# Physics

Introduction
and
Chapter 1



## Physics

- Fundamental Science
  - foundation of other sciences

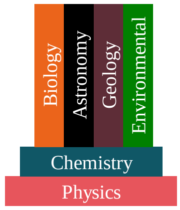



**Table 1 Areas Within Physics**

| Name | Subjects | Examples |
|---|---|---|
| Mechanics | motion and its causes, interactions between objects | falling objects, friction, weight, spinning objects |
| Thermodynamics | heat and temperature | melting and freezing processes, engines, refrigerators |
| Vibrations and wave phenomena | specific types of repetitive motions | springs, pendulums, sound |
| Optics | light | mirrors, lenses, color, astronomy |
| Electromagnetism | electricity, magnetism, and light | electrical charge, circuitry, permanent magnets, electromagnets |
| Relativity | particles moving at any speed, including very high speeds | particle collisions, particle accelerators, nuclear energy |
| Quantum mechanics | behavior of submicroscopic particles | the atom and its parts |

## Why we start with Mechanics

- Has many basic principles that are used in the other major areas
- Based on studies of motion by Greeks through Galileo
- Newton's *Principia* in 1687 is the basis of our study of mechanics

## Hypothesis

- **Hypothesis:** A tentative statement about the natural world leading to deductions that can be tested.
  - If the deductions are verified, the hypothesis is provisionally corroborated. If the deductions are incorrect, the original hypothesis is proved false and must be abandoned or modified.
  - Hypotheses can be used to build more complex inferences and explanations.
  - Must be Reasonable
  - Must be Testable
  - Must not be an Opinion

## Scientific Method

- Identify a Problem
- Perform Research
- Create Hypothesis
- Test Hypothesis
- Interpret Results
- Create Rule

https://sites.google.com/site/duellingwithscience/_/rsrc/1466430701515/integrated-physical-science-old/key-concepts/the-metric-system/Map.png

## Terms Related to Experiments

- Model- A representation or copy of something, often on a different scale
- Systems- a group of related components
- Controlled Experiment- Limit the experiment to testing one factor at a time.

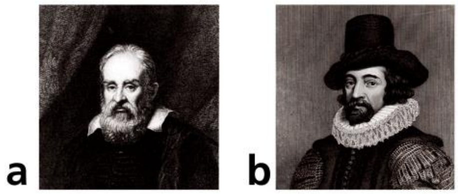
## Fact, Law, Theory

•**Fact:** In science, an observation that has been repeatedly confirmed and for all practical purposes is accepted as "true." Truth in science, however, is never final and what is accepted as a fact today may be modified or even discarded tomorrow.[3] A fact, is a hypothesis that has been tested over and over again with the same general results.

•**Law:** A descriptive generalization about how some aspect of the natural world behaves under stated circumstances.[3] **A law tells what happens but not why it happens.**

•**Theory:** A well-substantiated explanation of some aspect of the natural world that can incorporate facts, laws, inferences, and tested hypotheses.[3] **A theory, tells why something happens**

## Scientific Method Founders




Galileo Galilei (a.) and the English philosopher Francis Bacon (b.).

**Homework: Scientific Method Problem Sheet**

## Mathematical Toolkit

## How were the following Units Originally Defined?

- Inch
- Foot
- Yard
- Rod
- Pound

LINK

- Countries with our Measuring System

## Measurements

- Basis of testing theories in science
- 7 Basic Measurements all others are based on
- Uncertainties are inherent
  - Need rules for dealing with the uncertainties which we will study later.

