Physics 121, Spring 2026
Mechanics, Lecture 01

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Physics 121, Spring 2026. What are we going to talk about today?

- Goals of the course
- Who am I?
- Who are you?
- Course information:
  - Text books
  - Lectures
  - Workshops
  - Homework
  - Exams
  - Quizzes
- Units and Measurements
- Error Analysis.

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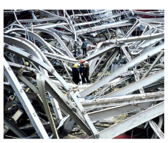
Physics 121, Spring 2026. Goal of the course.

- Physics 121 is a survey course for physics and engineering majors.
- Course topics include motion (linear, rotational, and harmonic), forces, work, energy, conservation laws, and thermodynamics.
- I assume that you have some knowledge of calculus, but techniques will be reviewed when needed.
- I do not assume you have any prior knowledge of physics.



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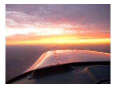
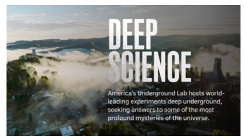
Physics 121, Spring 2026. Who am I?



- I am Frank Wolfs!
- I am a professor in Physics in the Department of Physics and Astronomy.
- I am an experimental nuclear physicist. I have looked for the quark-gluon plasma (the state of matter that existed a few microseconds after the Big Bang) at Brookhaven National Laboratory on Long Island. Currently, I am looking for dark matter at the Sanford Underground Research Facility (SURF) in South Dakota.
- I consider teaching a very component of my job, and I will do whatever I can to ensure you succeed in this course.



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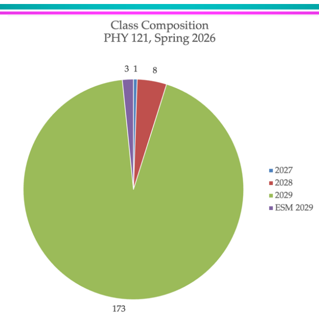
Physics 121, Spring 2026. Who are you?



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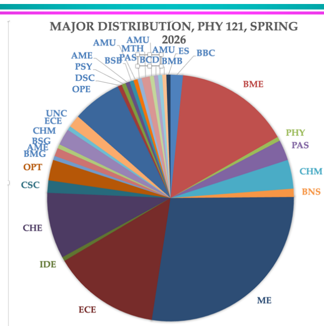
Physics 121, Spring 2026. Who are you?



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Physics 121, Spring 2026.
Why are you here?

- Most of you will say:
  - It is a requirement of my major!
  - I have no clue! I want to be an engineer, and computers do all the engineering calculations.
- Some you may say:
  - I was excited about Physics in high school and I like to learn more about the subject.

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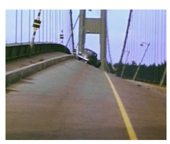
Physics 121, Spring 2026.
Why should you be here?

- All engineering calculations and models are based on physics.
- A basic understanding of the principles of mechanics and the capability to determine whether solutions to problems make sense is a skill that any engineer needs to have.
- Remember ….. A computer is only as smart as the person who programmed it (although some computers are smarter than others).



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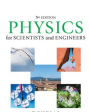
Physics 121, Spring 2026.
Course Information.

- Text Book:
  - Giancoli, Physics for Scientists and Engineers, Fifth Edition.
  - We will cover Chapters 1 – 20, except Chapters 13, 15, and 16.



- Poll Everywhere:
  - For quizzes and conceptual tests, we will use the Poll Everywhere tool (using a web browser or text message). **To receive credit for your answers, you will need to use your UR email address**. You should have received an invitation from the system.

or PollEv.com/frankwolfs050

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Physics 121, Spring 2026. Course Components.

- Lecture:
  - Focus on the concepts of the material, and its connections to areas outside physics.
  - Not a recital of the text book!
  - The lecture presentation is interspersed with conceptual questions and quizzes, solved with and without help from your neighbors.
- Workshops:
  - Small group meetings with a trained workshop leader.
  - Institutionalize the “study group”.
  - You discover how much you can learn from you fellow students.
  - Consistent attendance of workshops correlates with better grades.

