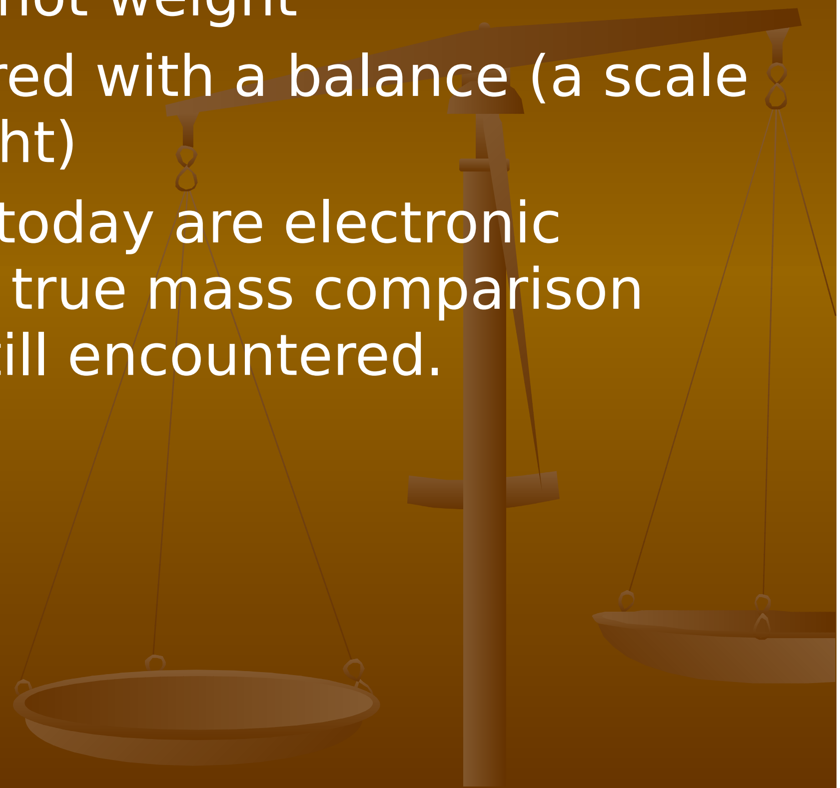
# 2: Mass, Volume, Significant Figures

**Outline**

- Measuring Mass
- Measuring Volume
- Significant figures

# Mass Measurement



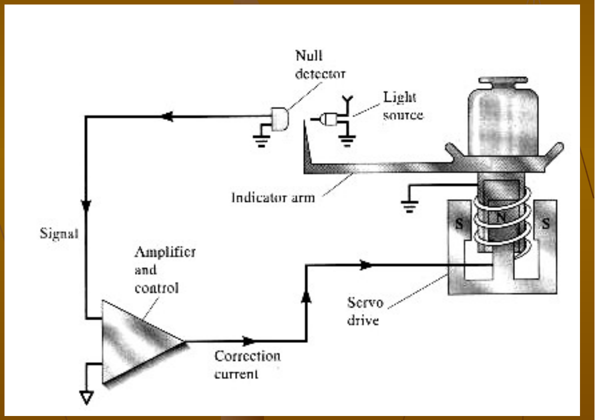
- Measure mass not weight
- Mass is measured with a balance (a scale measures weight)
- Most balances today are electronic although some true mass comparison balances are still encountered.

# Balances

- Balances come in a variety of capacities and sensitivities.
- Large capacity
  - >1 kg
  - Usually have only 0.1 g readability
- Analytical
  - Readability to 0.001 or 0.0001 g
  - Usually capacities of less than 200 g