## Quantity vs. Dimension vs. Unit

| Quantity | Dimension | Unit |
|---|---|---|
| Length | Length [L] | meter |
| Mass | Mass [M] | kilogram |
| Time | Time [T] | second |
| Amount of a Substance | Avogadro's Number [N] | mole |
| Area | Length² [L²] | meter^2 |
| Pi | None | None |
| pH | None | None |

All Dimensions are Quantities but not all quantities are Dimensions

## Systems of Measurement

- Standardized systems
  - agreed upon by some authority, usually a governmental body
- SI -- Systéme International
  - agreed to in 1960 by an international committee
  - main system used in this text
  - also called mks for the first letters in the units of the fundamental quantities

## Metric Prefixes

- Prefixes correspond to powers of 10
- Each prefix has a specific name
- Each prefix has a specific abbreviation

| SI PREFIXES | | |
|---|---|---|
| Abbreviation | Prefix | Power |
| G | Giga | $10^9$ |
| M | Mega | $10^6$ |
| k | kilo | 1 000 or $10^3$ |
| h | hecta | 100or $10^2$ |
| da | deka | 10 or $10^1$ |
| THE BASE | ----- | 0 |
| d | deci | 0.1 or $10^{-1}$ |
| c | centi | 0.01or $10^{-2}$ |
| m | milli | 0.001 or $10^{-3}$ |
| µ | micro | $10^{-6}$ |
| n | nano | $10^{-9}$ |

## Length

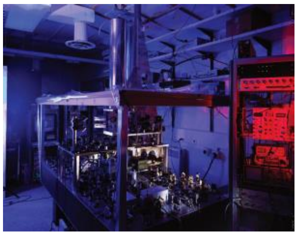
- Units
  - Meter
- Defined in terms of a meter -- the distance traveled by light in a vacuum during a given time

http://scaleofuniverse.com

## Mass

- Units
  - SI – kilogram
- Defined in terms of kilogram, based on a specific cylinder kept at the International Bureau of Standards

## Time



- Units
  - seconds, s in all three systems
- Defined in terms of the oscillation of radiation from a cesium atom

## The other 4 SI Dimensions and their Units

- **Electric Current - Ampere [A]**
  - The unit of measurement of **electrical current** flow, named after André Ampère, a 19th century French physicist. One ampere is the value of current that will be maintained in a circuit with an electromotive force of one volt and a resistance of one ohm. One ampere = $6.25 \times 10^{18}$ electrons/second
- **Temperature - Kelvin [K]**
  - The Kelvin is the basic unit of **temperature**. It is 1/273.16*th* of the thermodynamic temperature of the triple point of water. *It is named after the Scottish mathematician and physicist William Thomson 1st Lord Kelvin (1824-1907).*

## The other 4 SI Dimensions and their Units

- **Substance - mole [mol]**
  - The mole is the basic unit of **substance**. It is the amount of substance that contains as many elementary units as there are atoms in 0.012 kg of carbon-12.
- **Luminous Intensity - candela [cd]**
  - The candela is the basic unit of **luminous intensity**. It is the intensity of a source of light of a specified frequency, which gives a specified amount of power in a given direction.

## All Other SI Units

- All other SI units are derived from the 7 basic dimensions just mentioned.
- Example
  - Distance/ Time = [meter/second]

**SI Base Units**

| Quantity Measured | Unit | Symbol |
|---|---|---|
| Length | meter | m |
| Mass | kilogram | kg |
| Time | second | s |
| Electric current | ampere | A |
| Temperature | kelvin | K |
| Amount of substance | mole | mol |
| Intensity of light | candela | cd |

**Homework: Measurement Systems Problem Sheet**

## Dimensional Analysis

- Technique to check the correctness of an equation
- Dimensions (length, mass, time, combinations) can be treated as algebraic quantities
  - add, subtract, multiply, divide
- Both sides of equation must have the same dimensions
- Cannot give numerical factors: this is its limitation
- Example
  - foot * yd / foot = yd
  - Slug * gram / slug = gram

**Homework: Dimensional Analysis Problem Sheet**

## Conversions

- When units are not consistent, you may need to convert to appropriate ones
- Metric Conversions require us to shift the decimal point
- Nonmetric conversions require conversion factors
- Units can be treated like algebraic quantities that can cancel each other out

