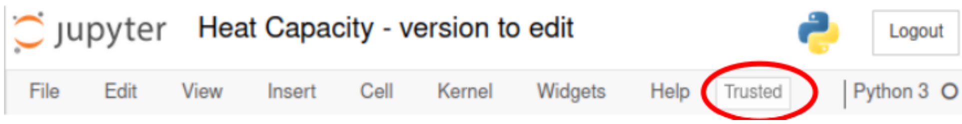
This example Jupyter notebook embedded lab is based on the "Measurements, Significant Digits and Density lab" used recently in the first semester of general chemistry at UW Oshkosh. Contributors included: Mike Foley, Jonathan Gutow, Sharon Hawi, Sheri Lense, Jennifer Mihalick, George Olsen, Greg Potratz and Yijun Tang.

You must initialize the software each time you use this notebook.

1. First, check that the notebook is "Trusted" by looking near the right of the Jupyter toolbars at the top of this notebook (see the image below).



If the notebook is not trusted you need to click on the "not trusted" button and trust the notebook. **You should only trust notebooks that come from a *trusted source*, such as the class website.**

2. The cell immediately below contains code that loads the software modules necessary for this notebook to run. It also collects some bookkeeping information that can be used for troubleshooting. **You must run this cell (click in the cell to select it and then click the "Run" button in the toolbar) each time you open the notebook or later cells may not work.**

In [1]:
```
from algebra_with_sympy import *
import JPSLUtils
JPSLUtils.record_names_timestamp()
# Initialization -- Computer: jonathan-XPS-13-7390 | User: jonathan | Ti
# Partners: Completion Example
```

Initialization -- Computer: jonathan-XPS-13-7390 | User: jonathan | Time: Mon Sep 27 20:15:28 2021

Introduction

In laboratory we make both qualitative and quantitative observations. Quantitative observations are also called measurements. Sometimes measurements only have to be approximate, but most of the time the goal is to make any laboratory measurements as precise and reproducible as possible. In order for this to happen, everybody has to take readings with the measuring devices in the same way. In this lab we will practice the proper way to use some of the measuring devices commonly encountered in a chemistry lab.

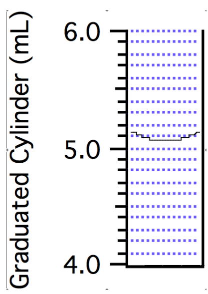
Since measurements are not perfectly reproducible (two people reading from the same device may get slightly different values or the device may work slightly differently each time it is used), we also need to indicate the scale of this uncertainty. This is done using significant figures (significant digits). In this experiment you will practice recording the proper number of significant digits for each measurement. You will also practice accounting for the impact of this uncertainty on the number of significant digits available after using an uncertain number in a calculation.

Measuring Devices

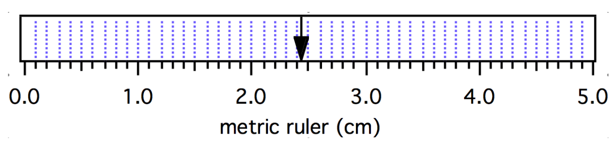
There are two main categories of measuring devices graduated and digital. Graduated devices have marks (graduations) on them like a ruler. Digital devices provide a numeric value for the measurement like a digital scale at the grocery. Properly reading a graduated device is more difficult than reading a digital device.

Reading Graduated Devices:

1. Make sure to check which way the numbers increase and where the zero mark is.
2. The experience of many laboratory workers shows that humans can reliably estimate position on a graduated scale to 1/10th of the smallest division. Thus if a graduated scale is marked off in 10ths of a unit the reading should be reported to 100ths of a unit (1/10th of the smallest division). Both of the graduated measuring devices pictured below are marked off in 10ths of a unit so the measured values are reported to the 100ths place.
3. When liquids are measured the value is read from the bottom of the meniscus (when the surface curves down) or the top of the meniscus (when the surface curves up). See the diagram for the graduated cylinder immediately below.



