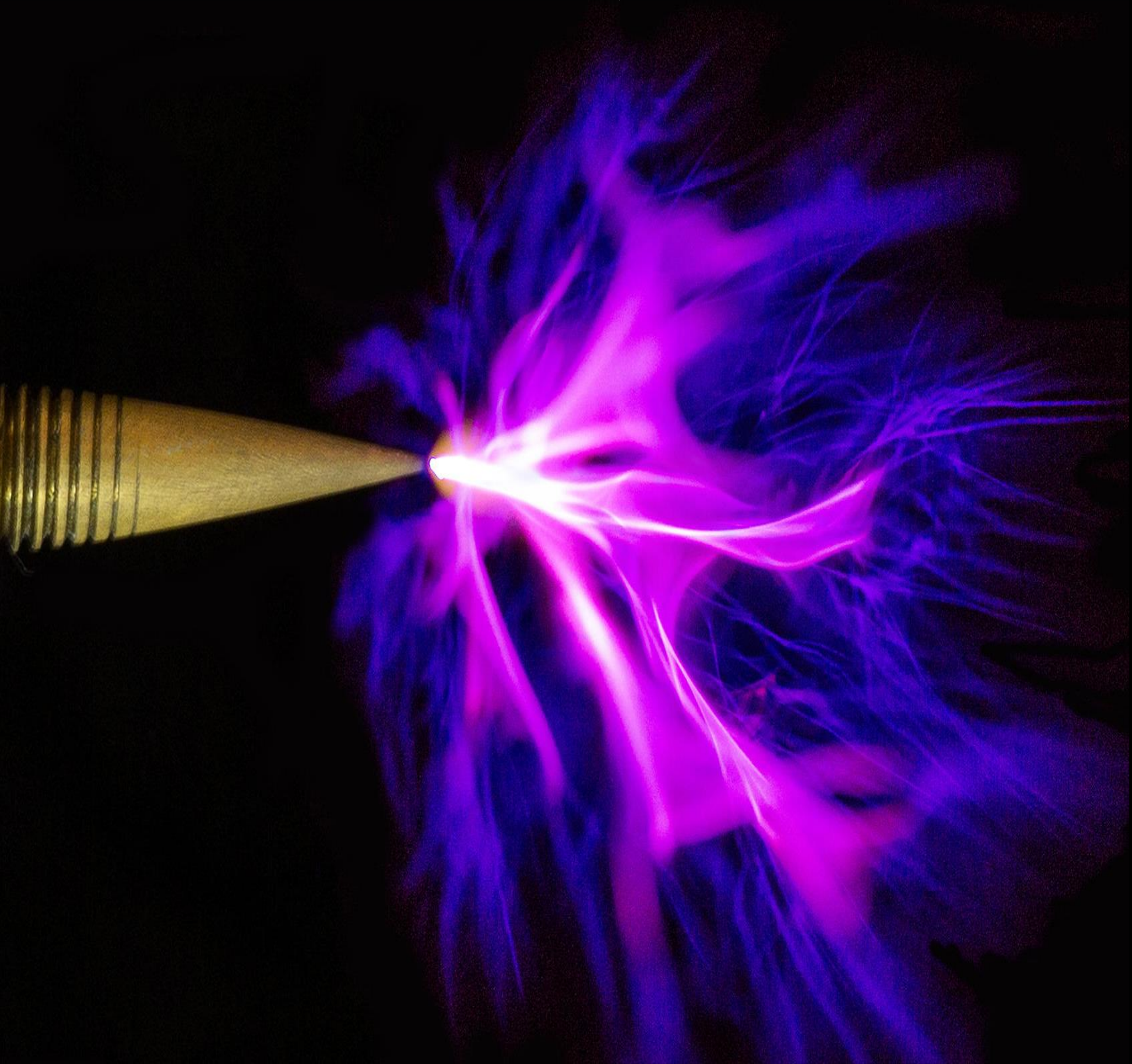


INTERNATIONAL INSTITUTE OF INFORMATION TECHNOLOGY
HYDERABAD

IIIT Hyderabad

SCIENCE LABORATORY INTRODUCTION

Science Lab I Course (SC4.110)

TOPICS

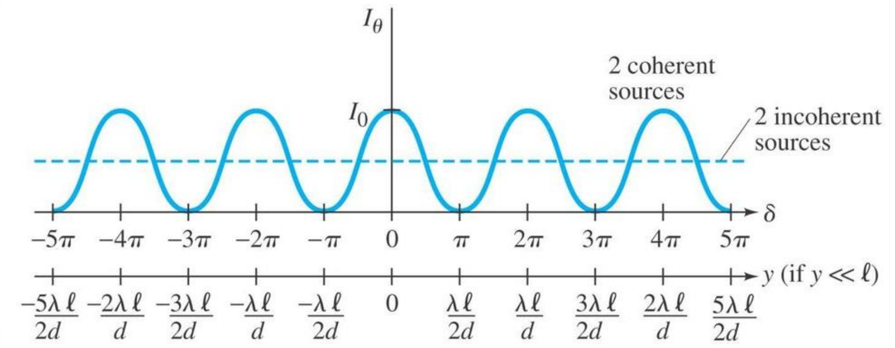
- ❑ Objectives
- ❑ Laboratory Notebook Writing
- ❑ Plotting Graphs
- ❑ Errors
- ❑ Least Square Fitting
- ❑ Laboratory Safety Protocol
- ❑ References

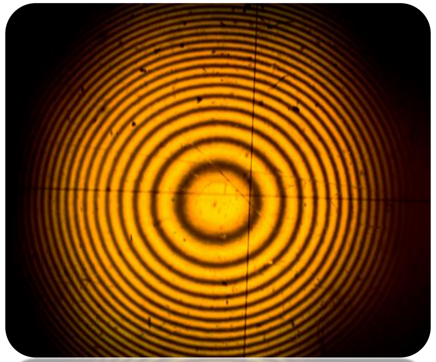
OBJECTIVES

LEARNING BY DOING

TO DEMONSTRATE THEORETICAL IDEAS IN PHYSICS

- A demonstration is often a great help in understanding it.
- Example: Interference of Light





- But the demonstration is no substitute for a proper explanation, which goes into the details of geometry and phase relations. So the first object, the demonstration.
- The demonstration of theoretical ideas, has a definite but limited usefulness.

TO PROVIDE A FAMILARITY WITH APPARATUS

- Train you how to use instruments in general.
- Example: Different types of instrument

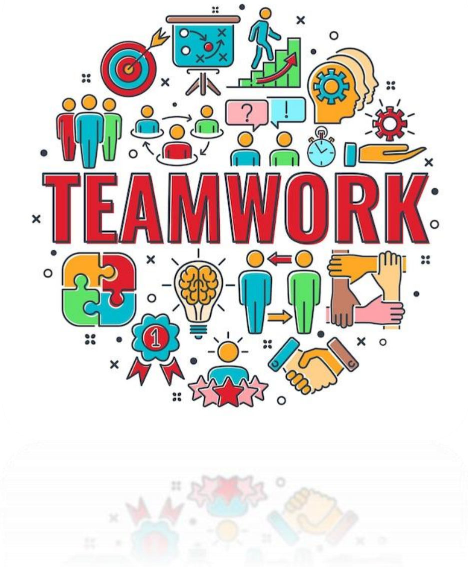
- There is a certain attitude of mind that an experimenter should adopt when handling any instrument, and this **the course should try to instil**.