## Conversion Factors

- **1 meter = 3.2808399 feet**
- **1 slug = 14.5939029 kilogram**
- **1 mile = 1.609344 kilometer**
- **1 pound force = 4.44822162 Newton**
- When ever you need a conversion factor use the following format on google ("what you have" to "what you want")

## Factor Label Method

- We take the dimensions we have, and determine which dimension we are looking for. By multiplying what we have by a series of conversion factors we get what we are looking for
- 100 yards to miles
- 100 yards * 3 feet / 1 yard * 1 mile / 5280 feet=

**Homework: Conversion Problems Problem Sheet**

## Scientific Notation

- Placing numbers in scientific (exponential) notation has several advantages.
- We use it because of this: http://htwins.net/scale2/
  - For very large numbers and extremely small ones, these numbers can be placed in scientific notation in order to express them in a more concise form.
  - In addition, numbers placed in this notation can be used in a computation with far greater ease. This last advantage was more practical before the advent of calculators and their abundance.

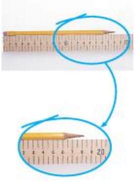
## Scientific Notation

- Placing numbers in scientific notation from standard form with the following rules:
  - Move the decimal so that there is only 1 non-zero number to the left of the decimal.
  - If you move the decimal to the left add the number of moves you made to the exponent.
  - If you move the decimal to the right subtract the number of move you made from the exponent
- Placing number in standard notation from scientific notation
  - If the power is positive move the decimal to the right an equal number of spaces as the exponent.
  - If the power is negative move the decimal the left an equal number of spaces as the exponent.

## Try these Numbers

- 123,876.3
- 1,236,840.
- 4.22
- 0.000,000,000,000,211
- 0.000238
- 0.910

## Accuracy vs Precision



- Accuracy describes the nearness of a measurement or set of measurements to the standard or true value.
  - A highly accurate measuring device will provide measurements very close to the theoretical (standard, true, known) value.
- Precision is the degree to which several measurements provide answers very close to each other.
  - It is an indicator of the scatter in the data.
    - The lesser the scatter, higher the precision.

## Approximations

- Even though physicists usually try for a high degree of precision, there are times when only a close approximation is needed. Physicists some times make rough estimates for making tentative decisions. The accuracy of estimates depends on reference materials available, time devoted, and experience with similar problems.

## Uncertainty in Measurements

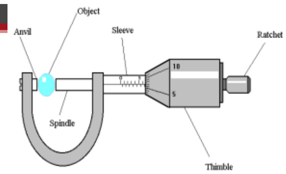
- There is uncertainty in every measurement, this uncertainty carries over through the calculations
- We will use rules for significant figures to approximate the uncertainty in results of calculations

## Errors in Measurement

- Instrument error
  - Instrument error is caused by using measurement instruments that are flawed in some way.
  - Instruments generally have stated accuracies such as "accurate to within 1%."
- Method error
  - Method error is caused by poor techniques (see picture below)

  - This ruler has PARALLAX which is the apparent change in the position of objects due to a change in the position of the observer

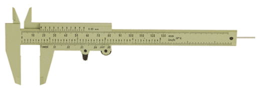
## Micrometers




- <u>WARNING</u>
  The micrometer is a precision instrument and should be treated with care,
  it should NEVER be forced.

- We would typically use a micrometer to measure very small thicknesses around (0.01mm ) and diameters of wires and spheres. To improve accuracy (as with all measurements) we would take several readings and find their average. Thus we could not only ensure accuracy but, by taking readings at different positions along the length, we could test for a consistent diameter along a piece of wire.

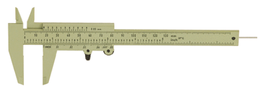
## Vernier Calipers



- The Vernier caliper is an extremely precise measuring instrument; it measures items around mm = 0.1 mm.