# Electronic Balances

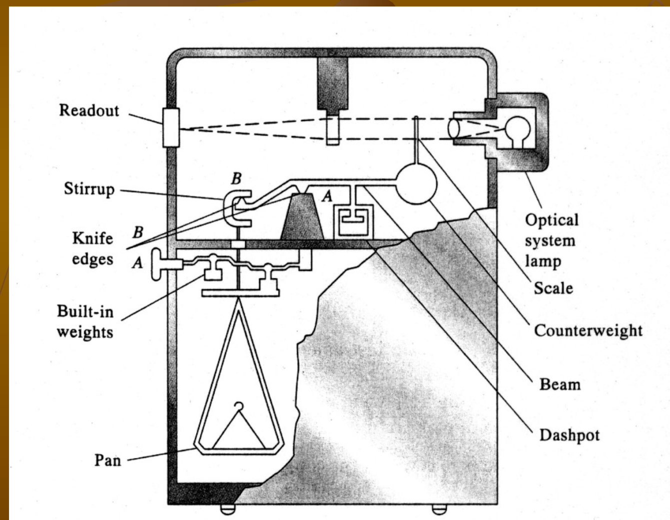
- Balance pan placed over electromagnet
- Mass depresses the pan
- Current applied to electromagnet restores pan to original position
- Amount of current necessary is proportional to mass on the pan




*Anal. Chem.*, **1982**, *54*, 973A.

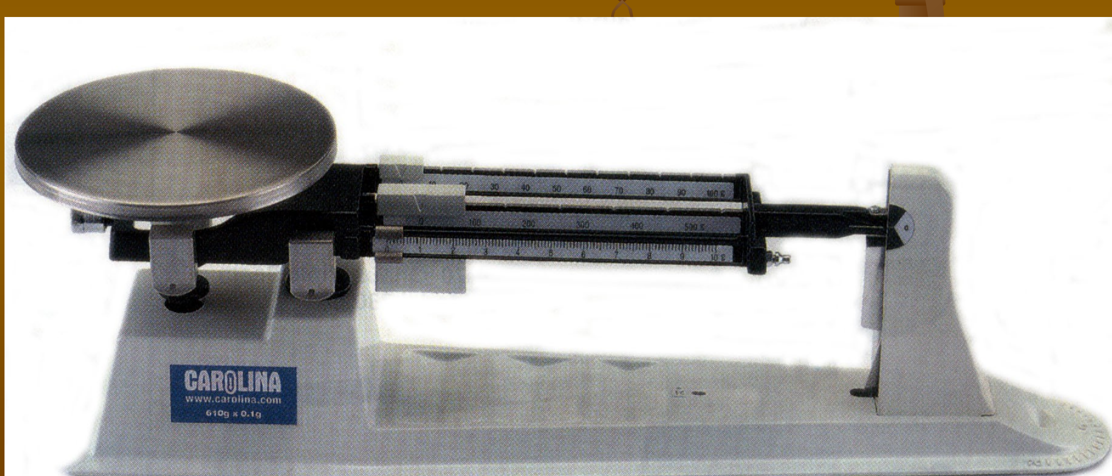
# Single-Pan Mechanical Balance

- Previous generation of analytical balances.
- Still very usable!
- Require more maintenance
- Less easy to read than electronic balances




# Triple-beam Balances

- Still useful when precision not critical



## Balances are Sensitive and Delicate

- Analytical balances can measure the mass of the dot on an ‘i’.
  - Should be placed somewhere without vibrations
  - Stone-top table is best.
- Must be very level in order to perform properly.
  - Always check the bubble level before using
- Do not to touch object you are massing with your fingers!

## Balances are Sensitive and Delicate

- Close doors to avoid air currents
- Samples must be at room temperature
  - Air currents from heat exchange cause errors
- Never put chemicals directly on balance pan
  - Use clean receiving vessels (weigh paper, beaker, etc.)

# Issues that can affect measurement

- Off-center load
  - place mass in center of pan
- Static electricity
  - especially at low humidity
- Buoyancy
- Evaporation of volatile materials
  - Use a closed container for these
- Spilled materials from earlier use – **ALWAYS CLEAN UP SPILLS IMMEDIATELY!!!**

# Buoyancy Error

- Actual mass would be mass in a vacuum
- Apparent mass (measured in air) is less due to buoyancy
- Buoyancy is mass of the air displaced
- Buoyancy error occurs because density of object not equal to density of standard weights

## Buoyancy equation:

- $m = m'(1 - d_a/d_w)/(1 - d_a/d)$
  - m is true mass
  - m' is mass read from a balance
  - $d_a$ is density of air (0.0012 g/mL at 1atm and 25$^0$C)
  - $d_w$ is density of balance weights (8.0 g/mL)
  - d is density of the object being weighed