TO PROVIDE A TRAINING IN HOW TO DO EXPERIMENTS

- Plan an experiment whose precision is appropriate to its purpose.
- Be aware of and take steps to eliminate systematic errors in methods and instruments.
- Analyse the results in order to draw correct conclusions.
- Estimate the precision of the final result.
- Record the measurements and calculations accurately, clearly, and concisely.

TEAMWORK*

- Careful and stepwise observation of sequences during an experiment or activity facilitate personal investigation as well as small group or team learning.

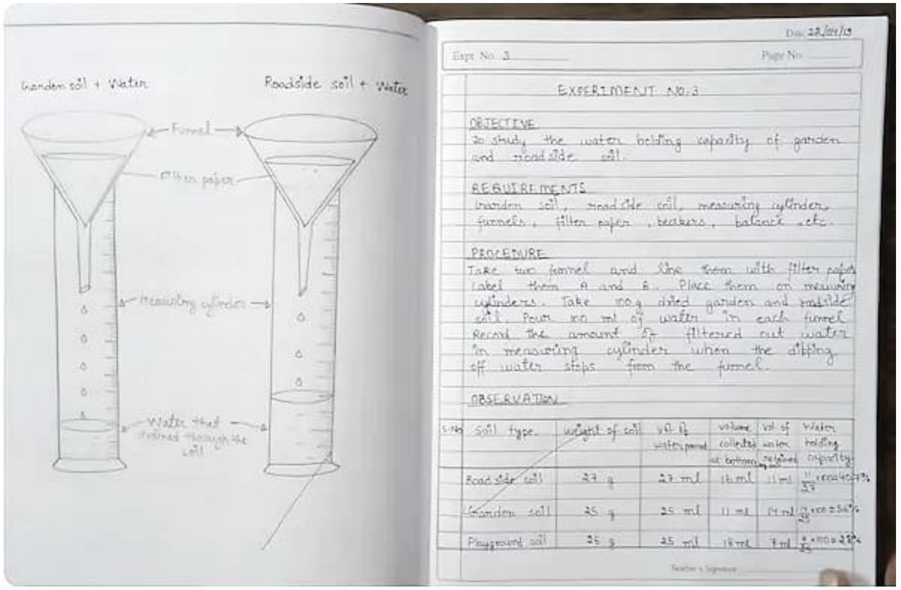


* NO TEAMWORK in ENDSEM!!!

LABORATORY NOTEBOOK WRITING

STRUCTURE OF WRITING

- The laboratory report should always be written for the convenience of the reader.
- Each section of the report should be headlined and the sections should be arranged in an appropriate, easily-understood sequence.
- the laboratory report serves to describe what you did during the laboratory session, how you manipulated the raw data, and what you conclude as a result.



SECTION REQUIRED TO COMPLETE PHYSICS LAB REPORTS

- The following heads may usually be followed for preparing the report:

Date: .... Experiment No:....................... Page No:...............

- **Aim:**
  - Write the aim of the experiment.

- **Theory/ Principle:**
  - Mention the principle underlying the experiment.
  - Also, write the formula used, explaining clearly the symbols involved (derivation required).
  - Draw a circuit diagram neatly for experiments/ activities related to electricity and ray diagrams for light.

- **Apparatus and Materials Required:**
  - Write down all the apparatus that you are using.

SECTION REQUIRED TO COMPLETE PHYSICS LAB REPORTS

- **Procedure:**
  - Write the procedure of the experiment in your own words.
  - Do the necessary preparatory calculations.

- **Experimental Data(s)/ Observation(s):**
  - Record the lab temperature before and after the experiment.
  - Record the observations in tabular form as far as possible.
  - Mention clearly, on the top of the observation table, the least counts and the range of each measuring instrument used.
  - If the result of the experiment depends upon certain conditions like temperature, pressure etc., then mention the values of these factors.

- **Calculation(s):**
  - Substitute the observed values of various quantities in the formula.
  - Wherever possible, use the graphical method for obtaining the result.

SECTION REQUIRED TO COMPLETE PHYSICS LAB REPORTS

- **Plotting Graph(s): (Discussed Later)**
  - Plot all the necessary graphs.
  - Write the name of the variable in the X and Y axes with proper units.
  - Mention the SSD (Smallest Scale Division) along both axes.
  - Mention all the conditions/ criteria for the graphs.
  - Do least square fitting (if needed).

- **Error Calculation(s):**
  - Calculate experimental error/ Maximum proportionality error.

SECTION REQUIRED TO COMPLETE PHYSICS LAB REPORTS

- **Precaution(s):**
  - Mention the precautions actually observed during the course of the experiment/activity.
  - Mention the possible sources of error that are beyond the control of the individual while performing the experiment and are liable to affect the result.

- **Discussion(s):**
  - The special reasons for the set up etc., of the experiment are to be mentioned under this heading.
  - Also mention any special inferences which you can draw from your observations or special difficulties faced during the experimentation.
  - These may also include points for making the experiment more accurate for observing precautions and, in general, for critically relating theory to the experiment for better understanding of the basic principle involved.

SECTION REQUIRED TO COMPLETE PHYSICS LAB REPORTS

- **Reference(s):**
  - Using **standard bibliographic format (APA)**, cite all the published sources you consulted during the conduct of the experiment and the preparation of your laboratory report.
    - Author's last name, Author's first initial. Author's middle initial. (Year, Month Date published). Article title. *Journal Name*, Volume(Issue), page number(s). https://doi.org/ or URL (if available).
    - **Example (Book):** Squires, G. L. (1985) "Practical physics," Cambridge University Press, Cambridge.
    - **Example (Research Paper):** Einstein, A., Podolsky, B., & Rosen, N. (1935). Can Quantum-Mechanical Description of Physical Reality Be Considered Complete? Phys. Rev., 47, 777–780. doi:10.1103/PhysRev.47.777
  - **Online Reference(s):**
    - List the author(s), Name of the article, URL, Date in DDMMYYYY and Time in 24hrs format.
    - **Example:** Rasmussen, C. (2021, October 12) Icy 'glue' may control pace of Antarctic ice-shelf breakup. National Aeronautics and Space Administration. https://www.nasa.gov/feature/jpl/icy-glue-may-control-pace-of-antarctic-ice-shelf-breakup (Cited on 03.08.2024 at 15:02 IST).

PLOTTING GRAPHS

AN EASY APPROACH

KEEP THE DATA IN ONE PLACE

- Choose the X axis variable and Y axis variable.
- Keep all data in one place.
- This helps you track your data, otherwise, you can be lost in all the data.
- You can rewrite the table in a different section.

Example:

A (unit)	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
B (unit)	30.914	34.751	39.188	43.494	47.817	51.266	52.998	59.444	63.441	67.733	72.165	76.213	80.461	84.272	88.078	92.064

- Here we will plot A in X axis and B at Y Axis.