Reading: 5.06 mL



Reading: 2.44 cm

Reading Digital Devices:

1. If all the digits show fixed values record all digits.
2. If some of the smaller digits are fluctuating report the smallest (right most) digit that is not fluctuating or the average of the fluctuating digit just to the right of the right most nonfluctuating digit.

The smallest (right most) digit you report is uncertain. In this class we will assume that this right most digit represents a range that is ±1 around the reported value. So 2.467 m represents the range 2.466 – 2.468 m.

Significant Figures (Significant Digits)

These are the number of known digits. The right most (smallest) digit is the only reported digit that is uncertain. When reading a number you can determine the number of significant digits (sometimes called significant figures) using the following rules:

1. Zeroes (0) on the left side of a number do not count, they are just placeholders as in 0.0012. Only the "1" and "2" are significant.

2. Zeroes on the right of a number with no decimal point do not count. Thus in 1200 there are only two significant digits: "1" and "2". This means the number is really only known to ± 100. It could be 1100 or 1300 or anywhere in between.
3. In numbers with decimal points all non-zero digits and zeroes that have a non-zero digit to their left are significant. Thus 0.0012030 has five significant digits: "1", "2", "0", "3" and "0".

Scientific Notation: This is a convenient way of writing very small and very big numbers without having to write lots of zeros that are not significant. See Section 1.4 and Appendix B of *OpenStax Chemistry* for a longer discussion. Two examples from above:

- The best way to write 1200 with the proper significant digits is 1.2×10^3.
- The best way to write 0.0012030 is 1.2030×10^{-3}.

Practice Measuring

Solid metal blocks containing 1 mole of atoms

From the four samples provided on your bench each pair should choose one small sample and one large sample. Record the element each sample is made of in the table below. Use the "Table Actions" menu to edit the table. Save after making entries.

Information in Table 1 (2.5 pts)

Table 1: Measurement of solid blocks

Table Acti	Element	Length (cm)	Width (cm)	Height (cm)	Initial water volume (mL)	Final water volume (mL)	Mass (g)
Sample #1	Al	6.20	1.27	1.28	25.0	35.0	27.01
Significant Digits (#1)	XXXX	3	3	3	3	3	4
Decimals (#1)	XXXX	2	2	2	1	1	2
Sample #2	Fe	4.45	1.26	1.28	20.5	27.8	55.85
Significant Digits (#2)	XXXX	3	3	3	3	3	4
Decimals (#2)	XXXX	2	2	2	1	1	2

1. Using a metric ruler measure the length, width and height of each metal block. Record the measurements with the proper number of digits in the table above (Table 1).
2. Obtain a 50 mL plastic graduated cylinder. Fill it about ½ full with water. Carefully record this initial volume in the table above.
3. Tipping the cylinder slightly, gently slide your first metal block into the cylinder so that no water drops splash out or get stuck above the water on the sides. Carefully record this final volume in your table.
4. Remove your metal block from the graduated cylinder and dry the block completely.

5. Repeat the measurements using the graduated cylinder with your second block. Dry this block completely when done.
6. Tare your bench top balance (it should read zero), then place each block on the balance and record the mass of the block in the table.
7. This is a good time to make sure your work is saved. Save the most recent changes to this notebook by clicking on the save icon (🖫) in the Jupyter menu bar. You should do this regularly while doing the lab.
8. After verifying with your instructor that you recorded the measurements properly, note the number of significant figures and decimal places for each of the measured values. Save again (🖫).

Liquid water near room temperature

Use the table below to record your measurements on water.

