Matter, Measurement, and Moles

Does any one of the following numbers express greater confidence in the accuracy of the measurement, or are they equivalent? 500.0 inches, 5 x 10^2 inches, 0.500 x 10^3 inches

"500.0" includes four significant figures, indicating that the person taking this measurement was confident about the first three digits while acknowledging some uncertainty in the fourth. This conveys more confidence in the accuracy of the measurement than any of the other three.

Suppose that I want to practice my skills of volummetric taxonomy -- identifying animals based on how much space they take up. I go out into the field and collect a number of mammals, identify them by conventional means, and measure their volumes. I find that the average volume of a squirrel is 1.5 L +/- 0.8 L, and the average volume of a groundhog is 4 L +/- 2 L. Now I want to test my ability to identify critters based solely on volume. I catch a small mammal and measure its volume at 2.0 L. Based on these data, can I conclusively identify it as either a squirrel or a groundhog? Why or why not?

The natural variability in the sizes of my target organisms (or my sloppy measurement skills) have led to such large confidence intervals that I cannot confidently classify my two-liter mammal -- it could equally be a squirrel or a groundhog.

Suppose a pharmacist asks her 4 assistants to each weigh out samples of a granulated medicine prior to packaging it in time-release capsules. Her assistants record the four sample masses as:

300.12 grams 25.348 grams 4220 grams 5.339 grams

Can the pharmacist confidently report the total weight as 4550.8 grams? Be sure to justify your answer.

No -- based on the significant figures of the individual measurements, there is uncertainty in the tens place (4220 has three sig.fig.s), so the proper way to report the total would be 4550 g.

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For each of the following situations, please answer the question in one or a few words, or indicate that there is INSUFFICIENT INFORMATION for you to be sure of the answer. Although you need not do so for full credit, if you would like to ensure that I understand the reasoning behind your answer, you may justify your choice in one short sentence. (3 points each)

a) True or False? The nucleus of atom contains protons, neutrons, and electrons. It constitutes most of the atom's mass, but only a small portion of its volume.

False. The nucleus does NOT contain electrons.

b) What is the formula for chromium (III) carbonate? [I want you to practice these, but will NOT ask you to have mastered your polyatomic ions for the first test.]

$Cr_2(CO_3)_3$

d) Imagine that I am in the market for a small, nuclear-powered boot warmer to keep my toes toasty on cold winter mornings. I find a model that is advertised to have a normal operating temperature of 106 ºF (+/- 9 ºF), which sounds about right. The product literature boasts about the safety features of this model, which include a warning buzzer that will sound if the nuclear reactor begins to overheat, something it says occurs when the operating temperature reaches 135 ºF (+/- 20 ºF). Based solely on this information, can you think of any reasons why I should not keep this model on my short list?

The "normal" range of operating temperatures for this device overlaps with the range of "dangerous" temperatures. That sounds like a bad thing to me, as it either means that "normal" could be dangerous, or that there would be lots of false alarms.

e) Which (one or more) of the following elements would you expect to form an cation with a +2 charge? Chlorine (Cl), sulfur (S), phosphorus (P), silicon (Si), aluminum (Al), magnesium (Mg), or sodium (Na)?

Mg^{+2}

g) Which is larger: a liter or a deciliter?

*A **liter** is 10 times as large as a deciliter.*

h) One of my cats is named Picchu. Suppose that I take her temperature once a day for a week, and record these readings: 101 ºF, 100.3 ºF, 102.2 ºF, 100.7 ºF, 102.9 ºF, 101.6 ºF, and 100.8 ºF. The average of these seven values is 101.357143, the standard deviation is 0.92530561, and the 95% confidence interval is 0.68546298. If I want to report Picchu's typical body temperature over this period in such a way that it conveys my true confidence in the measurements, **how many significant figures should my answer contain**? Please justify your answer in one short sentence.