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Physics 121, Spring 2026. Course Components.

- Homework assignments:
  - Homework is assigned to practice the material covered in this course and to enhance your analytical problem solving skills.
  - You will need to struggle with the assignments to do well in this course.
  - You will need to make sure you fully understand the solution to these problems!
- Labs:
  - Give you hands-on experience with making measurements and interpreting data.
  - Labs are pretty much separated from the course (not controlled by me), but are **a required component**. No labs, no grade!

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Physics 121, Spring 2026. Course Components.

- Exams:
  - Test you on your basic understanding of the material and your quantitative problem solving skills.
  - There will be three midterm exams and one final exam.
  - There is no need to memorize formulas; you will be given an equation sheet with all important equations for the material covered on the exam.
- Final grades:
  - Calculated in 4 different ways: the highest grade counts.
  - No grading on a curve: grade scale is fixed and known to you!

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Physics 121.
Course Components.

- I am here to help you learn this material, but it is up to you to actually master it:
  - If there is something you do not understand you need to ask for help …….. (come and talk, email, ask after class, etc.)
  - It is my job to teach you …… you are paying my salary ………
  - In lecture courses it is difficult to see who needs help. You need to ask for the help you need before you fall behind.

Your instructor's father.

Your instructor.

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Physics 121.
Understanding your instructor.

So Very Dutch

Dutch directness

The Dutch are renowned for speaking their minds: from complete strangers reprimanding you for chatting in the train's quiet zone, to a friend not telling you a white lie about your bad haircut. Outsiders often see this as being rude or tactless, but for the Dutch it is actually a virtue of sincerity and honesty. They don't mince their words or beat around the bush, and are often not afraid to discuss hot topics such as religion, politics, immigration or money. In fact, it is even seen as a cultural faux pas to not have an opinion. Some studies trace this directness back to the country's history of Calvinism: Calvinists are concerned with the essence of things and what is really important. The good thing about this 'callous' openness? At least you know exactly where you stand with the Dutch.

From KLM Holland Herald

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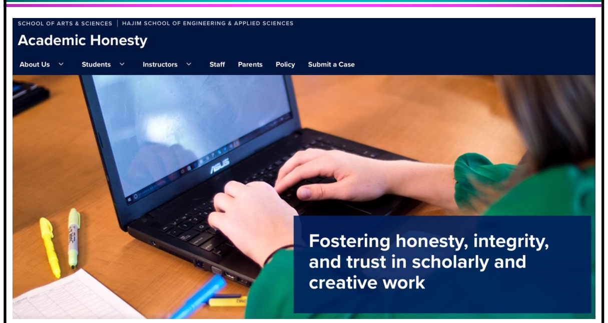
Academic Honesty
https://www.rochester.edu/college/honesty/



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Some examples of what is acceptable in Phy 121.

- Working together on homework assignments.
- Working together on the analysis of your lab experiments.
- Helping each other understanding difficult concepts of the course.
- Asking questions.
- Asking for help when you need help.

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Some examples of what is NOT acceptable in Phy 141.

- Copying the homework solutions of another student and submitting it as your own.
- Copying the lab report of another student and submitting it as your own.
- Using the lab data collected by a different group.
- Cheating on exams.
- Bringing cell phones to exams.
- If in doubt, ask!