CALCULATE THE SMALLEST SCALE DIVISION

- Fix the origin. You can shift the origin to have a clear visibility of the plot.
- Count the number of small boxes along x and y.
- Take the origin value (min value) and the maximum value of the data set of both axes. (**N.B.:** Take the maximum value greater than the data set, so that you don't end up with the final point at the corner of the graph.)
- Subtract and divide them by the number of small boxes to get the SSD.

Example:

A (unit)	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
B (unit)	30.914	34.751	39.188	43.494	47.817	51.266	52.998	59.444	63.441	67.733	72.165	76.213	80.461	84.272	88.078	92.064

- Here we can choose the origin at (0, 30). No. of small boxes along x = 170, and y = 220.
- The origin value of A is 0 and the max value from the data set is 15. Let's take the max value of A as 15. Therefore the SSD is (15-0)/170 unit ≈ 0.094 unit.
- The origin value of B is 30 and the max value from the data set is 92.064. Let's take the max value of B as 93. Therefore the SSD is (93-30)/220 unit ≈ 0.286 unit.

FINDING THE (X,Y)

- Choose a data point.
- Subtract the corresponding value with the origin value (or min value) of the axis and divide it by the SSD of the axis.
- Approximate it to the nearest integer.
- Write the (x,y) value for each.

Example:

A (unit)	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
B (unit)	30.914	34.751	39.188	43.494	47.817	51.266	52.998	59.444	63.441	67.733	72.165	76.213	80.461	84.272	88.078	92.064
(x,y)						(53, 74)										

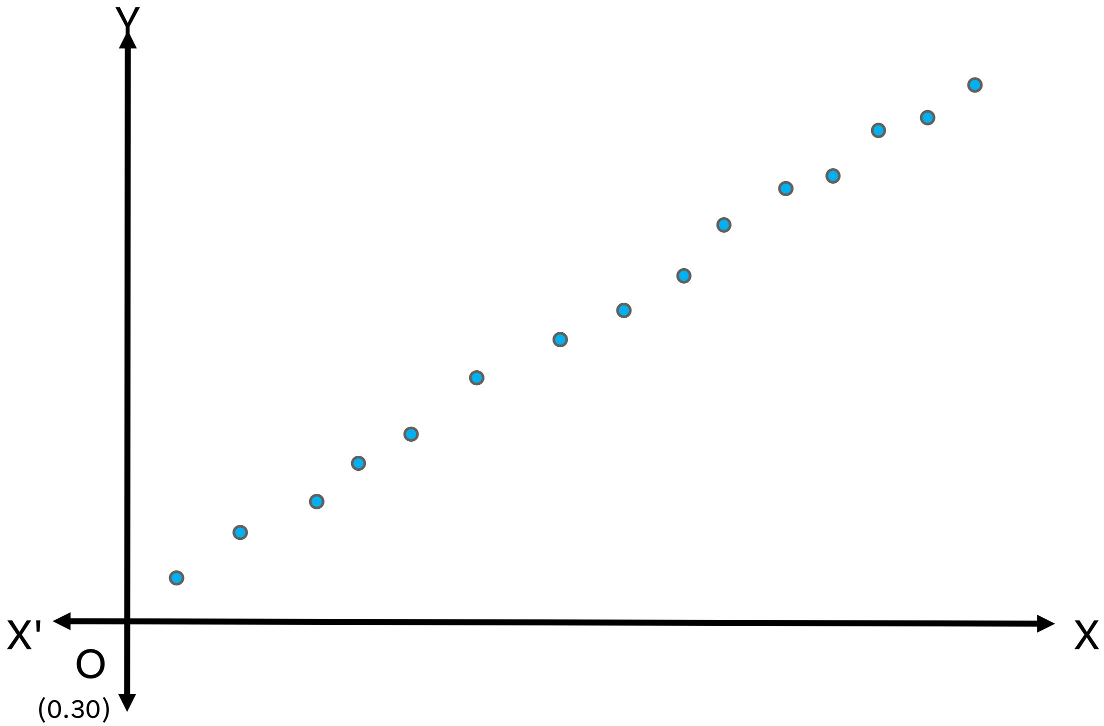
- For the highlighted value, the value of A is 5, and B is 51.266.
- Therefore, $x = (5-0)/0.094 = 53.19 \approx 53$ and $y = (51.266-30)/0.286 = 74.36 \approx 74$.
- So, (x,y) = (53,74) for the highlighted value.

DRAW THE AXES AND LABEL IT

- Choose a data point.
- Subtract the corresponding value with the origin value (or min value) of the axis and divide it by the SSD of the axis.
- Approximate it to the nearest integer.
- Write the (x,y) value for each.