*There are at least two ways to come at this question. The simplest is to observe that the number with the fewest significant figures, 101, has three significant digits. This value will therefore constrain the number of digits that can be considered significant, or reliable, in subsequent calculations. The average temperature, therefore, should only be reported with **three digits**.*

Bob has a family history of adult-onset diabetes. He recognizes that a critical behavioral change he can make to reduce his risk of diabetes is staying fit and keeping getting overweight. After experimenting with a few diets, he decides that the only way to maintain his target weight over the long term is to carefully monitor his weight, so he starts recording his weight after he gets out of the shower each morning. Here are some of his measurements (all in pounds):
199.6
202.2
203.4
203.6
205.8
202.4
203.2
200.8

For this set of measurements, the average weight is 202.625 lbs
For this set of measurements, the standard deviation is 1.87749834

a) Please rewrite the average and standard deviation to convey the true level of precision in these data

average weight = 202 +/- 2 lbs
(I'd also accept 202.6 +/- 1.9 lbs)

b) Unfortunately, Bob's roommate tries to use Bob's scale to determine the mass of his motorcycle, and breaks the scale. Bob goes shopping, and finds that he can get a scale that measures only to the one's place (e.g., 202 pounds) for $15, but a scale with accuracy to the tenths of a pound (e.g., 202.3 pounds) will set him back $45. Given the data above, would you recommend that Bob get the more expensive scale? Please justify your choice briefly.

There's really no point in buying the pricey scale because Bob's weight fluctuates by more than a pound from day to day, so the extra accuracy is really wasted on this low-precision measurement.

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8. A student generates a set of data relating the masses of a collection of unknown solid compounds and the volumes of gas they produce when combusted.

(a) The student plots the data and calculates the slope of the best fit line for the data (mass in grams versus volume in liters). EXCEL tells her that the slope = 2.4769439 and the 95% confidence interval on the slope is 0.9446618. Please report the slope and 95% C.I. to the correct number of significant figures and with the correct units. (5 points)

(b) If you wanted to report the volumes in milliliters rather than liters, what would the new slope be? (2 points)

a) slope = 2.5 +/-0.9 g/L
b) 2.5 g/L x 1L/1000 mL = 2.5×10^{-3} g/mL

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1. True or false? 365 grams is equal to 3.65×10^{5} kilograms.

FALSE -- 365 grams = 3.65×10^{-1} kg

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On the assessment quiz in lab two, you calculated the density of a 1 in^3 chunk of aluminum to be 2.7 g/cm^3. Suppose that you have a sample of liquid methylene iodide (CH_2I_2) whose mass is 1.596 kg and whose volume is 479.82 cm^3. Will the cube of aluminum sink or float on this liquid sample?

$$\frac{1.596\ kg}{479.82\ cm^3} \times \frac{1000\ g}{kg} \times \frac{1596\ g}{479.82\ cm^3} = 3.326\ g/cm^3$$

This is greater than the density of aluminum. The aluminum will float.