Information in table 2 (2 pts)

Table 2: Measurements of water

Table Actic	Volume in Grad. Cyl. (mL)	Mass in Cyl. (g)	Buret Initial (mL)	Buret Final (mL)	Mass water delivered (g)
Measurement	9.72	9.70	15.05	27.32	12.23
Significant Digits	3	3	4	4	4
Decimals	2	2	2	2	2

1. Find your 10 mL graduated cylinder. Make sure it is clean and dry. Place it on your bench top balance and tare it. Remove it from the balance. The balance should not be used for anything else until you complete your measurement in step 3.
2. Put between 9 and 10 mL of deionized water in your 10 mL graduated cylinder. Carefully record the actual volume in your table.
3. Gently place the graduated cylinder with water back on the balance. Record the mass of the water contained in the graduated cylinder in the table above (Table 2).
4. Find a 50 mL or larger beaker in your drawer. Fill your buret about 2/3 full with deionized water as demonstrated by your instructor. Use the beaker to collect waste water used to run the air bubble out of the tip.
5. Find your smallest beaker (30 mL). Make sure it is clean and dry. Tare it on your bench top balance.
6. Carefully record the initial reading of your buret in your table. Notice that the numbers increase downwards (half-way between 25 and 26 is 25.5 not 26.5).
7. Place the small tared beaker under your buret and using the graduations on the buret as a guide deliver 10 – 15 mL of water into the beaker (do this based on the buret readings). Carefully record the final reading of the buret in your table.
8. Gently transfer the beaker with water back onto the balance. Record the mass of the water contained in the beaker in your table.

9. After verifying with your instructor that you recorded the measurements properly, note the number of significant figures and decimal places for each of the measured values.

Calculations

Significant Digits in Calculations

As you verified in the pre-lab calculations, numbers that represent a range of values (have uncertainty) yield calculated results that also represent a range of values. The rules for handling significant digits in calculations ensure that the right-most digit kept in the result of a calculation is the only uncertain digit, with an uncertainty of about ±1 in the last digit. You can verify the rules by calculating the range of values produced in a calculation with uncertain numbers.

Addition and Subtraction

1. Line up the decimal places of the numbers.
2. Do the addition or subtraction.
3. Round to the least number of decimals, while rounding properly. Note: rounding up for a dropped digit of 5 is OK since that is what calculators do. Technically you should round odd digits up and leave even digits unchanged if the dropped digit is 5.

Example:	1.2345
+	1.230
	2.465 (calculator rounding)

Multiplication and Division

1. Perform the multiplication or division.
2. Count the number of significant figures in each of the factors.
3. Round the calculated result to the same number of significant figures as the factor with the least number of significant figures.

Example: (100.0)(63.7) = 6370 or better 6.37×10^3.

Multistep Calculations that Combine Addition or Subtraction with Multiplication or Division

1. At the end of each step evaluate the number of significant figures and decimal places the calculation yields. Record this in some way.
2. Keep at least one digit beyond the last significant figure to use in the next step of the calculation. This avoids rounding errors.
3. Use the recorded significant figures and decimal places from the previous step to evaluate the number of significant figures yielded by the most recent step.

Example: (1.2345 + 1.230)(2000.0) = (2.464|5)(2000.0) = 4929.0000 (w/SF 4.929×10^3)

but because the addition only gave four significant figures (indicated by the vertical line between the 4 and 5) the final answer can only have four significant figures. The correct answer is 4929. or better 4.929×10^3. If you had calculated (2.465)(2000.0) = 4.930×10^3 you would be at the upper limit of the range for the correct answer, but still OK.

Recording calculations in this notebook (using the computer as a calculator with super-powers)

We will only use four of the "super-powers" in this notebook: the ability to copy numbers from the tables you recorded them in; the ability to record what calculations were done and label them; the ability to do calculations with units in the equations; the fancy output of results (nearly typeset quality mathematical expressions.

Commands telling the computer what to do are entered into grey cells called `code` cells. You may have noticed some locked ones that you cannot edit used to initialize this notebook. You can make two basic kinds of entries in `code` cells:

- *Comments* are any line that start with a `#` symbol. Each new comment line must begin with a `#`. The computer ignores comments. You will use comments to label your calculations.
- *Commands* are anything that is not a comment. The computer will try to run the operations specified by the command and return the result to you. Just like your calculator it will return an error if you make a typo. Initially we will limit ourselves to calculator like operations.

You enter calculations in the same format you would into your calculator with two exceptions:

- On most calculators `^` is used to indicate raising to a power. The computer uses `**` instead.
- On most calculators scientific notation is indicated by an `EE` key. For example, 1.2 EE 5 is understood by the calculator as 1.2×10^5, which is often displayed as `1.2e5`. On the computer you just enter `1.2e5` directly.