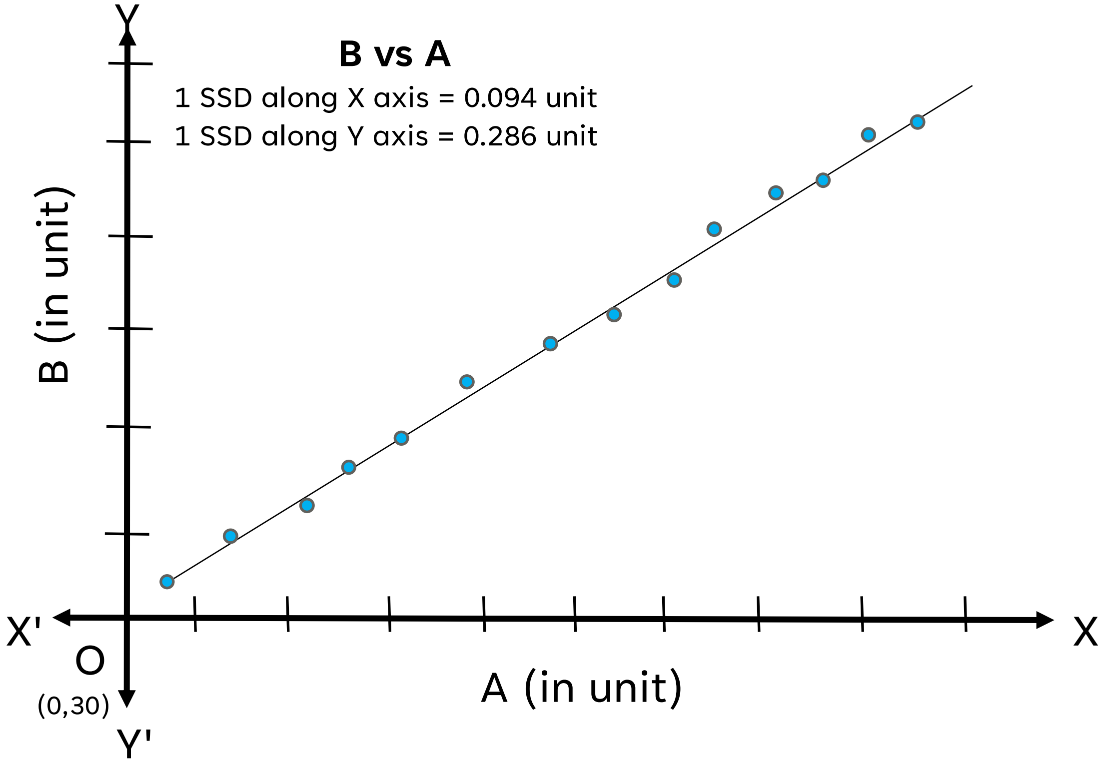
PLOT THE POINTS

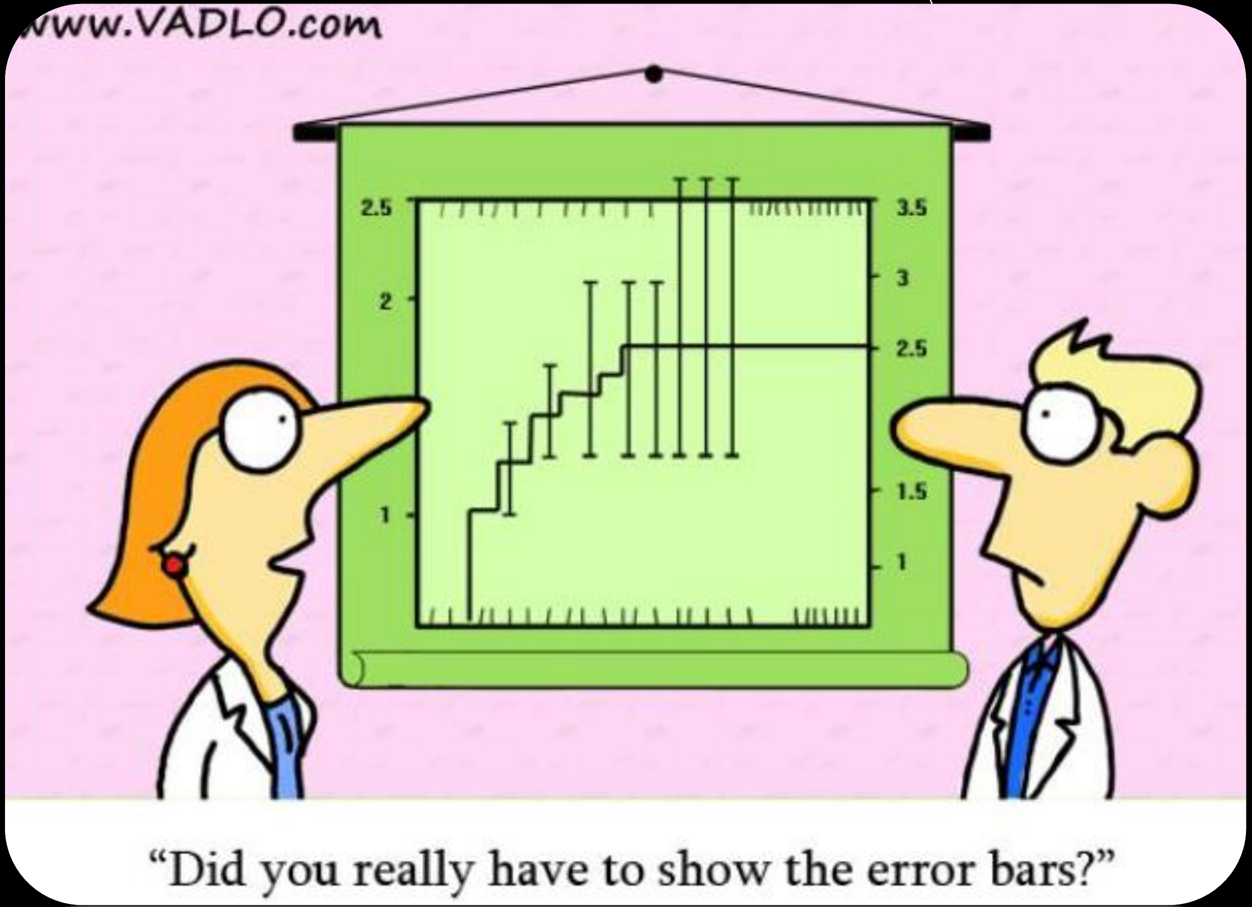
- Choose a data point.
- Subtract the corresponding value with the origin value (or min value) of the axis and divide it by the SSD of the axis.
- Approximate it to the nearest integer.
- Write the (x,y) value for each.



FINISHING TOUCH

- Write the name of the plot. Always write Y vs X.
  - **Example:** B vs A.
- Write the SSD along the axes.
  - **Example:** 1 SSD along X = 0.094 unit, 1 SSD along Y = 0.286 unit.
- Write the name of the variable beneath or aside of axes along with its unit. (which is suitable).




www.VADLO.com
2.5
2
1
3.5
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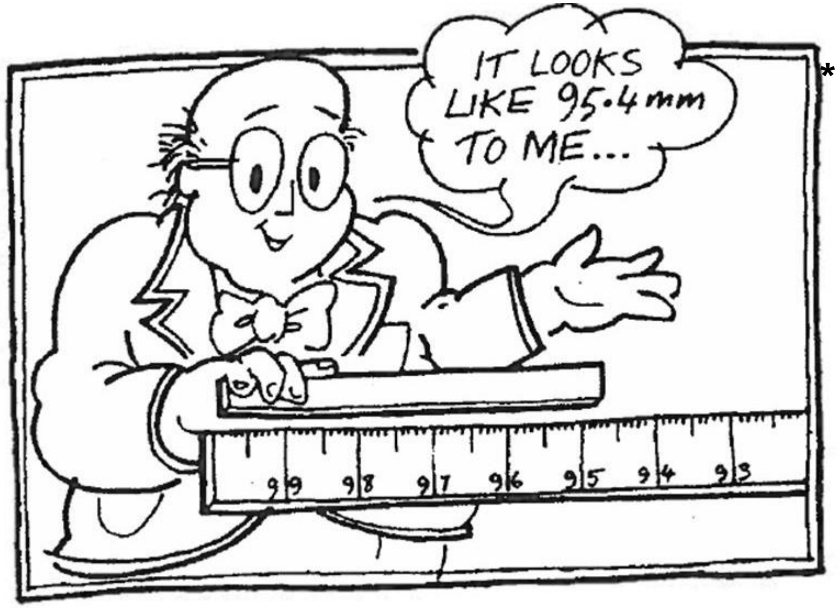
1
"Did you really have to show the error bars?"

ERRORS!

ERRORS............. TO ERR IS HUMAN!

- We expect the measurment outcome of a quantity is exactly equal to the true value.
- It is important to give some indication of how close the result is likely to be to the true value.
  - Example: Focal length f of a lens is $f = (256 \pm 2)$ mm.
- It means, not that we are certain that the value lies between the limits quoted, but that our measurements indicate that there is a certain probability of its doing so.