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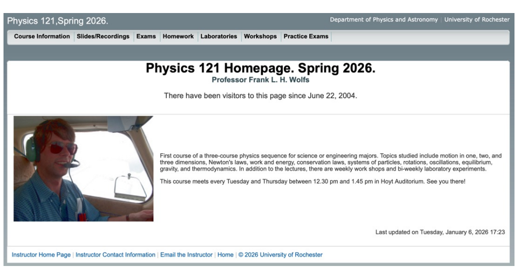
The Physics 121 Home Page

http://teacher.pas.rochester.edu/PHY121/



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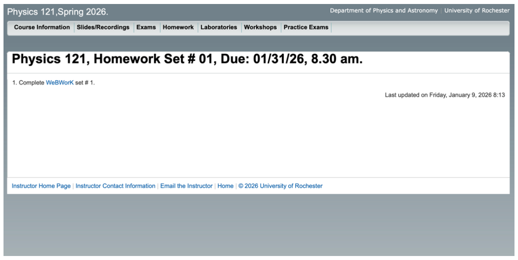
Physics 121 Homework.
More details during Lecture 02.



Let us get started.
Chapter 1.

Chapter 1.
Making measurements. Using units.

- Theories in physics are developed on the basis of experimental observations, or are tested by comparing predictions with the results of experiments.
- Being able to carry out experiments and understand their limitations is a critical part of physics or any experimental science.
- In every experiment you make errors; understanding what to do with these errors is required if you want to compare experiments and theories.

Making measurements.
Using units.

- In order to report the results of experiments, we need to agree on a system of units to be used.
- Only if all equipment is calibrated with respect to the same standard can we compare the results of different experiments.
- Although different units can be used to report different measurements, we need to know what units are used and how to do unit conversions.
- Using the wrong units can lead to expensive mistakes.

http://science.ksc.nasa.gov/mars/msp98/images.html

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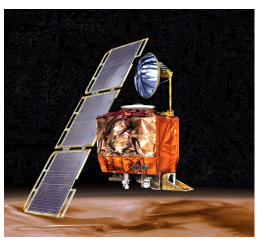
The Mars Climate Orbiter.

- The orbiter burned up in the atmosphere of Mars on September 23, 1999.
- The cause of the burn up was due to different units used by different groups and lack of unit conversion:
  - The navigation team used the metric units: kg, m, s.
  - The company that built the orbiter used English units: pound, feet, second.
  - Someone did not convert the units.



https://science.nasa.gov/mission/mars-climate-orbiter/

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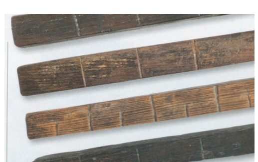
Making measurements.
Which mile? Which inch?

- If you use inches, which inches?
  - Swedish inches?
  - Dutch inches?
  - US inches?
- If you use miles, which miles?
  - Statute mile?
  - Nautical mile?
  - Scots mile?
  - Irish mile?
- Notes:
  - 1 nautical mile is 1/60th of a degree of latitude.
  - 1 nautical mile is 1,852 m.
  - 1 statute mile is 1,609 m.



Several carpenter's rulers were found aboard *Vasa*. The top three rulers employ the Swedish foot, with 12 inches, while the last one is based on the Dutch 11-inch foot. Measurement differences might have resulted in one side of the ship weighing much more than the other.

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Making measurements.
Using units.

- In this course we will use the SI System of units:
  - Length: meter
  - Time: second
  - Mass: kg
- The SI units are related to the units you use in your daily life:
  - Length: 1" = 2.54 cm = 0.0254 m
  - Conversion factors can be found in the front cover of the book.

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The base units.
The unit of length: changes over time!

- One ten-millionth of the meridian line from the north pole to the equator that passes though Paris.
- Distance between 2 fine lines engraved near the ends of a Platinum-Iridium bar kept at the International Bureau of Weights and Measures in Paris.
- 1,650,763.73 Wavelengths of a particular orange-red light emitted by Krypton-86 in a gas discharge tube.
- Path length traveled by light in vacuum during a time interval of 1/299,792,458 of a second.

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The old base SI units.

The old standard of the kilogram and the the meter.

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The base units. Their current definitions.

