Measurement and sig figs

Unit 01, Chemistry Themed

Scientist's duty: Report all he/she knows… No more, no less

- Scientific experiments give results – measurements are taken
- Instruments are not and cannot be perfect
- Expensive measuring devices give better results (numbers)
- Say your scale says something weighs 3.11 grams
  - Reporting 3 grams fails to communicate ALL you know
  - Reporting it weights 3.110 grams is equally irresponsible - your scale is only "good enough" to find the weight to the nearest "thousandths" of a gram
- Part of being a Scientist, is understanding the integrity of any data you report

Scientist’s duty: Manipulate data in a meaningful, responsible way

- If a scientist wants to find density it requires
  - Measuring mass
  - Measuring volume
  - Taking measurements and THEN Doing subtraction and division
  - Do necessary conversions to units the communicate results to reader
- The scientist must still report all he/she knows
- Calculations and conversions don’t make the original measurements any better or worse

Making measurements – Metric system

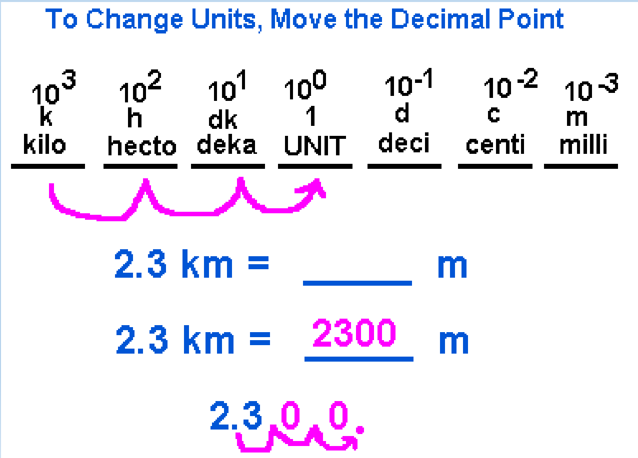
- We say it's 85° out today, or he's six feel tall, or the car was going 45 mph, or I put 12 gallons of gas in the car – these are common units
- Scientists use the metric system – not the units we commonly use in the US
- Metric units consist of a prefix and a base
- Examples:
  - mL is milliliter and is a volume measurement
    - Milli is the prefix and means thousandths
    - Liter is a base unit whose volume is a little more than a quart
  - Cm is centimeter and is a length measurement
    - Centi is a prefix meaning hundredths
    - Meter is a base unit whose length is a little more than a yard

Making measurements – Metric system

- Bases you need to know
  - Gram (g), mass – 1 g is about the mass of a paper clip
  - Liter (l), volume (commonly fluid volume) – about a quart
  - Cubic meters (m^3), volume (commonly for volumes of solids)
  - Meter (m), length – about a yard
- Prefixes you need to memorize (below: name (abbreviation, value))
- Kilo(k, thousands), hecto(h, hundreds), deka(dk, tens), deci(d, tenths), centi(c, hundredths), milli(m, thousandths)
- It’s expected you know “reasonable” values for real world measurements (example: Is 2 m tall the height of a little kid, NBA player or tall building?)
- Memorize for whole year: 1 cm^3 = 1 mL, density of water = 1.00 g/mL

Making measurements – Metric system

- So, who was King Henry and why is his death important to us?
- King Henry's tragic death* came as a result of drinking chocolate milk
- We like to say: King Henry died by drinking chocolate milk
- This helps us to honor the great man and memorize prefixes
- Move decimal pt. same as steps and direction
- "b" in "by" stands for base unit



* He didn't really die, we just use the story to help us with metric system conversions

Making measurements – Metric system

- Identify the base unit and prefix in each of the following
    - Kilometer
    - Milligram
    - Dekameter
    - Kilojoule
    - Centigrams
    - Hectoliters
    - Kilometers/hour
    - Decigram