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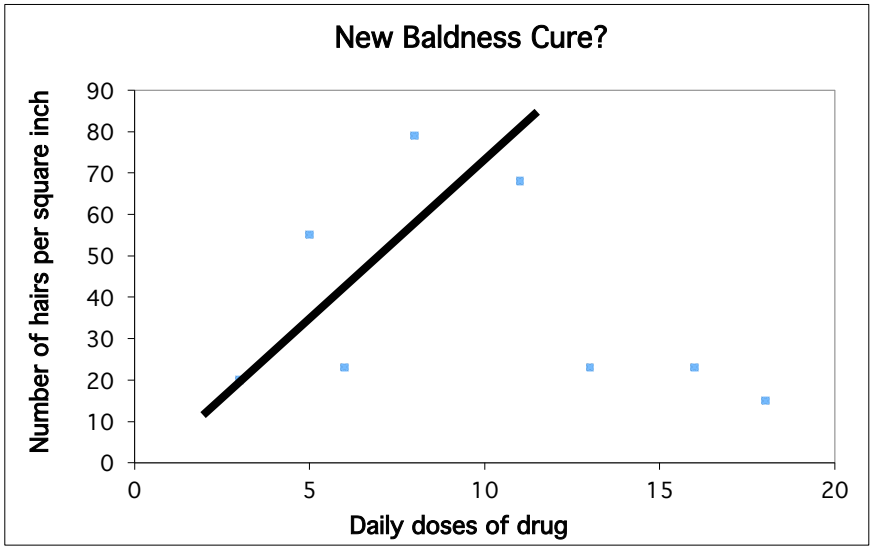
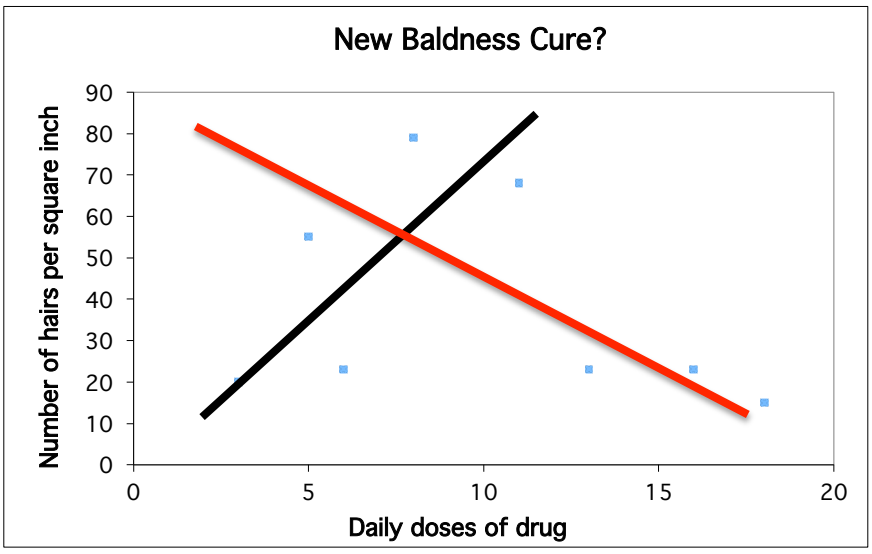
4. The following graph shows the results of a (hypothetical) test of a new drug to be used in treatment of male pattern baldness. The line was drawn by the investigator to indicate the trend he perceived in the data -- that higher doses of the drug led to increased hair growth. If you saw these data, **would you recommend that your prematurely-balding friends take this drug?** Why or why not?



NO, I'm not impressed by these data -- one could just as easily draw a down-ward trending "best fit" line. There is too much scatter in the data to make any inference about a relationship between the two variables.



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Suppose a student creates a number of solutions containing variable concentrations of copper ions and then measures the absorbance of each solution on a spectrophotometer. The data are presented below.

concentration of copper ions (M)	absorbance
0.007920	0.533
0.01122	0.755
0.01320	0.888

What is the ***approximate*** concentration of copper ions in an unknown solution that gives an absorbance reading of 0.567? One-digit accuracy is sufficient for your estimate. (6 points)

An absorbance reading of 0.567 is a little larger than the absorbance of the first known solution, but less than that of the second. It should therefore have a concentration of about 0.009 M.

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5. Many compact fluorescent lightbulbs have an operating lifespan of 7500 hours. Over this period, using a compact fluorescent bulb rather than a conventional incandescent one requires a considerably lower amount of electricity -- enough to save 600 pounds of coal for someone whose electricity comes from a coal-fired powerplant (as does most of the electricity in Ohio). If you have a desklamp that you leave on for 4 hours per day, **how many pounds of coal would you save by using a compact fluorescent bulb in your lamp for one full year?**

365 days x 4 hrs/day x 1 bulb/7500 hrs x 600 pounds coal/bulb = **116.8 pounds coal saved**
(this number should really only be reported to one digit to reflect the inaccuracy of the number "600")

6. A solid will float on a liquid of higher density than itself. For example, a bar of iron ($d = 7.86\ g/cm^3$) would sink in water ($d = 1.00\ g/cm^3$) but float on mercury ($d = 13.55\ g/cm^3$). Consider a cube of aluminum that's 1.00 inches on each side and weighs 1.56 ounces. **Would you expect it to float on glycerol ($d = 1.26\ g/cm^3$)?**

1.56 oz/1 in^3 x 1 $in^3/2.54^3\ cm^3$ x 1 pound/16 oz x 454 grams/1 lb = **2.7 g/cm^3**
This would sink in glycerol.