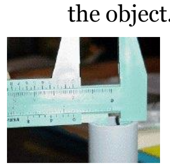
- If you are measuring something with a round cross section, make sure that the axis of the object is perpendicular to the caliper. This is necessary to ensure that you are measuring the full diameter and not merely a chord.

## Vernier Calipers



- Check that the vernier caliper correctly reads zero when the jaws are closed. (if not, check with the lab instructor.)

- Close the jaws around the object but do not over tighten. The jaws should exert a firm pressure on the object.



## Significant Figures

- A significant figure is one that is reliably known
- All non-zero digits are significant
- Zeros are significant when
  - between other non-zero digits
    - 502 the zero is significant
    - 5130 the zero is not significant
  - after the decimal point and another significant figure
    - 15.03, the zero is significant
    - 0.0183, the zero is not significant
  - can be clarified by using scientific notation

## Significant Figures-Atlantic-Pacific Rule

## Operations with Significant Figures

- Accuracy -- number of significant figures
- When multiplying or dividing, round the result to the same accuracy as the least accurate measurement
- When adding or subtracting, round the result to the smallest number of decimal places of any term in the sum

**Homework: Significant Figures Problem Sheet**

## Order of Magnitude

- Approximation based on a number of assumptions
  - may need to modify assumptions if more precise results are needed
- Order of magnitude is the power of 10 that applies

**Homework: Order of Magnitude Problem Sheet**

# Statistical Analysis

For all Sciences

## Error Calculations

- Error Calculations are a form of statistics that are used to mathematically determine if some trend is accurately predicating a set of outcomes.
- Each Calculation has a limited but accepted range of use.
- Scientists (Natural and Social) and Mathematicians have come to a common agreement about when and where to use each analysis.
- IN GENERAL- Each calculationis giving us Accuracy and/or Precision

## Error Calculations

### Percent Error

- (Accuracy Calculation)
- Used to determine the percent difference between the theoretical and experimental values

$$\%Error = \frac{Theoretical - Exprimental}{Theoretical} x100\%$$

accepted value

your value

## Average Deviation from the Mean (a.d.)

Note: Some books call this Mean Absolute Deviation (M.D.)

- measurement is compares measurement to each other
- (Precision Calculation)
  - Step 1: Calculate the absolute deviation for each measurement

$$D_i = |x_i - \bar{x}|$$

  - Step 2: Average the absolute deviations

$$D_{\bar{X}} = \frac{\sum_{i=1}^{n} |x_i - \bar{x}|}{N}$$

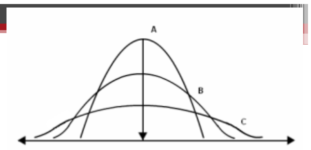
$$D_{\bar{X}} = \frac{\sum_{i=1}^{n} D_i}{N}$$

## Average Deviation of the mean (A.D.)

- (Accuracy Calculation)
  - Used to calculate how accurate a set of measurements are compared to the theoretical value

$$A.D. = \frac{D_x}{\sqrt{N}}$$

## Interval Range




- The interval range for Mean Absolute Deviation (a.d.) is 57.7%
  - This means 57.5% of all data randomly collected should fall in the range of the a.d.
- The interval range of the Average Deviation from the mean is 50%
  - This means that means that there is a 50% chance that the accepted (or true) value falls in the range.

## Variance

- Statistical variance gives a measure of how the data distributes itself about the mean or expected value. Unlike range that only looks at the extremes, the variance looks at all the data points and then determines their distribution.
- Although variance could describe the a.d., it usually is represented by the following equation.

$$s^2 = \frac{\Sigma(x - \bar{x})^2}{n - 1}$$

- $s^2$ = variance
- $\sum (x - \bar{x})^2$ = The sum of $(x - \bar{x})^2$ for all data points
- x = individual data points
- $\bar{x}$ = mean of the data
- n = number of data points

## Standard Deviation

- The most common statistical predictor of precision

$$s = \sqrt{s^2} = \sqrt{\frac{\Sigma(x - \bar{x})^2}{n - 1}}$$

- x = individual data points
- $\bar{x}$ = mean of the data
- n = number of data points