- TIME - UNIT: SECOND (s)
  - One second is the time occupied by 919,263,170 vibrations of the light (of a specified wavelength) emitted by a Cesium-133 atom.
- LENGTH - UNIT: METER (m)
  - Path length traveled by light in vacuum during a time interval of 1/299,792,458 of a second.
- MASS - UNIT: KILOGRAM (kg)
  - Defined by taking the fixed numerical value of the Planck constant h to be $6.62607015 \times 10^{-34}$ $kg \cdot m^2 \cdot s^{-1}$. A Kibble balance can be used to measure the mass of an object.

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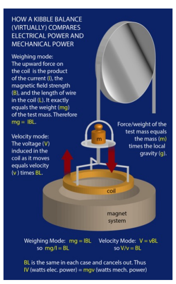
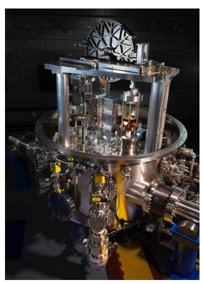
Calibrating the new mass scale.





https://www.nist.gov/si-redefinition/kilogram-kibble-balance

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3 Minute 37 Second Intermission

- Since paying attention for 1 hour and 15 minutes is hard when the topic is physics, let's take a 3 minute 37 second intermission.
- You can:
  - Stretch out.
  - Talk to your neighbors.
  - Ask me a quick question.
  - Enjoy the fantastic music.
  - Solve a WeBWork problem.
  - Go asleep, as long as you wake up in 3 minutes and 37 seconds.

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Error Analysis.
Some (but certainly not all) important facts.

- Why should we care?
- Types of errors.
- The Gaussian distribution - not all results can be described in terms of such distribution, but most of them can.
- Estimate the parameters of the Gaussian distribution (the mean and the width).
- Error propagation.
- The weighted mean.

- Note: Some of the following slides are based on the slides for a lab lecture, prepared by Prof. Manly of the Department of Physics and Astronomy.

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Error Analysis.
Is statistics relevant to you personally?

	Month 1	Month 2	
Bush	42%	41%	
Dukakis	40%	43%	
Undecided	18%	16%	±4%

Headline (1988): Dukakis surges past Bush in polls!

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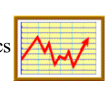
Error Analysis.
Is statistics relevant to you personally?

Global Warming

Analytical medical diagnostics



Effect of EM radiation

33

Error Analysis. Type of Errors.

- Statistical errors:
  - Results from a random fluctuation in the process of measurement. Often quantifiable in terms of "number of measurements or trials". Tends to make measurements less precise.
- Systematic errors:
  - Results from a bias in the observation due to observing conditions or apparatus or technique or analysis. Tend to make measurements less accurate.

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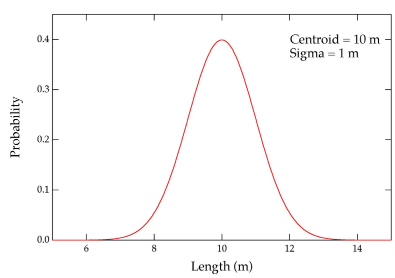
The Gaussian distribution: the most common error distribution.



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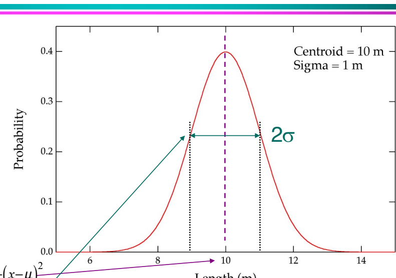
The Gaussian Distribution: its mean and its standard deviation.



$$g(x) = \frac{1}{\sqrt{2\pi}\sigma} e^{\frac{-(x-\mu)^2}{2\sigma^2}}$$

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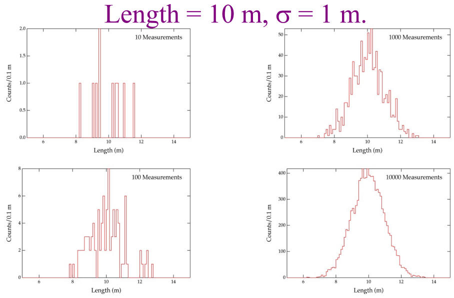
Making measurements: increasing the number of measurements increases the accuracy.