## Example: Buoyancy correction

- Find the true mass of water (density=1.00 g/mL) if the apparent mass is 100.00 g.
  - Answer: 100.11 g
  - Note: the buoyancy error for water can be significant, especially when using water to calibrate volumetric glassware

# Outline

- Measuring Mass
- **Measuring Volume**
- Significant figures

# Volumetric Ware

- Beakers
- Erlenmeyer Flasks
- Graduated Cylinders
- Volumetric Flasks
- Pipets
  - Transfer / Volumetric - single volume
  - Graduated – Mohr and serological
  - Mechanical – syringe and pump
- Burets

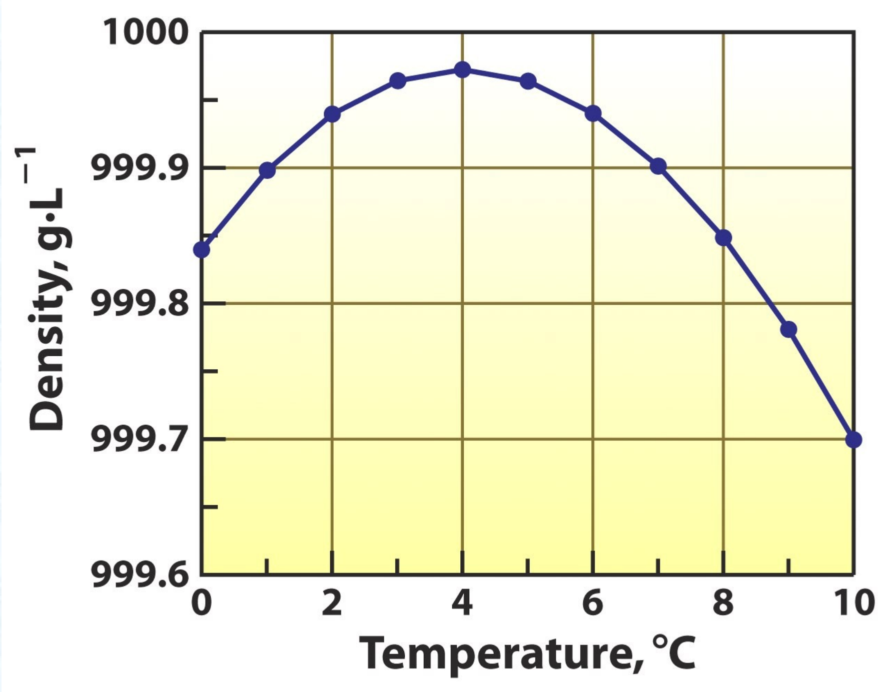
# Types of Calibration

- TD: “To Deliver”
  - Will deliver the volume indicated when filled to calibration mark and then drained.
  - Pipettes, burets, some grad cylinders
- TC: “To Contain”
  - Will contain the volume indicated when filled to calibration mark
  - Volumetric flasks, some grad cylinders

# Temperature Effects

- Liquid volume varies with temperature
  - 5 °C change in temp can cause significant change in volume of water (~ 0.025%/ °C)
  - For some organic liquids, 1°C can be significant
- Volumetric ware expands and contracts
  - Glass has low thermal coefficient of expansion
  - Change does not need to be considered for most analytical work