The cells below demonstrate some of this. Select a cell and click on the "Run" button near the top of the page to see how they work. You can edit the cells to try other things. Only the result from the computation on the last line of a cell will be displayed.

In [8]:
```
# Example showing addition, division and scientific notation
2e3 + 200.3/3
```
Out[8]:
```
2066.766666666667
```

In [9]:
```
# Multiplication and powers
2000*(4**2)
```
Out[9]:
```
32000
```

Notice that just like your calculator, the computer does not keep track of significant digits.

Calculations showing units

The computer understands how to do math with symbols as well as numbers. Thus we can include unit symbols in our calculations. You still have to worry about the conversions.

To include units we have to tell the computer what symbols we are going to use and to treat the symbols as if they are positive real numbers. To define the units of cm (centimeters) and m (meters) we would use the command `var('cm m', positive=True)` . Notice that each unit is separated by a space in this command. In a mathematical expression units multiply the number they are associated with. Try the examples below.

In [10]:
```
var('cm m', positive=True) # units of centimeters and meters
# You will notice that the computer understands that you cannot
# add different units together.
5.00*cm + 1.2*m
```

Out[10]: $5.0cm + 1.2m$

In [11]:
```
# However, if you properly convert the units it can do the addition.
5.00*cm*(1*m/(100*cm))+1.2*m
```

Out[11]: $1.25m$

In [12]:
```
# Alternatively
5.00*cm + 1.2*m*(100*cm/m)
```

Out[12]: $125.0cm$

Notice that just like your calculator, the computer does not keep track of significant digits.

Calculations with your data

Write out your calculations directly in this notebook.

- To avoid typing errors copy the numbers from the tables you recorded them in using the normal copy and paste keys.
- Make sure that each calculation is labeled.
- Include units.
- Keep track of significant figures.
- Record the results, with the correct number of digits, in the tables at the end.

Calculations for the metal blocks

1. (1 pt) Calculate the volume of the metal blocks based on the ruler measurements. `V = l*w*h` , where V = volume, l = length, w = width and h = height. Use the code cell immediately below. **Include Units**. If you ran the example cells since opening this notebook the units of `cm` and `m` are already defined. You recorded the dimensions you need in Table 1

In [13]:
```
# Use this cell to calculate the volume of sample 1.
6.20*cm*1.27*cm*1.28*cm
```

Out[13]: $10.07872cm^3$

In [14]:
```
# Use this cell to calculate the volume of sample 2.
4.45*cm*1.26*cm*1.28*cm
```

Out[14]: $7.17696cm^3$

- Record these volumes with correct significant digits in [Table 3](#).

- 2. (0.5 pts) Calculate the density of the metal blocks based on your mass measurement and the volume calculated from the ruler measurements. `D = m/V` , where D = density, m = mass and V = volume. You will have to define the `g` symbol for the units of grams. Use comments to indicate which block you are doing the calculation on. Note that `1 cm**3 = 1 mL` .

In [15]:
```
var('g',positive=True)
# density block 1 Al
27.01*g/(10.1*cm**3)
```

Out[15]: $\frac{2.67425742574257g}{cm^3}$

In [16]:
```
# density of block 2 Fe
55.85*g/(7.18*cm**3)
```

Out[16]: $\frac{7.77855153203343g}{cm^3}$

- Record these densities with correct significant digits in [Table 3](#).

- 3. (0.5 pts) Calculate the volume of the blocks measured by water displacement (difference between the final and initial volumes). *You will need to define the unit of mL*.

In [17]:
```
var('mL', positive=True)
# displacement volume block 1 Al
35.0*mL - 25.0*mL
```

Out[17]: $10.0mL$

In [19]:
```
# displacement volume block 2 Fe
27.8*mL - 20.5*mL
```

Out[19]: $7.3mL$

Record these volumes with correct significant digits in Table 3.