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5. It's crunch time. You've been spending too many late nights in the library and strangely you find that to wake up in the morning you need some of this: $C_8H_{10}N_4O_2$. (No, it's nothing you'd go to jail for synthesizing in lab, just caffeine.)
a) what is its molar mass?
b) how many moles of nitrogen (monatomic) are present in 13.6 moles of caffeine?
c) how many moles of nitrogen are present in 13.6 grams of caffeine?
d) what percent of caffeine is oxygen (by mass)? That is, how many grams of oxygen are there in 100 grams of caffeine?

a: 194 g/mol

b: 54.4 mol
c: 0.280 mol
d: 16.5%;

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Write a balanced chemical equation corresponding to the following verbal description:

One of the most economically important industrial chemical reactions is the production of gaseous ammonia (also known as nitrogen trihydride) from hydrogen gas and nitrogen gas.

$3\ H_{2\ (g)} + N_{2\ (g)} \rightarrow\ 2\ NH_{3\ (g)}$

2. *Moles and masses.*

a) Suppose that I want to calculate the number of atoms of aluminum in a block of Al_2O_3 that has dimensions of 1.0 x 1.0 x 0.91 inches and a density of 3.97 grams per milliliter.

For starters, what is the **volume of this cube in milliliters**? (2 points)

1.0 in x 1.0 in x 0.91 in = 0.91 in^3 Al_2O_3 0.91 in^3 x (2.54 cm/in)^3 x 1 mL/cm^3 = 15 mL Al_2O_3

And what is its **mass in grams**? (3 points)

15 mL Al_2O_3 x 3.97 g Al_2O_3/mL Al_2O_3 = 59 g Al_2O_3

So **how many aluminum atoms** are present? (6 points)

$$59\ g\ Al_2O_3 \times \frac{1\ mol\ Al_2O_3\ molecules}{101.96\ g\ Al_2O_3} \times \frac{2\ mol\ Al\ atoms}{1\ mol\ Al_2O_3\ molecules} \times \frac{6.02 \times 10^{23}\ Al\ atoms}{1\ mol\ Al\ atoms}$$

$= 7.0 \times 10^{23}$ *Al atoms*

And what is the **name of this compound**? (3 points)

Aluminum oxide (Aluminum (III) oxide also accepted)

Do you expect that it is an **ionic or a molecular** (covalent) compound? (3 points)

*This compound consists of a metal and a non-metal, so it is expected to be **ionic**.*

3. *Atomic structure*. Please fill in ***all*** the blank squares to complete this table detailing the composition of several atoms and ions. (9 points)

atomic symbol	$^{11}_{5}B$	$^{125}_{53}I^{-}$	$^{108}_{47}Ag^{+}$
protons	5	53	***47***
neutrons	6	72	61
electrons	***5***	54	46
net charge	0	***-1***	+1
mass number	***11***	***125***	***108***

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3. Please describe what you'd expect to find in the **nucleus of an atom of Helium-5.**

Helium five has a mass number of five, but it's helium so it has 2 protons. Therefore I expect to find
2 protons
3 neutrons

Match each description with ***one or more*** of the following elements that fits the description. Each description may have more than one correct answer. (14 points)

Bromine(Br) ***Silicon(Si)*** ***Barium(Ba)*** ***Xenon(Xe)*** ***Aluminum(Al)***

_____ Has many chemical properties like those of iodine.
_____ Is a metalloid
_____ Forms a cation with a +2 charge
_____ Its elemental form is a diatomic molecule
_____ Forms a cation with a +3 charge
_____ Readily conducts electric current and heat
_____ Primarily forms molecular compounds

Br, Si, Ba, Br, Al, Al and Ba, Si

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5. Fill in the blanks for the following table of different atoms and ions: (15 points)

symbol				$^{19}_{9}F^{-}$
protons	6	53		
neutrons	8	74	8	
electrons		54	10	
net charge	0		-2	-1

Symbol	**$^{14}_{6}C$**	**$^{127}_{53}I^{-1}$**	**$^{16}_{8}O^{-2}$**	**$^{19}_{9}F^{-}$**
Protons	**6**	**53**	**8**	**9**
Neutrons	**8**	**74**	**8**	**10**
Electrons	**6**	**54**	**10**	**10**
Net charge	**0**	**-1**	**-2**	**-1**

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(a) Give the name or chemical formula as appropriate for each of the following: (6 pts)

phosphorous triiodide _____

iron(III) sulfide _____

N_2O_3 _____

(b) Are the following compounds ionic or molecular? (6 points)

H_2S _____

$AlCl_3$ _____

CO_2 _____

a) PI_3, Fe_2S_3, dinitrogen trioxide
b) molecular, ionic, molecular

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2. ***Electrons in atoms***.

a) Please give the **complete electron configuration** for a neutral atom of molybdenum in its ground state.