Length = 10 m, σ = 1 m.



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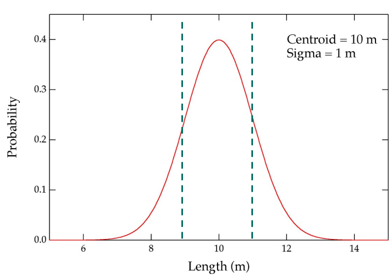
Probability of a single measurement falling within $\pm 1\sigma$ of the mean is 0.683.



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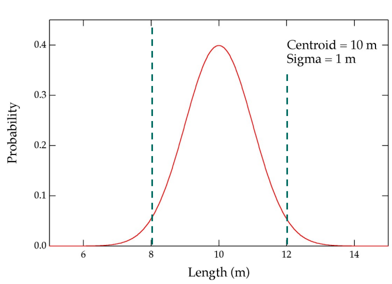
Probability of a single measurement falling within $\pm 2\sigma$ of the mean is 0.954.



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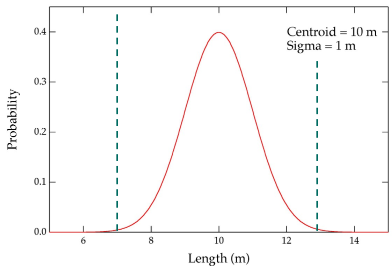
Probability of a single measurement falling within ±3σ of the mean is 0.997.



40

Do you agree?

	Month 1	Month 2	
Bush	42%	41%	
Dukakis	40%	43%	
Undecided	18%	16%	±4%

Headline: Dukakis surges past Bush in polls!

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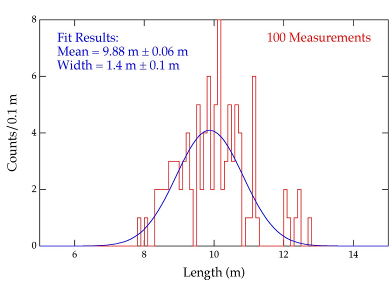
How to determine the mean μ and width σ of a distribution based on *N* measurements?



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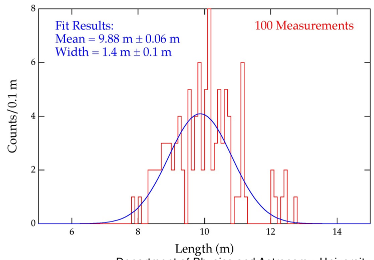
How to determine the mean μ and width σ of a distribution based on N measurements?

$$x = \frac{x_1 + x_2 + \ldots x_{N-1} + x_N}{N} = \frac{1}{N}\sum_{i=1}^{N} x_i = ?\, \mu$$



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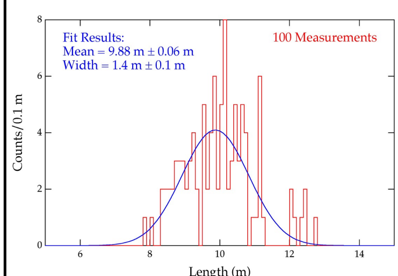
How to determine the mean μ and width σ of a distribution based on N measurements?



The "standard deviation" is a measure of the error in each of the N measurements:

$$\sigma = \sqrt{\frac{\sum_{i=1}^{N}(x_i - \mu)^2}{N}}$$

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How to determine the mean μ and width σ of a distribution based on N measurements?