Note: Although it is the most common,

## Population vs Sample

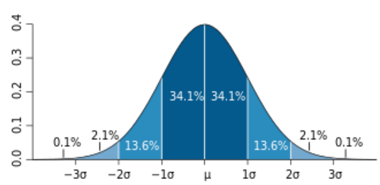
- Population
  - When we are using all of the possible data points that exist we use:

$$s = \sqrt{s^2} = \sqrt{\frac{\Sigma(x - \bar{x})^2}{n}}$$

- Sample
  - When we take a **sample** of the entire population, we error on the side of caution and increase our error position by using **N-1**.

$$s = \sqrt{s^2} = \sqrt{\frac{\Sigma(x - \bar{x})^2}{n - 1}}$$

## Interval Range




- 1 Standard Deviation = 68.27%
- 2 Standard Deviations = 95.45%
- 3 Standard Deviations = 99.73%
- 4 Standard Deviations = 99.99%

## Standard Deviation of the Mean

- Similar to Average Deviation of the Mean in that it tells the Accuracy of our data.

$$SE_{\bar{x}} = \frac{s}{\sqrt{n}}$$

**OR**

$$s_{\bar{x}} = \frac{s}{\sqrt{n}}$$

- It's interval range is 50%

## Standard Deviation vs. Mean Absolute Deviation

- Standard deviation exaggerates the impact of larger deviations. This emphasizes point that are outliers.
- Mean Absolute reduces the weight of outliers. And therefore the value does not reflect the impact of larger scatter or dispersion properly.
- For Data Sets with wide ranges of data, Standard Deviation is Better.
- For Sets of data where errors may be greater than 3% Mean Absolute Deviation is better.
  - Note in labs we usually assume error as 0% so Standard Deviation is used more often.

## Addition information on Standard Deviation

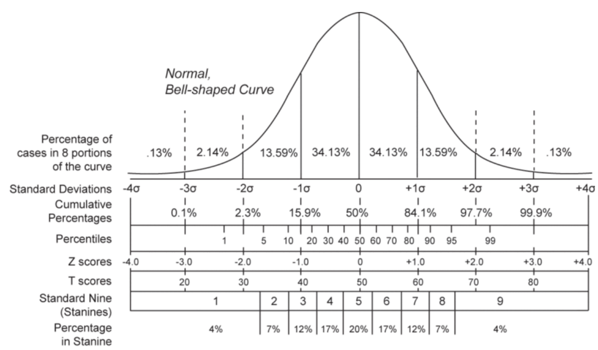
- Instructional Video
  - http://www.youtube.com/watch?v=HvDqbzu0i0E
- Example Problems
  - http://www.mathsisfun.com/data/standard-deviation-formulas.html
- Example Physics Problem
  - http://www.batesville.k12.in.us/physics/apphynet/Measurement/standard_deviation.htm

## Student T-Test

- The T-Test test can be used to test the accuracy of your data to the theoretical value.
- T-Tests are used for data sets of 30 pieces of data or less. There is another test called the Z-Test for data sets larger than 30.
- The equation for the t-test is
- $t = \frac{\bar{x}-\mu}{\sigma/\sqrt{n}} = \frac{\bar{x}-\mu}{\sigma_{\bar{x}}}$