A more flexible conversion method Factor label method, or T-charts

- Multiply a data value by the number "1"
- Example:
  - 1 = 12 in/30.48 cm (check a ruler and you'll see that 12 in. = 30.48 cm)
  - Sam's phone is 14.5 cm long. How many inches is that?
  - 14.5 cm x (12 in/30.48 cm) = 5.71 inches
  - Do you see how the stuff in red is just equal to 1? See how the cm units cancel out leaving only inches? (do the algebra is you don't see it)
- See the example below and note: 1) how each conversion factor has numerators equivalent to the denominators 2) units ALWAYS cancel algebraically on diagonals

$$1.25\ \text{days} \times \frac{24\ \text{hours}}{1\ \text{day}} \times \frac{60\ \text{min}}{1\ \text{hour}} \times \frac{60\ \text{s}}{1\ \text{min}} = 108000\ \text{s}$$

Responsible Scientist’s duty – significant figures

- Remember, you must report all you know from your experimental measurement – no more and no less
- Let’s say you want to find the density of a meteor fragment.
  - You measure mass and get 20.00000 grams (you have an awesomely expensive, reliable gram scale)
  - You measure volume and you can only find a beaker to using “water displacement”. You measure the volume is about 3/10th between the 0 and 100 mL mark, so as best you can determine, volume = 30 mL
  - Since density = mass/volume, you punch these numbers into your calculator and get 0.6666666667 on your calculator’s display. As a responsible scientist, what do you report for: Mass? Volume? Density? Be “responsible”!

Responsible Scientist's duty – significant figures

- Warning: the following slide is wordy.
- You will be given simpler rules later, but if you can follow the long explanation, you will know WHY significant figures have meaning
- Do you like following rules without knowing why?

Significant figures – the direct measurements

- Your scale is electronic and the display says 20.00000 g. Report this value exactly. Digital displays give you a value and you report that value exactly.
- Your beaker has marks at 0, 100, 200, 300, 400 mL, etc. Humans can estimate how many tenths a value is between two markings. Humans are NOT capable of estimating how many hundredths.
    - *You measure the volume is about 3/10th between the 0 and 100 mL mark*
    - *You can safely report there are zero hundreds of mL, 3 tens and you CANNOT SAY how many ones. Maybe a better volume measure device could determine the volume to be 28 mL, or 33 mL, but you must report what you know from YOUR measurement with whatever device you used.*
    - *You report the value for the volume as 30 mL*
    - *By leaving the ones with a value of zero, you are communicating your instrument did not let you measure volumes to the "ones"*
    - *The only digit with meaning regarding your measurement is the "3", as in the number of "tens", so we say your measurement has one significant figure*
- How many significant figures are in your mass measurement?
    - *For 20.00000, you know there are two tens, zero ones (it's not their as a place holder because there are even more digits afterward that are not place holder), you know there are 0 tenths, 0 hundredths, 0 thousandths, 0 ten thousandths and 0 hundred thousandths (all these small digits cannot possible be place holders). All seven of the digits that are reported are measured values and not place holders. This measurement has seven significant figures.*

Rules for determining number of significant figures (“ sig figs”)

- Rationale: Any digit that CAN POSSIBLY serve the purpose of just be a place holder is assumed to be a place holder and not a sig fig
- Sig figs ONLY apply to MEASURED quantities (this comes up several times this year!)

Determining how many sig figs - Three kind of numbers

- Standard (decimal) notation – decimal point **p**resent
  - “Spear away” any zeroes starting on the left (“**p**acific side”) up to a non-zero
  - Examples: 3.40 (3 sigs), 0.0340 (3 sigs), 34000. (5 sigs)
- Standard (decimal) notation – decimal point **a**bsent
  - “Spear away” any zeroes starting on the right (“**a**tlantic side”) up to a non-zero
  - Examples: 340 (2 sigs), 34 (2 sigs), 34000 (2 sigs), 34001 (5 sigs)
- Scientific notation
  - The left side is entirely significant (the right side is JUST the place holder)
  - Example: 3.4×10^2 (2 sigs), 3.40×10^2 (3 sigs), 3.40×10^7 (3 sigs), 0.04×10^5 (Illegal – not scientific notation)

Atlantic/Pacific rules summarized

- Don’t use with scientific notation
- Counts the digits left after spearing away zeroes that are not “significant”
- Digits left (zeroes and non-zeroes) are all “significant”

Pacific
Present (decimal pt)
Spear away those zeroes from left until you reach a non-zero

Atlantic
Absent (decimal pt)
Spear away those zeroes from right until you reach a non-zero

Summarize where we are:

- Numbers we report must reflect limits of measuring instruments
- Scientists use metric system to make measurements and report data
- We use “King Henry” for simple conversions and T-charts for harder conversions
- Atlantic/Pacific system counts sig figs with less thinking

Ready to go on? Well, we have to go on anyway!

