fig., same as 0.01061 Mg and 10.61 kg.

Are all trailing zeros not sig. fig.?

- 0.0150 km has _____ sig figs because the last zero on the right is the __________ digit so it is _________.

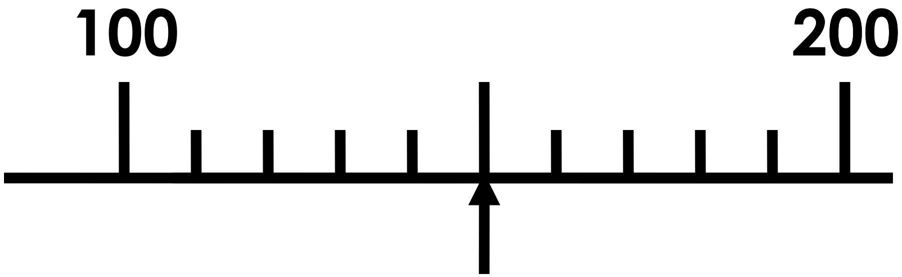
(3 sig figs; estimated; significant)

- What about 150 m?



If measured by this ruler, which digit is estimated? How many sig fig?

5 is estimated; 2 sig fig



If measured by this ruler, which digit is estimated? How many sig fig?

0 is estimated; 3 sig fig

Trailing Zeros, cont'd

- Without knowing the uncertainty of the measuring device, we are not sure if the reported value of 150 m has 2 or 3 sig. figs.
- Therefore, we can not assume the trailing zero is significant.
- We can only say it has at least 2 sig. figs.

Conclusion: if there is a decimal, trailing zeros are sig figs. If there is no decimal, trailing zeros are not assumed as sig figs.

Counting Significant Digits

0.00110 m

3 sig figs

0.3100 m

4 sig figs

32.00 mL

4sig figs

The leading zeros are not significant but the trailing zero are when there is a decimal.

321,210,000 miles

5 sig figs (at least)

84,000 mg

2 sig figs (at least)

The trailing zeros can not be assumed significant when there is no decimal.

What about zeros in the middle?

302.120 lbs

6 sig figs

Zeros *sandwiched* between two significant digits are **always significant**.

Let's summarize:
When are zeros significant?

Determine the number of significant figure for measurements in each group and state the rule for counting sig. fig. in each group.

1. 1.0001 km 2501 kg 140.009 Mg

5 SF4 SF 6 SF

Rule ______________________________________

2. 0.0003 m 0.123 mm   0.0010100 μm

1 SF3 SF5 SF

Rule ______________________________________

When are zeros significant?

1. 3.0 m 12.000 mm 1000.0 μm

2 SF 5 SF5 SF

Rule ______________________________________

2. 3000 m 1230 μm 92,900,000 miles

at least: 1 SF 3 SF3 SF

Rule ______________________________________

A better way for trailing zeros…

- To avoid the ambiguity about the trailing zeros, it is always better to record a large number in scientific notation.

For example, if 3000 m was measured to the nearest meter (last zero is estimated), the measurement should be written as

3.000×10^3 m

Scientific Notation

- When reporting very small or very large values, it is convenient to use scientific notation.

$0.0034\ L = 3.4 \times 10^{-3}\ L$

$34020.5\ g = 3.40205 \times 10^{4}\ g$

The power of 10 equals to the number of decimal place being moved.

- True scientific notation can only have one non-zero digit before the decimal.

  0.34×10^{-2} L and 34.0205 g $\times 10^{3}$ g are not true scientific notations.

Scientific Notation and Sig Figs

- When converting a measurement to scientific notation, the number of sig figs should not be changed.

Example:

0.01234 kg

4 SF 1.234×10^{-2} kg

0.012340 kg

5 SF 1.2340×10^{-2} kg

Practice

–**How many significant figures are there in each of the following measurements?**

1010.010 g

32010.0 g

0.00302040 g

0.01030 g

101000 g

100 g

Express the above measurements using scientific notation.

Answers to Practice

– **How many significant figures are there in each of the following measurements?**

SF

1010.010 g   71.010010 x 10^{3}

32010.0 g   63.20100 x 10^{4}

0.00302040 g   63.02040 x 10^{-3}

0.01030 g   41.030 x 10^{-2}

101000 g   at least 31.01 x 10^{5}

100 g   at least 11 x 10^{2}