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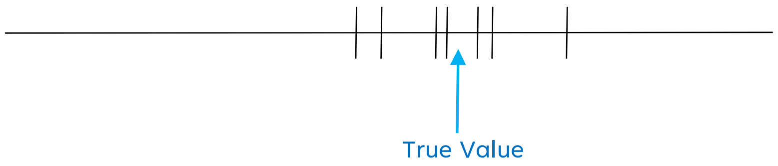
*Wilcock, A. (2015), *The Realm of Physics, Measurement and Uncertainty.* https://slideplayer.com/slide/2519394/.

SYSTEMATIC ERRORS

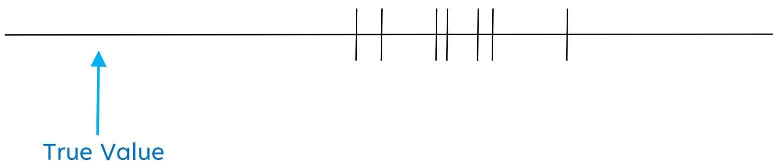
- A systematic error is one which is constant throughout a set of readings.
- Systematic errors often arise because the experimental arrangement is different from that assumed in the theory, and the correction factor which takes account of this difference is ignored.
- Repeated measurements with the same apparatus neither reveal nor do they eliminate a systematic error.



- Systematic errors do not lend themselves to any clear-cut treatment.
- Your safest course is to regard them as effects to be discovered and eliminated.
- There is no general rule for doing this.

RANDOM ERRORS

- A random error is onewhich varies and which is equally likely to be positive or negative.
- Random errors may be detected by repeating the measurements.
- Furthermore, by taking more and more readings we obtain from the arithmetic mean a value which approaches more and more closely to the true value.

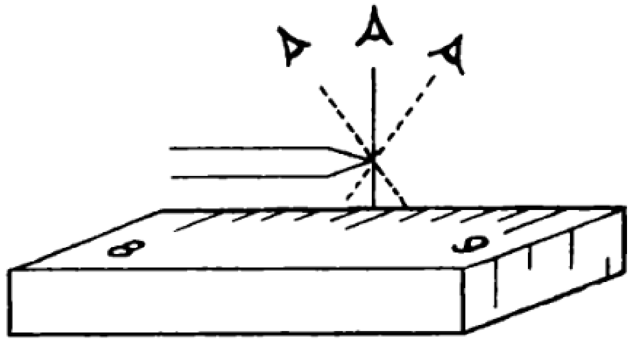


- Random errors may be estimated by statistical methods.

SYSTEMATIC ERRORS!

PARALLAX ERROR

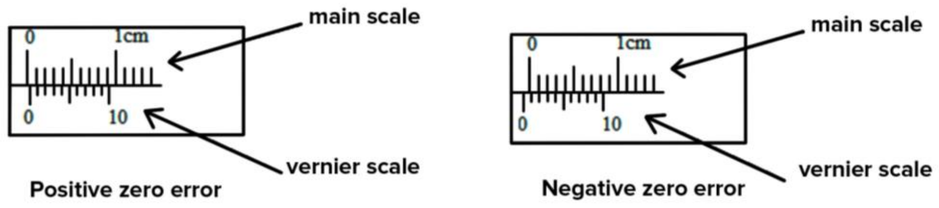
- A gap between the object being measured and the scale, and the line of sight is not at right angles to the scale.



- **Remedy:**
  - Align the image of the eye with the object.
  - Ensure the line of sight is at right angles to the scale.

ZERO ERROR

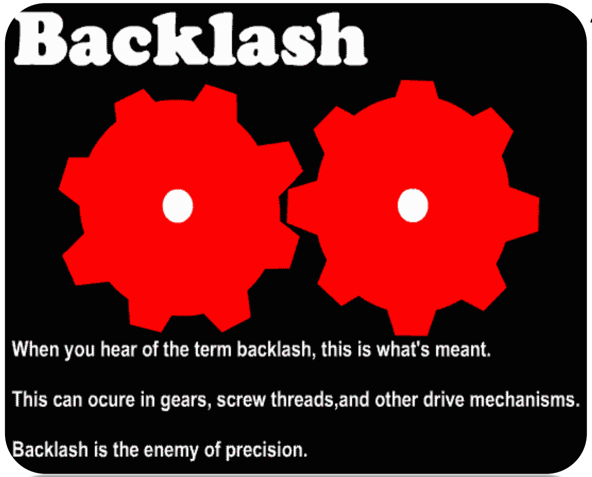
- In general the zero position of any instrument should be regarded as suspect.
- Zero is not at zero!



- **Remedy:**
  - A Simple substraction.
  - Actual value = (Observed value – zero error)

BACKLASH ERROR

- When gears are changed, a motion error known as a backlash error might happen.
- When the thimble's direction of rotation is reversed, backlash error happens when the screw's tip does not start moving in the other direction right away but instead stays still for a portion of the revolution.
- Wear and tear on the screw threads is the cause of it.



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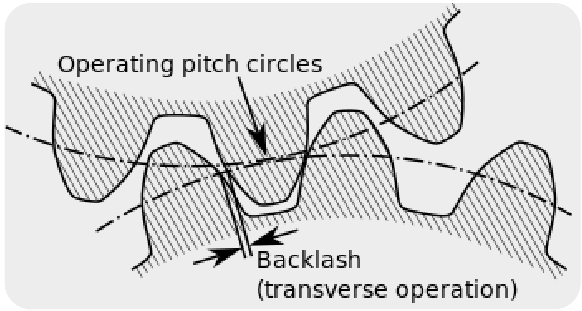
- **Remedy:**
  - Rotating the screw head always in the same direction while taking a set of observations.



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*From https://www.quora.com/What-is-backlash-in-instrumentation

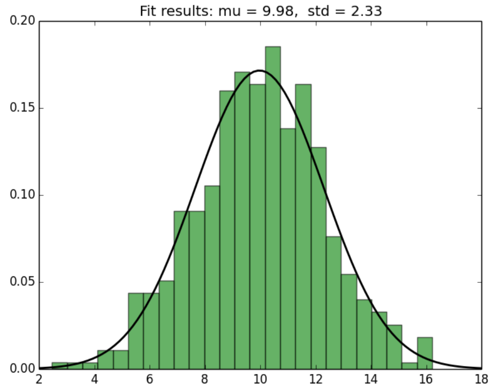
RANDOM ERRORS

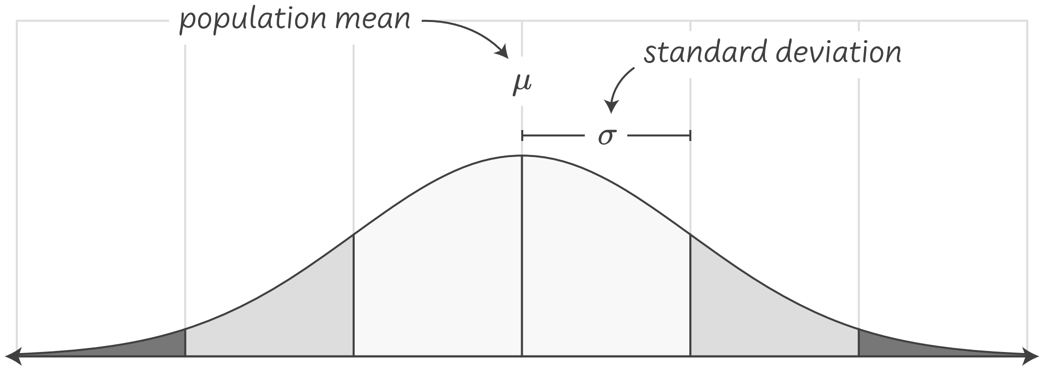
INTRODUCTION

- Let, there be no systematic error in our measurement of a given quantity.
- Each time we measure, we have different values of the same quantity.
- The individual values x_1, x_2 etc., vary owing to random errors.
- **Remedy:**
  - Take the arithmetic average: $\langle x \rangle = \frac{1}{N}\sum_i x_i$
- **Question: How many values do we actually need to take?**
- **Answer: 3 to 5**

DISTRIBUTION IS NORMAL!