Sig figs when calculations are involved

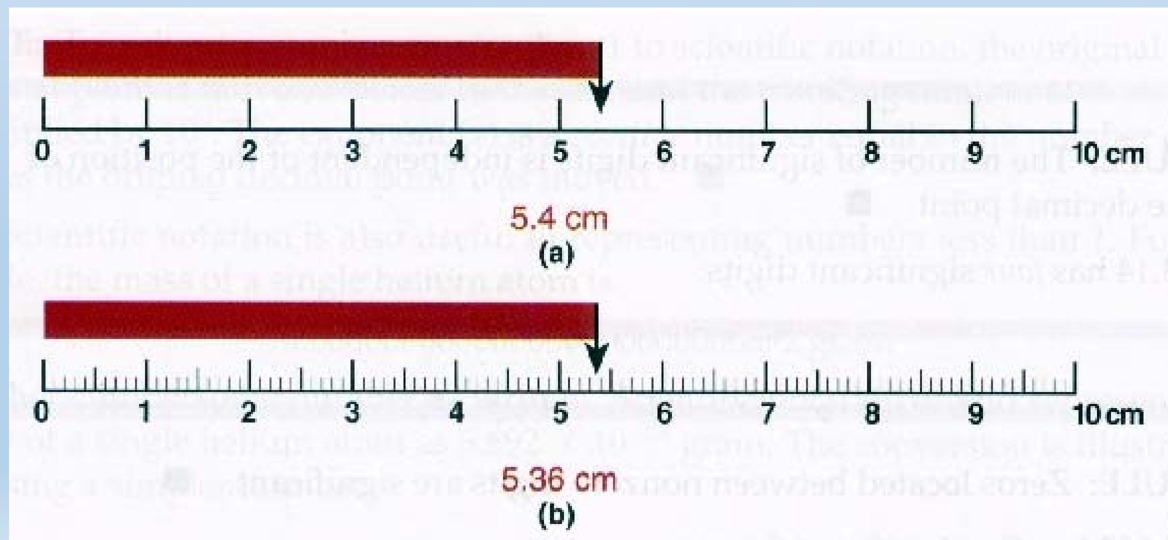
- There are two kinds of calculations we use: Add/subtract, Multiply/divide
- Add/Subtract: Answer has "Digits you know for all numbers"
  - Example: 12.50 g – 0.0450 g. There are two numbers and you know the tens, ones, tenths, hundredths values for all numbers. You DO NOT know the values for thousandths, ten thousandths for all numbers, so these are not significant to your final answer. Calculator gives: 12.455 g. But, you don't know the thousandths, so you can't report last "5", but use it for rounding: **12.46 g**
- Multiply/divide: Answer has LEAST sig figs present in ALL numbers in computation
  - Example: A meteor with a mass of 20.00000 g has a volume of 30 mL. What is the density of the meteor? (density = mass/volume) → d = 20.00000/30 = 0.7 g/mL (explanation: numerator has 7 sig fig, denominator has 1 sig fig, answer must have same sig figs as least number used in the computation: 1 sig fig).

Rounding and Scientific Notation (review)

- Rules for rounding (review)
  - Digits 0-4 round down, 5-9 round up.
    - 0.499 rounded to 1 sig fig is 0.5, to 2 sig figs is 0.50, to three sig figs is 0.500
    - 2,300 rounded to 1 sig fig is 2,000, to 2 sig figs is 2,300, to 3 sig figs is 2.30×10^3. There is no way to express this number with 3 sig figs in standard notation. 2,300 rounded to 4 sig figs is 2,300. The decimal point at the end makes it four sig figs (use the Pacific rule for yourself and prove it!)
- Scientific Notation to decimal (standard) and vice versa
  - Scientific notation: a.bcde x 10^z, a is a number 1-9 (not zero!), numbers after decimal point (bcde, etc.) are there for sig figs of measurement, z is the exponent (base 10).
  - Sci → standard example: 3.52×10^2: The exponent tells you how many places to move the decimal point. If the exponent is positive, move the decimal right, if the exponent is negative, move the decimal left. Pad with zeroes (holding places) as needed. In this case, answer is: <u>352</u>
  - Sci → standard example, small number: 3.52×10^{-4}: Move decimal point over three places left and pad with leading zeroes needed: <u>0.000352</u>.
  - Standard → Sci example: 220,000: Move the decimal point five places over and keep two sig figs: 2.2×10^5.