T-Test Table

| α | 0.25 | 0.20 | 0.15 | 0.1 | 0.05 | 0.025 | 0.01 | 0.005 | 0.0025 | 0.0010 | 0.0 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| *One Sided* | 75% | 80% | 85% | 90% | 95% | 97.50% | 99% | 99.50% | 99.75% | 99.90% | 99. |
| *Two Sided* | 50% | 60% | 70% | 80% | 90% | 95% | 98% | 99% | 99.50% | 99.80% | 99. |
| 1 | 1 | 1.376 | 1.963 | 3.078 | 6.314 | 12.71 | 31.82 | 63.66 | 127.3 | 318.3 | 63 |
| 2 | 0.816 | 1.061 | 1.386 | 1.886 | 2.92 | 4.303 | 6.965 | 9.925 | 14.09 | 22.33 | 3 |
| 3 | 0.765 | 0.978 | 1.25 | 1.638 | 2.353 | 3.182 | 4.541 | 5.841 | 7.453 | 10.21 | 12 |
| 4 | 0.741 | 0.941 | 1.19 | 1.533 | 2.132 | 2.776 | 3.747 | 4.604 | 5.598 | 7.173 | 8. |
| 5 | 0.727 | 0.92 | 1.156 | 1.476 | 2.015 | 2.571 | 3.365 | 4.032 | 4.773 | 5.893 | 6. |
| 6 | 0.718 | 0.906 | 1.134 | 1.44 | 1.943 | 2.447 | 3.143 | 3.707 | 4.317 | 5.208 | 5. |
| 7 | 0.711 | 0.896 | 1.119 | 1.415 | 1.895 | 2.365 | 2.998 | 3.499 | 4.029 | 4.785 | 5. |
| 8 | 0.706 | 0.889 | 1.108 | 1.397 | 1.86 | 2.306 | 2.896 | 3.355 | 3.833 | 4.501 | 5. |
| 9 | 0.703 | 0.883 | 1.1 | 1.383 | 1.833 | 2.262 | 2.821 | 3.25 | 3.69 | 4.297 | 4. |
| 10 | 0.7 | 0.879 | 1.093 | 1.372 | 1.812 | 2.228 | 2.764 | 3.169 | 3.581 | 4.144 | 4. |
| 11 | 0.697 | 0.876 | 1.088 | 1.363 | 1.796 | 2.201 | 2.718 | 3.106 | 3.497 | 4.025 | 4. |
| 12 | 0.695 | 0.873 | 1.083 | 1.356 | 1.782 | 2.179 | 2.681 | 3.055 | 3.428 | 3.93 | 4. |
| 13 | 0.694 | 0.87 | 1.079 | 1.35 | 1.771 | 2.16 | 2.65 | 3.012 | 3.372 | 3.852 | 4. |
| 14 | 0.692 | 0.868 | 1.076 | 1.345 | 1.761 | 2.145 | 2.624 | 2.977 | 3.326 | 3.787 | 4. |
| 15 | 0.691 | 0.866 | 1.074 | 1.341 | 1.753 | 2.131 | 2.602 | 2.947 | 3.286 | 3.733 | 4. |
| 16 | 0.69 | 0.865 | 1.071 | 1.337 | 1.746 | 2.12 | 2.583 | 2.921 | 3.252 | 3.686 | 4. |
| 17 | 0.689 | 0.863 | 1.069 | 1.333 | 1.74 | 2.11 | 2.567 | 2.898 | 3.222 | 3.646 | 3. |
| 18 | 0.688 | 0.862 | 1.067 | 1.33 | 1.734 | 2.101 | 2.552 | 2.878 | 3.197 | 3.61 | 3. |
| 19 | 0.688 | 0.861 | 1.066 | 1.328 | 1.729 | 2.093 | 2.539 | 2.861 | 3.174 | 3.579 | 3. |
| 20 | 0.687 | 0.86 | 1.064 | 1.325 | 1.725 | 2.086 | 2.528 | 2.845 | 3.153 | 3.552 | 3. |
| 21 | 0.686 | 0.859 | 1.063 | 1.323 | 1.721 | 2.08 | 2.518 | 2.831 | 3.135 | 3.527 | 3. |
| 22 | 0.686 | 0.858 | 1.061 | 1.321 | 1.717 | 2.074 | 2.508 | 2.819 | 3.119 | 3.505 | 3. |
| 23 | 0.685 | 0.858 | 1.06 | 1.319 | 1.714 | 2.069 | 2.5 | 2.807 | 3.104 | 3.485 | 3. |
| 24 | 0.685 | 0.857 | 1.059 | 1.318 | 1.711 | 2.064 | 2.492 | 2.797 | 3.091 | 3.467 | 3. |
| 25 | 0.684 | 0.856 | 1.058 | 1.316 | 1.708 | 2.06 | 2.485 | 2.787 | 3.078 | 3.45 | 3. |
| 26 | 0.684 | 0.856 | 1.058 | 1.315 | 1.706 | 2.056 | 2.479 | 2.779 | 3.067 | 3.435 | 3. |
| 27 | 0.684 | 0.855 | 1.057 | 1.314 | 1.703 | 2.052 | 2.473 | 2.771 | 3.057 | 3.421 | 3. |
| 28 | 0.683 | 0.855 | 1.056 | 1.313 | 1.701 | 2.048 | 2.467 | 2.763 | 3.047 | 3.408 | 3. |
| 29 | 0.683 | 0.854 | 1.055 | 1.311 | 1.699 | 2.045 | 2.462 | 2.756 | 3.038 | 3.396 | 3. |
| 30 | 0.683 | 0.854 | 1.055 | 1.31 | 1.697 | 2.042 | 2.457 | 2.75 | 3.03 | 3.385 | 3. |