# Temperature and Density (g/mL)




# Temperature and Density (g/mL) of Water

| | 0.0 | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 | 0.9 |
|---|---|---|---|---|---|---|---|---|---|---|
| 15 | 0.999099 | 0.999084 | 0.999069 | 0.999054 | 0.999038 | 0.999023 | 0.999007 | 0.998991 | 0.998975 | 0.998959 |
| 16 | 0.998943 | 0.998926 | 0.998910 | 0.998893 | 0.998877 | 0.998860 | 0.998843 | 0.998826 | 0.998809 | 0.998792 |
| 17 | 0.998774 | 0.998757 | 0.998739 | 0.998722 | 0.998704 | 0.998686 | 0.998668 | 0.998650 | 0.998632 | 0.998613 |
| 18 | 0.998595 | 0.998576 | 0.998558 | 0.998539 | 0.998520 | 0.998501 | 0.998482 | 0.998463 | 0.998444 | 0.998424 |
| 19 | 0.998405 | 0.998385 | 0.998365 | 0.998345 | 0.998325 | 0.998305 | 0.998285 | 0.998265 | 0.998244 | 0.998224 |
| 20 | 0.998203 | 0.998183 | 0.998162 | 0.998141 | 0.998120 | 0.998099 | 0.998078 | 0.998056 | 0.998035 | 0.998013 |
| 21 | 0.997992 | 0.997970 | 0.997948 | 0.997926 | 0.997904 | 0.997882 | 0.997860 | 0.997837 | 0.997815 | 0.997792 |
| 22 | 0.997770 | 0.997747 | 0.997724 | 0.997701 | 0.997678 | 0.997655 | 0.997632 | 0.997608 | 0.997585 | 0.997561 |
| 23 | 0.997538 | 0.997514 | 0.997490 | 0.997466 | 0.997442 | 0.997418 | 0.997394 | 0.997369 | 0.997345 | 0.997320 |
| 24 | 0.997296 | 0.997271 | 0.997246 | 0.997221 | 0.997196 | 0.997171 | 0.997146 | 0.997120 | 0.997095 | 0.997069 |
| 25 | 0.997044 | 0.997018 | 0.996992 | 0.996967 | 0.996941 | 0.996914 | 0.996888 | 0.996862 | 0.996836 | 0.996809 |
| 26 | 0.996783 | 0.996756 | 0.996729 | 0.996703 | 0.996676 | 0.996649 | 0.996621 | 0.996594 | 0.996567 | 0.996540 |
| 27 | 0.996512 | 0.996485 | 0.996457 | 0.996429 | 0.996401 | 0.996373 | 0.996345 | 0.996317 | 0.996289 | 0.996261 |
| 28 | 0.996232 | 0.996204 | 0.996175 | 0.996147 | 0.996118 | 0.996089 | 0.996060 | 0.996031 | 0.996002 | 0.995973 |
| 29 | 0.995944 | 0.995914 | 0.995885 | 0.995855 | 0.995826 | 0.995796 | 0.995766 | 0.995736 | 0.995706 | 0.995676 |
| 30 | 0.995646 | 0.995616 | 0.995586 | 0.995555 | 0.995525 | 0.995494 | 0.995464 | 0.995433 | 0.995402 | 0.995371 |

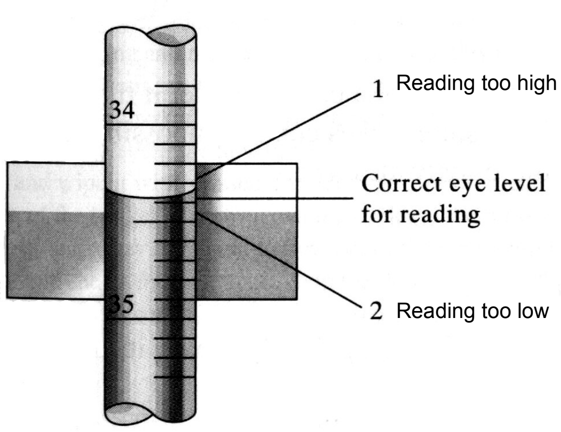
# Temperature and Density (g/mL) of Water

| | 0.0 | 0.1 | 0.2 | 0.3 |
|---|---|---|---|---|
| **15** | 0.999099 | 0.999084 | 0.999069 | 0.999054 |
| **16** | 0.998943 | 0.998926 | 0.998910 | 0.998893 |
| **17** | 0.998774 | 0.998757 | 0.998739 | 0.998722 |
| **18** | 0.998595 | 0.998576 | 0.998558 | 0.998539 |

- What is the actual mass of 5.000 mL $H_2O$ at 16.2 °C? Answer: 4.994 g

# Reading Volumetric Ware

- The problem of parallax
  - Liquid sags (meniscus) in the center of the column due to gravity
- Eye must be at a 90° angle to the volumetric device in order to read the level properly.