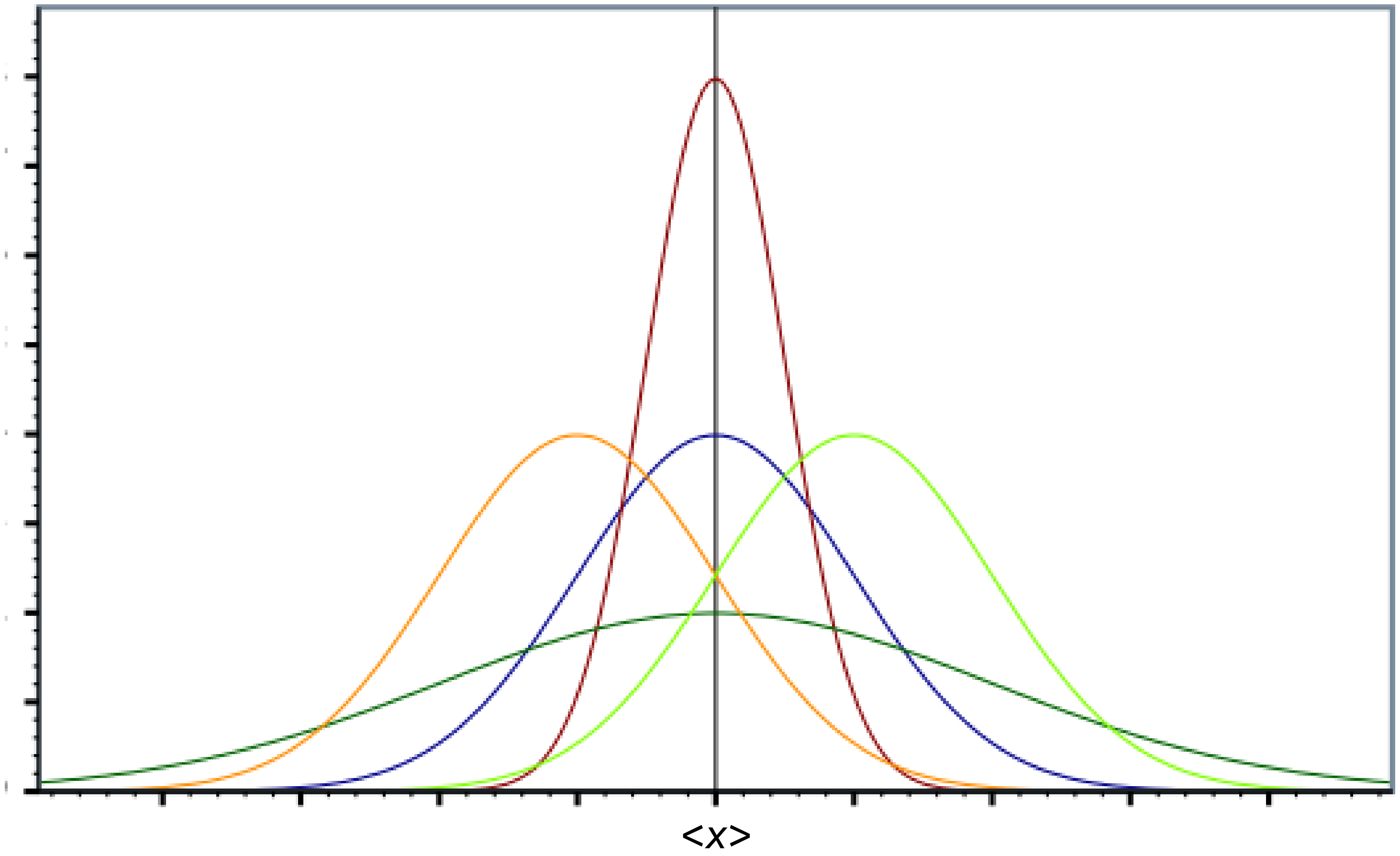
- Although we have only n actual measurements, we imagine that we go on making the measurements so that we end up with a very large number N.
- Suppose N is say 10000000. We call this hypothetical set of a very **large number of readings a distribution.**
- If we plot the Number of readings (Data Frequency) vs the value of the quantity (Data range), then it is a Normal (Gaussian) distribution.
- Let the mean is at $\langle x \rangle = \mu$.
- We calculate the standard deviation (σ) of the curve which is measure of the spread of the distribution.
- If σ is small, the measurements will be highly peaked near the $\langle x \rangle$.
- If σ is large, the measurements will be scattered around $\langle x \rangle$.





EXERCISE: WHAT YOU CHOOSE? WHY YOU CHOOSE?

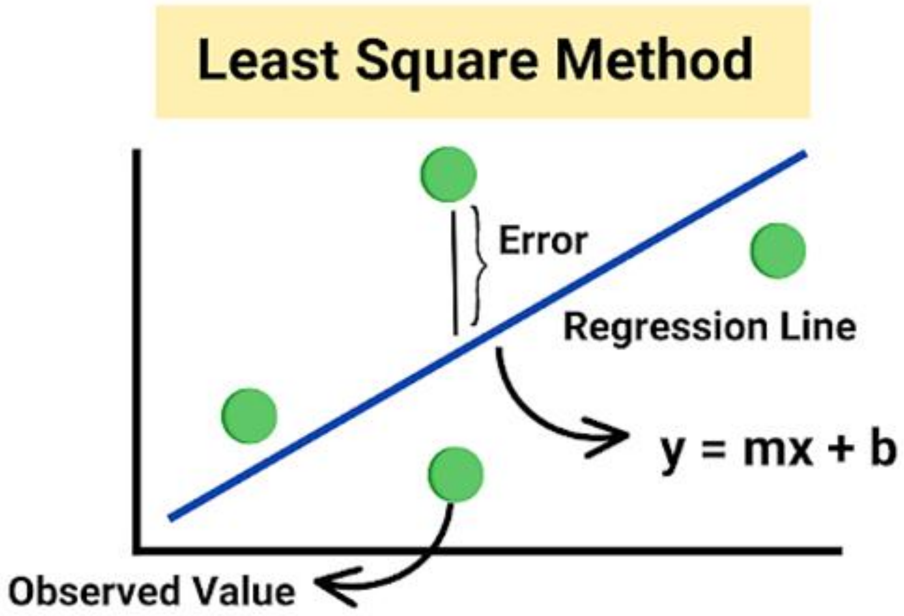
- Can you comment on every plot?
- What do you choose for your measurement?