- The standard deviation is equal to

$$\sigma = \sqrt{\frac{\sum_{i=1}^{N}(x_i - \mu)^2}{N}}$$

- But ….. μ is unknown. We will use the mean (which is your best estimate of μ). We also change the denominator to increase the error slightly due to using the mean. This is the form of the standard deviation you use in practice:

$$\sigma = \sqrt{\frac{\sum_{i=1}^{N}(x_i - x)^2}{N-1}}$$

- Note: **This quantity cannot be determined from a single measurement.**

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What matters? The standard deviation or the error in the mean?

- The standard deviation is a measure of the error made in each individual measurement.
- Often you want to measure the mean and the error in the mean.
- Which should have a smaller error, an individual measurement or the mean?
- The answer ….. the mean, if you do more than one measurement:

$$\sigma_m = \frac{\sigma}{\sqrt{N}}$$

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Measuring the gravitational acceleration g.

Student 1: 9.0 m/s^2
Student 2: 8.8 m/s^2
Student 3: 9.1 m/s^2
Student 4: 8.9 m/s^2
Student 5: 9.1 m/s^2

What is the best estimate of the gravitational acceleration measured by these students?

$$\bar{a} = \frac{9.0+8.8+9.1+8.9+9.1}{5} = 8.98\frac{m}{s^2}$$

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Measuring the gravitational acceleration g.

Student 1: 9.0 m/s^2
Student 2: 8.8 m/s^2
Student 3: 9.1 m/s^2
Student 4: 8.9 m/s^2
Student 5: 9.1 m/s^2

What is the best estimate of the standard deviation of the gravitational acceleration measured by these students?

$$\sigma = \sqrt{\frac{(9.0-9.0)^2+(8.8-9.0)^2+(9.1-9.0)^2+(8.9-9.0)^2+(9.1-9.0)^2}{5-1}}$$
$$= 0.12\frac{m}{s^2}$$

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Measuring the gravitational acceleration *g*.

Student 1: 9.0 m/s²

Student 2: 8.8 m/s²

Student 3: 9.1 m/s²

Student 4: 8.9 m/s²

Student 5: 9.1 m/s²

$$\sigma_m = \frac{0.12}{\sqrt{5}} = 0.054 \frac{m}{s^2}$$

Note: this procedure is valid if you can assume that all your measurements have the same measurement error.

Final result: $g = 8.98 \pm 0.05$ m/s². Does this agree with the accepted value of 9.8 m/s²?

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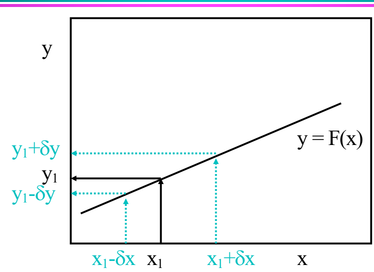
How does an error in one measurable affect the error in another measurable?



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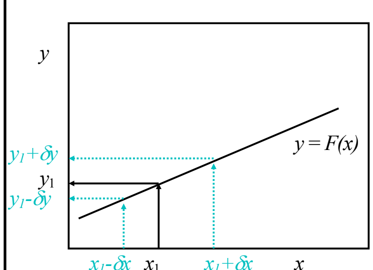
How does an error in one measurable affect the error in another measurable?



The degree to which an error in one measurable affects the error in another is driven by the functional dependence of the variables (or the slope: dy/dx)

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How does an error in one measurable affect the error in another measurable?

- But …… Most physical relationships involve multiple measurables!

$$x = x_0 + v_0 t + \frac{1}{2} a t^2$$

$$F = Ma$$

$$P = Mv$$

- We must take into account the dependence of the parameter of interest, f, on each of the contributing quantities, x, y, z, ….: $f = F(x, y, z, \ldots)$

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Error Propagation. Partial Derivatives.