## Try These

- The theoretical Value is 9.80. The experimental values are 9.75, 9.20, 9.85, 9.62, 9.98
  - Determine the percent error
  - Determine the (a.d.)
  - Determine the (A.D.)
  - Determine the σ
  - Determine the $s_{\bar{x}}$

**Homework: Error Calculation Problem Sheet**

## Tables

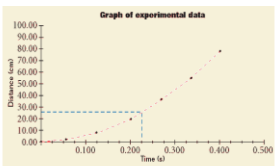
- This table organizes data for two falling balls (golf and tennis) that were dropped in a vacuum. (This is shown in **Figure 13** in your book).
- Can you see patterns in the data?

**Table 7 Data from Dropped-Ball Experiment**

| Time (s) | Distance golf ball falls (cm) | Distance table-tennis ball falls (cm) |
|---|---|---|
| 0.067 | 2.20 | 2.20 |
| 0.133 | 8.67 | 8.67 |
| 0.200 | 19.60 | 19.59 |
| 0.267 | 34.93 | 34.92 |
| 0.333 | 54.34 | 54.33 |
| 0.400 | 78.40 | 78.39 |

## Graphs

- Data from the previous table is graphed.
- A smooth curve connects the data points.
  - This allows predictions for points between data points such as $t$ = 0.220 s.
- The graph could also be extended.
  - This allows predictions for points beyond 0.400 s.




## Coordinate Systems

- Used to describe the position of a point in space
- Coordinate system consists of
  - a fixed reference point called the origin
  - specific axes with scales and labels
  - instructions on how to label a point relative to the origin and the axes

## Equations

- Show relationships between variables
  - Directly proportional
  - Inversely proportional
  - Inverse, square relationships
- Describe the model in mathematical terms
  - The equation for the previous graph can be shown as $\Delta y = (4.9)\Delta t^2$.
- Allow you to solve for unknown quantities

## Proportionality

- In an equation of a=b/c, if b increases and c remains the same then “a” must also increase. We then can say “a” is directly proportional to b
- In an equation of a=b/c, if c increases and b remains the same then “a” must decrease. We then can say “a” is indirectly (inversely) proportional to b

## Greek Letters that remain constant

- Alpha stands for proportional to
- Sigma stands for the sum of
- Delta stands for change in
- Almost all other variables change. DO NOT THINK OF VARIABLES AS CONSTANTS!

## What we did in this chapter

- Scientific Method
- Measurement
- Units
- Scientific Notation
- Conversion Factors
- What is  Mircometer and Vernier Caliper
- Significant Figures
- Error Calculations
- Problem Solving

## References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