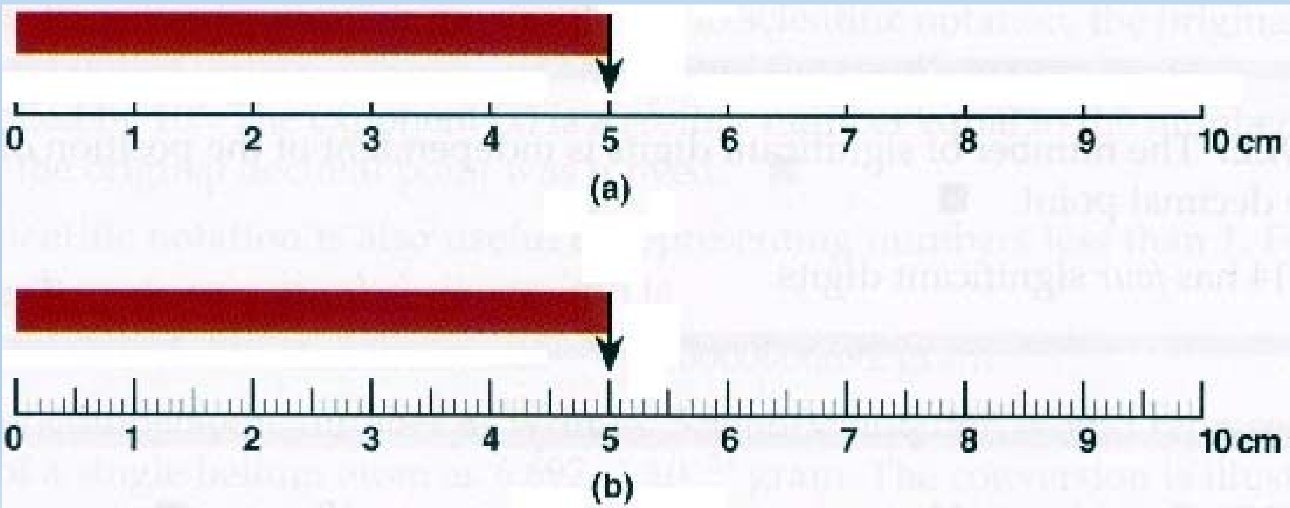
Reading analog measurements:

- Analog means it doesn't have a digital readout; you need skills and rules to read according to your duties as a scientist
- Analog examples: ruler, beaker, graduated cylinder, clock
- The rule: You must estimate the between lined values (next digit, never two digits). Try visual examples!



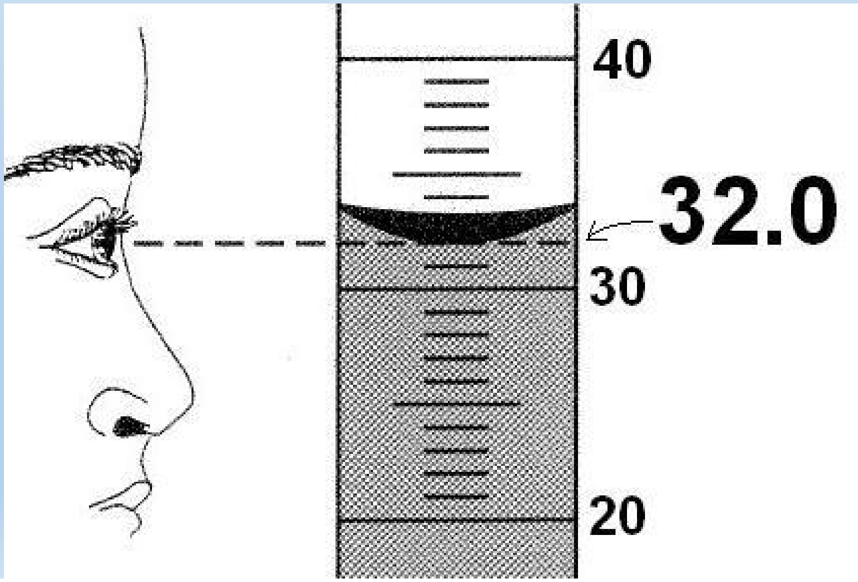
Reading analog measurements:

- If the line appears to be exactly on some number, you still don't gain the ability to estimate a hundred lines between instrument lines (just tenths between lines)
- For (a), you would report 5.0 cm
- For (b), you would report 5.00 cm

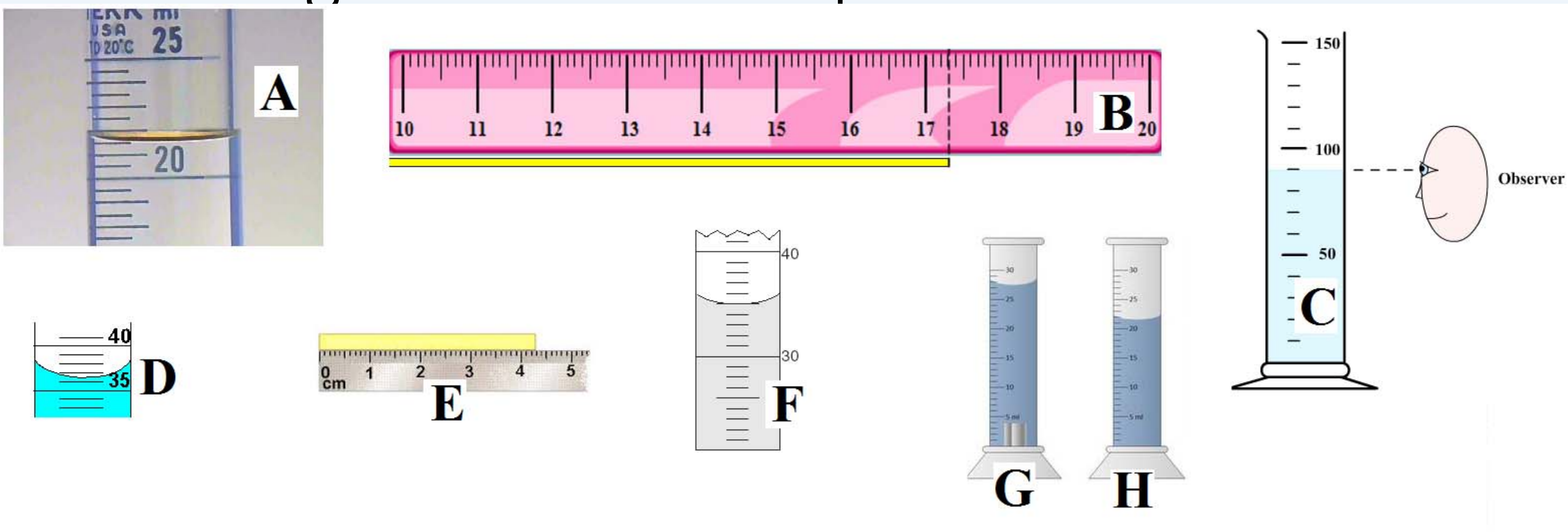


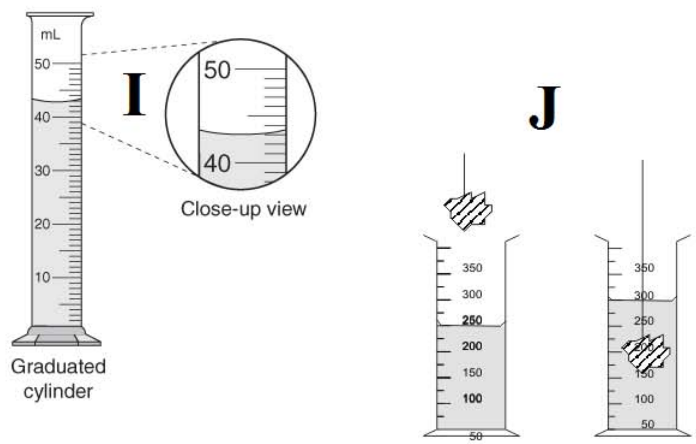
Reading a graduated cylinder - Meniscus

- Water tends to stick to glass surfaces forming a U-shaped dip called a meniscus, more noticeable in “skinny” containers, like graduated cylinders
- Proper measurement using a graduated cylinder:
  - Eye level even with bottom of meniscus
  - Report value at bottom-most part of meniscus (estimate next digit between lines, like we just taught!)