LEAST SQUARE FITTING

INTRO

- Let consider two quantities y and x such that, $y = y(x)$.
- The values are then plotted on a graph, and we try to find a curve corresponding to $y = y(x)$ which passes as closely as possible through the points.
- Let us consider the function is straight line i.e. $y = mx + b$.
- Our target: To calculate m and b.

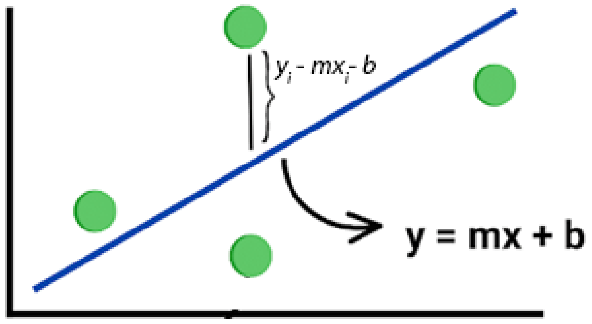


THEORY

- Suppose there are n pairs of measurements: $(x_1, y_1), (x_2, y_2), \ldots, (x_n, y_n)$.
- Assume that the errors are entirely in the *y* values.
- For a given pair of *m* and *b*, the deviation of the i^{th} reading is $y_i - mx_i - b$.
- The best values of *m* and *b* are taken to be those for which

$$S = \sum_i (y_i - mx_i - b)^2$$

  is minimum: Hence the name method of least square.



- Solution:

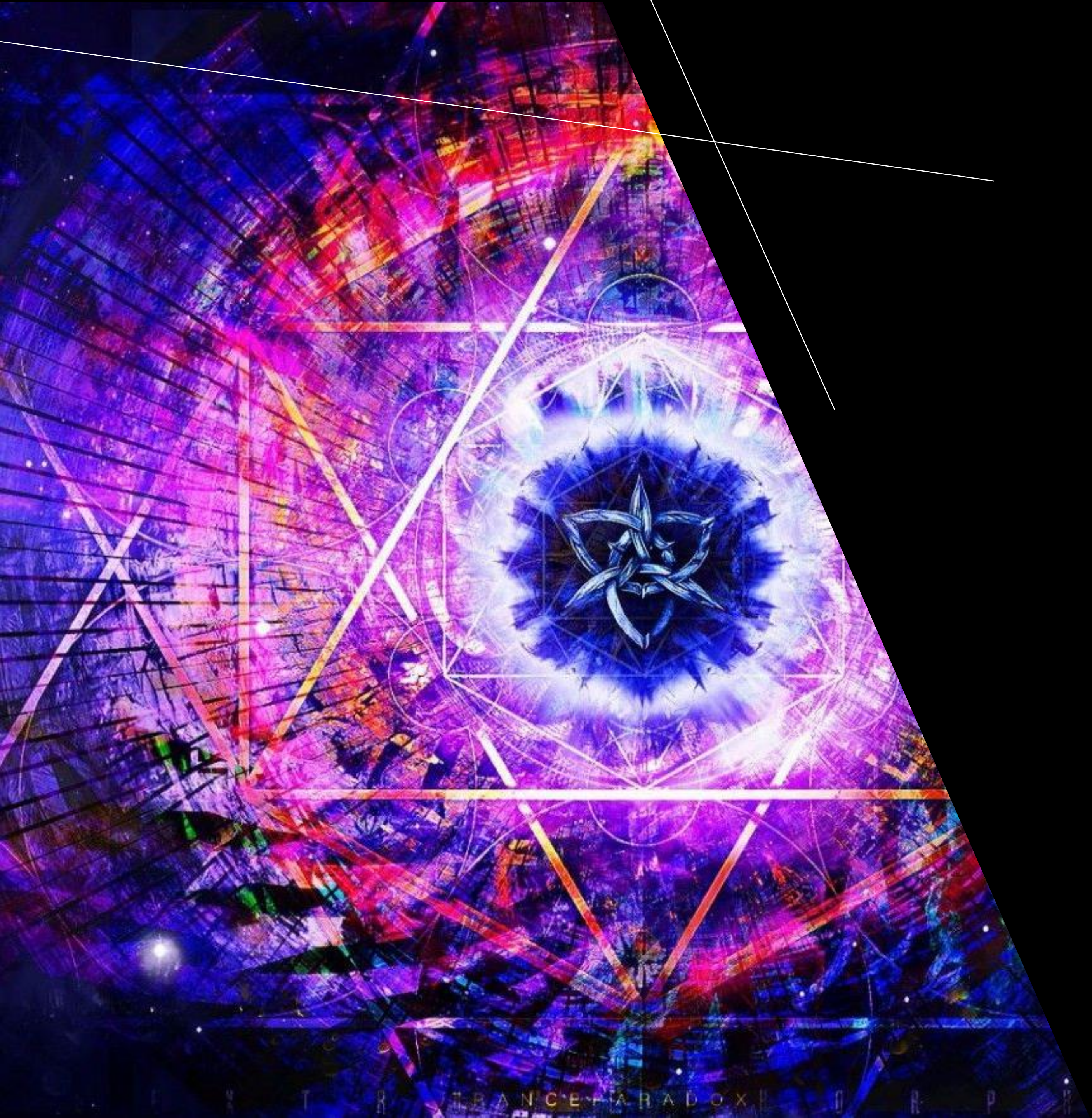
$$m = \frac{N\sum_i x_i y_i - \sum_i x_i \ \sum_i y_i}{N\sum_i x_i^2 - \left(\sum_i x_i\right)^2}$$

$$b = \frac{\sum_i y_i - m\sum_i x_i}{N}$$

EXERCISE

- Plot all the data points in a graph.
- Do the least square fitting by finding out the corresponding equation.
- Draw the straight line on the same graph.

A (unit)	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
B (unit)	30.914	34.751	39.188	43.494	47.817	51.266	52.998	59.444	63.441	67.733	72.165	76.213	80.461	84.272	88.078	92.064



ERROR CALCULATIONS IN PRACTICE

STANDARD ERROR

INTRO

- Let us calculate the Standard Error!
- Why we estimate error? It is to provide a measure of the significance of the final result.
- Let Z (the final quantity) is a function of the primary quantities A, B, C, ... which are either measured directly or are the slopes or intercepts of straight lines drawn through points representing directly measured quantities.
- The best value of Z is calculated from the best values of the primary quantities, and its error is obtained from their errors.
- There are often a large number of primary quantities to be measured, and it might be thought that the calculation of the error in each one and the subsequent calculation of the error in Z would be a laborious process.

CALCULATION TECHNIQUES

- Let you have the quantity: $Z = \frac{AB^2}{C}$.
- Take derivative.

$$\Delta Z = \frac{C\Delta(AB^2) - (AB^2)\Delta C}{C^2} = \frac{CB\Delta A + 2CAB\Delta B - AB\Delta C}{C^2}$$

- Now divide it with Z.