$1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^{10} 4p^6 5s^2 4d^4$

b) Please show an **orbital** (box) **diagram of the *valence* electrons** of a neutral sulfur atom.

S is [Ne] $3s^2 3p^4$. There are two S electrons in one orbital, and four P electrons in three orbitals.

c) What would you predict to be the **most stable ion of bismuth, based on its electronic configuration**? Please explain your answer briefly.

Bi^{3+}; Bismuth is [Xe] $6s^2 5d^{10} 4f^{14} 6p^3$, and can stably lose the 3 6p electrons

3. ***Light and electrons***. (3 points each)

The atomic emission spectrum of arsenic includes a pale blue line at 489 nm.

a) Please **calculate the energy of a single photon with this wavelength**.

4.07×10^{-19} J

b) Is it possible that this emission line corresponds to the energy involved in an electron moving from a **4d orbital to a 5d orbital**? Please justify your answer in one short sentence.

No, that's not possible. An electron moving from a 4d to a 5d orbital is moving UP in energy; this would require *absorbance* of light, not *emission*.

The atomic spectrum of bromine includes an orange line at 615nm
What is the energy of a single proton with this wavelength?
3.23×10^{-19}

Is it possible that the emission line corresponds to the energy involved in an electron moving from the 6s orbital to the 4s orbital?
Yes, the electron is moving to a lower energy level and will therefore give off light.

Write out the complete electron configurations for the following

Mn
1s2 2s2 2p6 3s2 3p6 4s2 3d5

Ag^{+}
1s2 2s2 2p6 3s2 3p6 4s2 3d10 4p6 5s0 4d10

1) Which atom has a larger atomic radius? Ca or Sr Which exhibits more of a metallic character? Which has a larger first ionization energy?

Sr has the larger atomic radius because it contains more shells of electrons. It's valence electrons have a principal quantum number (n) of 5, whereas Ca valence n=4. This means there is a wider radius for the electrons to be found around the atom, along with more electrons.

Sr will exhibit more metallic character because it's below Ca in the column 2A on the periodic table. Metallic character increases top to bottom of colmuns, and decreases left to right across rows.

Ca will have a larger first ionization energy. Ca valence electrons are closer to the nucleus and held more tightly than the valence electrons of Sr. The Ca will more readily give up an electron. The ionization energy decreases top to bottom in a column and increases left to right in rows. These trends of course are general and there are exceptions such as Ga having lower 1st ionization energy then Ca.

2)Which form of visible light would have less energy? Red or Blue?
Between these two colors, which would symbolize the emission of light from n=4 to n=2 and n=4 to n=1?

Red would have less energy because it has a longer wavelength and exhibits less frequency which results in lower energy. The less frequency there is, the less energy that can be emitted from the longer wavelengths.

n=4 to n=2 would be red light. Light is emitted when excited electrons fall back to lower orbitals releasing energy. Falling back from n=4 to n=1, which would be blue light, is a larger fall, therefore releasing more energy and emitting a different form of light. The blue light is involved with more energy because is has a shorter wavelength and has a higher frequency.

3) What ion would the F atom like to form?

F would like to form a F^{-1} atom because by gaining an electron it would achieve a more stable electronic configuration that resembles and is isoelectronic with Neon. F has a negative electron affinity, which means it has a high attraction for electrons and actually releases energy when gaining the electron rather than requiring energy to add the electron. The F atom holds electrons tightly and is looking for that extra electron to fill its s and p orbitals to achieve the desirable octet of electrons. The F negative ion would be larger than Ne because Ne has more protons and a higher nuclear charge making its electrons more closely bound to its nucleus than the F negative ion.