- The partial derivative with respect to a certain variable is the ordinary derivative of the function with respect to that variable where all the other variables are treated as constants.

$$\frac{\partial F(x,y,z,\ldots)}{\partial x} = \left.\frac{dF(x,y,z,\ldots)}{dx}\right]_{y,z,\ldots=\text{constant}}$$

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Error Propagation. Partial Derivatives: an example.

$$F(x,y,z) = x^2 y z^3$$

$$\frac{\partial F}{\partial x} = 2xyz^3$$

$$\frac{\partial F}{\partial y} = x^2 z^3$$

$$\frac{\partial F}{\partial z} = 3x^2 y z^2$$

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Error Propagation. The formula!

- Consider that a parameter of interest $f = F(x, y, z, \ldots)$ depends on the measured parameters $x, y, z, \ldots$.
- The error in f, σ_f, depends on the function F, measured parameters $x, y, z, \ldots$, and their errors, σ_x, σ_y, σ_z, …. and can be calculated using the following formula:

$$\sigma_f = \sqrt{\left(\frac{\partial F}{\partial x}\right)^2 \sigma_x^2 + \left(\frac{\partial F}{\partial y}\right)^2 \sigma_y^2 + \left(\frac{\partial F}{\partial z}\right)^2 \sigma_z^2 + \cdots}$$

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The formula for error propagation. An example.

A pitcher throws a baseball a distance of 30 ± 0.5 m at 40 ± 3 m/s (~90 mph). From this data, calculate the time of flight of the baseball.

$$t = \frac{d}{v}$$
$$\frac{\partial F}{\partial d} = \frac{1}{v}$$
$$\frac{\partial F}{\partial v} = -\frac{d}{v^2}$$

$$\sigma_t = \sqrt{\left(\frac{1}{v}\right)^2 \sigma_d^2 + \left(-\frac{d}{v^2}\right)^2 \sigma_v^2} = \sqrt{\left(\frac{0.5}{40}\right)^2 + \left(\frac{30}{40^2}\right)^2 3^2} = 0.058 \Rightarrow$$

$t = 0.75 \pm 0.06 s$

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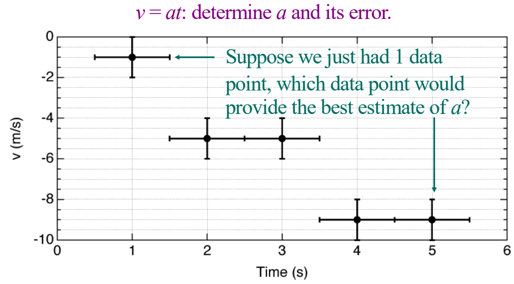
Another example of error propagation.

$v = at$: determine a and its error.



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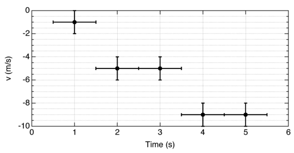
Another example of error propagation.

- For each data point we can determine a (= v/t) and its error:

$$\sigma_a = \sqrt{\left(\frac{1}{t}\sigma_v\right)^2 + \left(\frac{v}{t^2}\sigma_t\right)^2}$$

or

$$\sigma_a = \frac{v}{t}\sqrt{\left(\frac{\sigma_v}{v}\right)^2 + \left(\frac{\sigma_t}{t}\right)^2}$$



- We see that the error in a is different for different points. Simple averaging will not be the proper way to determine a and its error.

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The weighted mean.

- When the data have different errors, we need to use the weighted mean to estimate the mean value.
- This procedure requires you to assign a weight to each data point:

$$w_i = \frac{1}{\sigma_i^2}$$

- Note: when the error decreases the weight increases.
- The weighted mean and its error are defined as:

$$y = \frac{\sum_{i=1}^{N} w_i y_i}{\sum_{i=1}^{N} w_i} \qquad \sigma_y^2 = \frac{1}{\sum_{i=1}^{N} w_i}$$

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The end of my error analysis. The start of your learning curve.

- Certainly there is a lot more about statistical treatment of data than I can cover in part of one lecture.
- A true understanding comes with practice, and this is what you will do in the laboratory.

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We are done (for today)!

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