Analog measurement practice

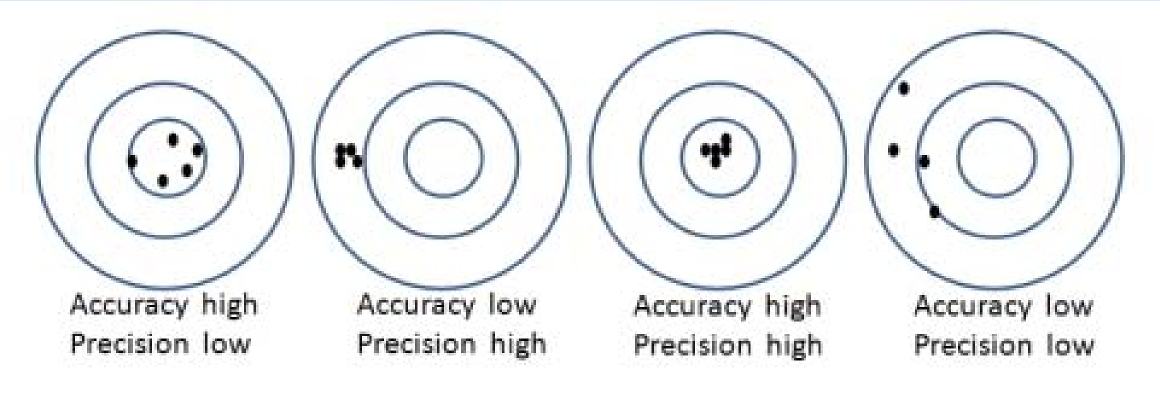


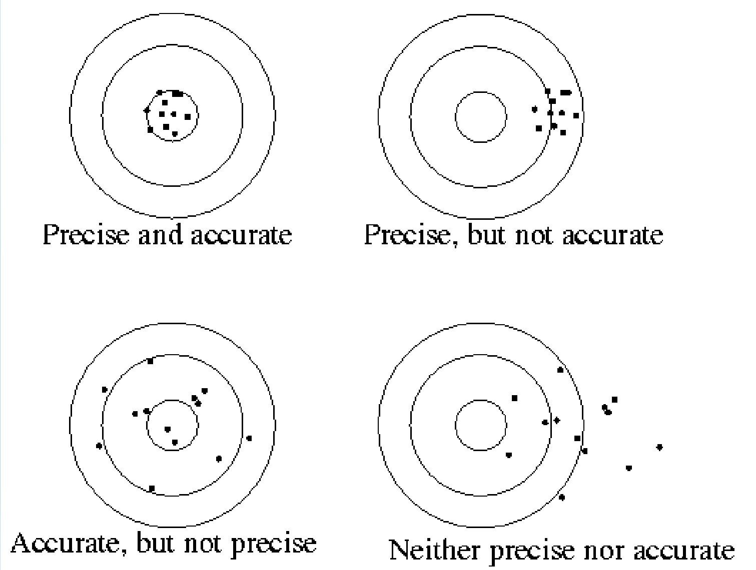


What's the volume for the rock using water displacement...use sig fig rules!

Accuracy and precision of measurements

- Some measurements are accurate, some precise, both or neither
- Terms are commonly used to mean the same thing – but scientifically they don't!
- Accurate measurements are close to the actual value
- Precise measurements get very near the same value each time
- Visual examples show this subtle difference





Rules for sinking and floating*

- Dense objects sink when placed in a less dense fluid
- Lower density objects float in more dense fluids
- Density is determined by: d = m/v
  - m in grams, v in mL, d in g/mL
- Students struggle with the math when finding v when given d and m
  - Helpful tip when finding v: make d, d/1 and cross multiply
- Best instrument for measuring volume is graduated cylinder (compared to beaker)

*Knock knock. Who's there? Dwayne. Dwayne who? Dwayne the bath tub, I'm dwowning!