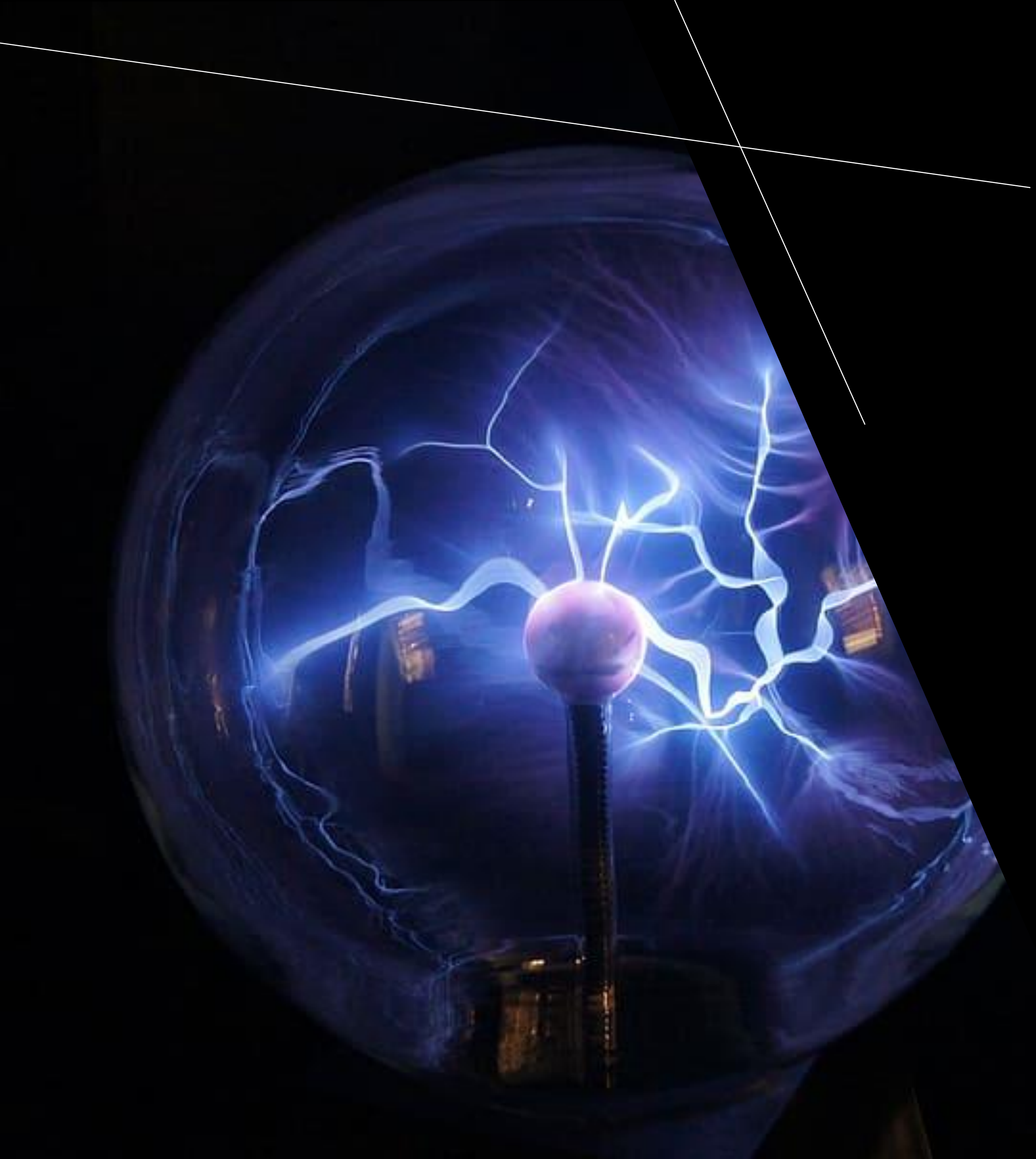
$$\frac{\Delta Z}{Z} = \frac{CB^2\Delta A + 2CAB\Delta B - AB\Delta C}{C^2 \times \frac{AB^2}{C}} = \frac{CB^2\Delta A + 2CAB\Delta B - AB\Delta C}{AB^2 C} = \frac{\Delta A}{A} + 2\frac{\Delta B}{B} + \frac{\Delta C}{C}$$

$$\boxed{\therefore \frac{\Delta Z}{Z} = \frac{\Delta A}{A} + 2\frac{\Delta B}{B} + \frac{\Delta C}{C}}$$

- Now put the values of everything for a typical set of observed values A, B, C.
- Remember: ΔA means the minimum value that you can measure of quantity A.
- If a value of a quantity X is known fairly accurately, then ΔX is 0.

EXERCISE

- Let you have the quantity: $Y = \frac{gL^3}{4bd^3} \cdot \frac{M}{l}$.
- Considering g is constant and M to be known fairly accurately, derive the formula for $\frac{\Delta Y}{Y}$.
- Let, L = 5±0.2 cm, b = 0.22±0.01 cm, d = 0.036±0.001 cm and l = 0.054±0.002 cm. Then calculate the value of $\frac{\Delta Y}{Y}$.
- Multiply it by 100 to find the % error in Y.



LABORATORY SAFETY PROTOCOL

GENERAL INSTRUCTIONS

- When entering a laboratory, avoid touching equipment, chemicals, electrical and electronic devices, or other materials until you are instructed to do so.
- The students should be careful when doing experiments involving current and electricity.
- He/she should not touch any wires if his/her hands are wet, even for low voltage equipment.
- Do not start any practical work unless you are clear about its directions. Double check any electrical circuit you are required to construct and ask Instructor/ TA before proceeding with the activity.
- Be cautious at all times in the laboratory. Call the Instructor/ TA immediately if you notice any risky conditions.
- In case of spillage, breakage or injury, report to the Instructor/ TA instantly: stay calm.
- When removing an electrical plug from its socket, switch off and grasp the plug, not the electrical cord. Hands must be dry when touching an electrical switch, plug or outlet/ socket.
- Wash your hands with liquid soap and water on leaving the laboratory.

INSTRUCTIONS FOR DARK ROOM

- A Optical Experiment room aka Dark room is available exclusively to conduct various experiments based on light.
- The dark rooms houses instruments that can be used to conduct various optical experiments along with several spectral lamps and experimental light sources, to learn and verify various optical phenomena.
- A laser is being used in optics experiment. Direct staring into the beam will damage the retina of the eye. Safety goggles should always be worn while working at the level of the laser beam.
- Do not create any nuisances in the lab.

REFERENCES

- Squires, G. L. (1985) “Practical physics,” Cambridge University Press, Cambridge.
- Laboratory Manual Physics, NCERT

(https://ncert.nic.in/pdf/publication/sciencelaboratorymanuals/classXI/physics/kelm101.pdf)
- Physics 123 Laboratory Manual, ILLINOIS Tech

(https://www.iit.edu/physics/student-resources/physics-123-laboratory-manual)

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