# Cleaning Glassware

- Volumetric glassware must be clean to perform properly
- Beakers, flasks, cylinders clean easily
  - Use detergent and brushes
- Buret, vol. flasks and pipets cannot be done with a brush!
  - Fill with detergent solution above the calibration mark(s).
  - Invert several times, carefully
  - Rinse with several portions of tap water and then distilled water
  - Check that it drains with no clinging drops.
  - Repeat washing if drops are observed.
  - If needed, consult instructor for stronger measures.

# Beakers and Flasks

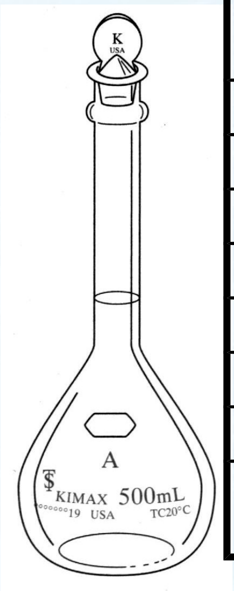
- Glass or plastic
- Accuracy of graduations: typically ±5% accuracy
  - TD vs TC doesn't matter

# Graduated Cylinders

- Glass or plastic
- Accuracy: usually 1% or better
- Calibrated 'to deliver' (TD) or 'to contain' (TC).
- Different grades: Certified, Class A, Class B, Educational-Grade, Economy-Grade, etc.
- Should **NEVER** be heated even if Pyrex®

# Volumetric Flasks

- For solutions of a single volume
- Designed 'to contain' (TC)
- Class A and Class B
- Accuracy varies with size of flask
- Pyrex® or Kimax® can be gently heated if need to dissolve solute
- NOT for long-term storage
- $$Expensive$$
- Question: % error of 1mL and 1000 mL flasks?




| Volume | Tolerance (Class A) |
|---|---|
| 1 mL | 0.01 mL |
| 10 mL | 0.02 mL |
| 25 mL | 0.03 mL |
| 50 mL | 0.05 mL |
| 100 mL | 0.08 mL |
| 250 mL | 0.10 mL |
| 500 mL | 0.15 mL |
| 1000 mL | 0.30 mL |

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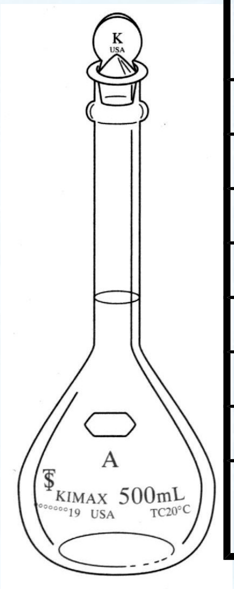
  - 1mL: 1%
  - 1000mL: 0.03 %

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# Pipets

- Filled using a bulb
- NEVER use mouth to apply suction
- Use your 'good' hand to hold pipet and your 'off' hand to squeeze the bulb
- Use your first finger, not thumb, to close the pipet and adjust meniscus to mark
- Be mindful of where the tip has been—is it clean enough to stick into a solution?

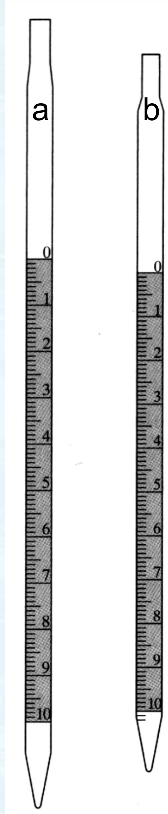
# Volumetric Pipets

- Designed to deliver (TD) a single volume
  - (usually at 20 $^0$C)
- Calibrated to account for the thin film of solution on inner wall and the drop at the tip
- Allow pipette to drain under gravity (no shaking or blowing) with tip touching the receiving container
- Lightly touch tip to transfer clinging drop; then remove soon after the transfer
- With care, accuracy is four digits with Class A