4. (0.5 pts) Calculate the density of the metal blocks using the volume measured by water displacement. Note that `1 cm**3 = 1 mL`.

In [20]:
```
# displacement density block 1 Al
27.01*g/(10.0*cm**3)
```

Out[20]: $\frac{2.701g}{cm^3}$

In [21]:
```
# displacement density block 2 Fe
55.85*g/(7.3*cm**3)
```

Out[21]: $\frac{7.65068493150685g}{cm^3}$

Record these densities with correct significant digits in Table 3.

Calculations for water (1 pt)

1. Calculate the density of the water using your graduated cylinder measurements. If you need additional *code cells* you can add them using the "Insert" menu. Your data is in Table 2.

In [22]:
```
# Water density volume from graduated cylinder
9.70*g/(9.72*mL)
```

Out[22]: $\frac{0.997942386831276g}{mL}$

2. Calculate the volume of water delivered from the buret.

In [23]:
```
# delivered from buret
27.32*mL - 15.05*mL
```

Out[23]: $12.27mL$

3. Calculate the density of the water using your buret measurements.

In [24]:
```
# water density from buret
12.23*g/(12.27*mL)
```

Out[24]: $\frac{0.996740016299919g}{mL}$

- Record the calculated volumes and densities of water with proper significant figures in Table 4 (below).
- Make sure to transfer data from Table 1 and Table 2 into the appropriate cells in Tables 3 and 4.

Results summary

Information in table 3 (2 pts)

Table 3: Results of calculations for solid blocks.

Table Acti	Element	Mass (g)	V using ruler (mL)	V using grad. cyl. (mL)	D using ruler (g/mL)	D using grad. cyl. (g/mL)
Sample 1	Al	27.01	10.1	10.0	2.67	2.70
Sample 2	Fe	55.85	7.18	7.3	7.78	7.7

Information in table 4 (1 pt)

Table 4: Density of water calculations.

Table Actions	Mass of water (g)	V of water (mL)	Density (g/mL)
Using grad. cyl.	9.70	9.72	0.998
Using buret	12.23	12.27	0.9967

Post lab questions

1. (1 pt) For the metal blocks which measurement methode gave the moste precise value for the density? Explain your reasoning.

The most precise is the least uncertain (the most decimal places). For the Fe (smaller) block this is the measurement using the ruler. For the Al (larger) block the volume has similar precision.

2. (1 pt) Do you think any of your measurements of the metal block were erroneous? If so,

which ones and what do you think the error was?

The densities determined via displacement and measurements are consistent for each sample. Thus it is unlikely that there was an erroneous measurement.

3. (1 pt) Which method produced the most precise density for water? Explain your reasoning.

Measuring the volume using the buret gave the most precise density for water. The calculated density had the most decimals and significant figures.

4. (1 pt) Compare your water densities with the literature value. Which method produced the most accurate density for water?

At 21 C the density for water according to the USGS is 0.99802 g/mL. The density measurement using the graduated cylinder was closest to this and thus the most accurate, despite being less precise than the buret method. This suggests an error was made reading the buret.

Prepare this document to turn in

To convert this notebook to a lab report to turn in you need to hide the majority of the instruction and informational cells and make a .pdf document.

1. Your instructor has already chosen the cells they want hidden. To hide them select "Hide Cells" from the JPSL Tools menu.
2. To make a pdf you must use the Browser's print capabilities. In most user interfaces this option is hidden in the little collapsed menu at the upper right of the browser window. On a macintosh it can be found in the file menu. Select "Print" and then set the destination to "Save to PDF". Make sure to save the file in a location you can find (your "Desktop" or maybe "Documents" directory). **Do Not use the options in the Jupyter "File" menu.**
3. It is a good idea to open the created document to make sure it is OK.
4. When everything is OK, save this document one more time and then close it using the "Close and Halt" option in the Jupyter "File" menu.
5. Turn in both the pdf and ipynb version of this notebook.

NB: Currently, the print to pdf output from Chrome is a little closer to what is displayed on the webpage. Unfortunately, which browser renders the best pdfs changes quite rapidly.