# Pipette Practice

- Obtain a 10 or 25 mL pipette
- Fill a 125 mL beaker with water
- Practice:
  - Squeeze bulb BEFORE putting on pipette
  - Seal bulb <u>just enough</u>
  - Pipette in “good” hand, bulb in other hand
- **<u>DO NOT</u>**
  - Slam pipette tip into bottom of beaker
  - Suck liquid into bulb

# Graduated Pipets




- Multiple graduations for delivering range of volumes.
- Look at how the bottom volume mark is applied
  - Some require you to stop at a line (a)
  - Some designed to be drained completely (b)
- Usually accurate at small volumes if filled and drained carefully
- With large volumes it is difficult to stop on the desired line readily

# Syringe Pipets

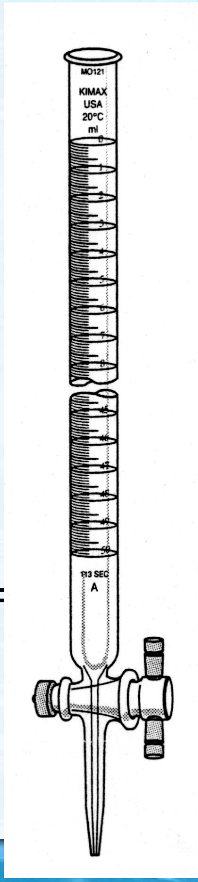
- Two types:
  - Simple manual syringe (a)
  - Spring-loaded with disposable tips (b)
- Used for very small volumes (1 to 1000 µL)
- Spring-Loaded types:
  - $$$
  - Lose accuracy over time and must be re-calibrated
  - NEVER turn upside down or lay down with a tip attached

a

b

# Burets

- Accurately deliver variable amounts of liquid
- 10, 25, 50 and 100 mL sizes
- Class A and Class B
- Readable to about 0.01 (±0.02) mL for 50 mL buret
- Valve (stopcock) permits careful release of liquid
- “Opposite” grip prevents loosening of stopcock
- Today most stopcocks are made of Teflon®; older burets had glass stopcocks that required grease




# Outline

- Measuring Mass
- Measuring Volume
- **Significant figures**

# Rules with Zeros

- Any digit that is NOT zero is considered significant.
- Zeros between non-zero digits ARE significant.
  ex: 101 (3 sig figs)
- Zeros to the left of the FIRST nonzero digit are NOT significant. They are just place holders.
  ex: 0.003 (1 sig fig)
- If number HAS a decimal point, any zeros to the right of the last nonzero digit ARE significant.
  ex: 0.500 (3 sig figs)
- If number DOES NOT HAVE a decimal point, zeros to right of last nonzero digit are NOT significant
  ex: 100 (1 sig fig)
  - To indicate sig figs, put in a decimal or use scientific notation
    ex: 100. or $1.00 \times 10^2$

# Practice

- How many significant figures in each number below?
  - 34.65
  - 0.7601
  - 4400
  - 810.3
  - 3.00
  - 0.0024

# Practice

- How many significant figures in each number below?
  - 34.65 **4**
  - 0.7601 **4**
  - 4400 **2**
  - 810.3 **4**
  - 3.00 **3**
  - 0.0024 **2**

# Arithmetic

- Multiplication and division: the number with the least significant figures governs

  ex: $0.25 \times 4.0034 = 1.0$

  $0.0354 \div 8.3 = 0.0043$

- Addition and subtraction: line up the decimals; number whose sig figs stop first governs

```
 100              100.24
+  1.1          -    1.1
--------        --------
100 (1 sig fig)    99.1 (3 sig figs)
```

# Practice

- 9.24 × 4.7619 =
- 1.24 – 0.872 =
- 0.51 + 0.8692 =

# Practice

- 9.24 × 4.7619 = **44.0**
- 1.24 – 0.872 = **0.37**
- 0.51 + 0.8692 = **1.38**

# Today's Lab

- Experiment 2a: Measuring Density of a Liquid and a Solid

$$\text{density} = \frac{\text{mass}}{\text{volume}}$$

  - Consider precision (significant figures) of different instruments to measure same quantities
- Experiment 2b: Calibration of Volumetric Glassware
  - Use density of water and high precision of balances to calibrate glassware