Physics - Not a Subject to Learn

Dr Subhash Kumar Joshi

PREAMBLE: *In an effort to help students to Grow with Concepts, and necessity of mathematics and physics in building thought process, this sub-column on Physics has become relevant. Making a beginning of this column in 9th e-Bulletin, it would be our endeavour to address one concept from first principle in each Bulletin.*

Physics is a phobia for most of the students in non-mathematics stream and sometimes it is seen that Physics is apparently tough to even a few students of mathematics. It would not be incorrect to say that mathematics is abstract without physics and physics is science fiction without mathematics. With this premise and that mathematics is a language of solving problems, and not a problem, ***phobia for physics is evident if it is treated as a subject to learn****. Growth of physics, from predator age, has taken place due to advent of men to observe the physical world around them. In this world everything is necessarily –*

- *Identifiable for presence,*
- *Quantifiable and measurable in magnitude,*
- *It is possible to correlate cause and effect in terms of underlying variables.*

Galileo made this journey experimental, reproducible and verifiable, with equations of motion, a shift in paradigm from observational or intuitional learning of physics. In such a situation it is ironical to say "I am learning physics"; rather ***it requires visualization of every concept of physics in real life and in surrounding****. It is no exaggeration to say that manifestation of laws of physics can be realized even in human behaviour. Physics become intuitive as one grows with study of laws of physics and their correlation with the observation, and application to analyse the observations in the surrounding. As journey of growing with concepts proceeds, such behavioural coincidence shall be brought out to establish relevance.*

On this regard a beginning is being made with pre-requisites for understanding physics; nevertheless attempt is to share understanding from first principle, based on conceptual problems encountered during mentoring and thus, it may not go in line with sequential treatment of the subject in text books or reference books.

1.0. PREREQUISITES FOR UNDERSTANDING PHYSICS:

1.1. **Measurement:** Understanding of physics started and grown with observations; sharper the observation better is the understanding. This is the secret of all discoveries in Physics, be it any scientist. These observations unless quantified lack scientific objectivity and thus remain subjective to each observer, an unscientific approach. Scientific technique of quantification of observation is known as **Measurement**.

1.2. **Quantification**:

1.2.1 Accuracy and Precision: These are two different parameters. Say a man of 72 kg is weighed on three different machines with three sets of observations: machine A weighs 70, 70.5, 70.3 kgs; machine B weighs 72.9, 73, 73.1 Kg; while machine C weighs 72, 72.1 72.2 kgs. All the three machines are precise in measuring weight at 70, 73 and 72 Kg respectively. But, only machine B is precise and accurate. This infers that ***precision*** *is about close conformance of measurement on repetitive measurement*; while ***accuracy*** *is about close conformance of measurement to the actual value*.

1.2.2 Errors: Any observation, howsoever accurate is bound to be a subject of –**a)** instrumental error, **b)** observational error, **c)** manual error, **d)** time dependent variation, **e)** parameter dependent variation etc. All these errors are real life propositions, and if ignored would lead to a theoretical study and contradict with the basic primes of growth of the concepts. While, there are other techniques to handle different types errors, here emphasis is only on error caused by scale of instrument.

1.2.2.1. Significant Figures: It is the most practical aspect in measurement, given a meter scale having graduation markings of – **a)** cm and millimetre all along, and alternatively **b)** have markings at an interval of 10 cm through the entire length graduated as 10, 20…90, 100, followed by centimetre markings within 0 to10 with graduation as 1,2..9 and within 0 to 1 millimetre markings as 1,2..9. Now for measuring a length measured to be 7.3 cm there is no sense in writing 07.3 cm. The leading zero is insignificant. Nevertheless, recording of this measurement as 7.0 cm or 7 cm is incorrect with First scale which has a capability to measure accurately upto 1 mm, while recording 7.0 cm with Second scale is incorrect since it cannot record below 1 cm. Accordingly, three rules are in use for determining significant digits (underlined).

Rule 1: Non-zero digits, wherever they occur, are always significant, viz. 234.657.

Rule 2: Any zeros occurring between significant digits are also significant, but trailing zeros in whole numbers are not significant digits, viz. 23504, 24670 .

Rule 3: In case of decimal, all trailing zeros only are significant, and not the zeros leading non-zero digit including those between decimal and leftmost non-zero digit, viz. 020.0730, 0.00560.

1.2.2.2. **Scientific Notation:** In this any number is expressed as $\boldsymbol{a}$[Decimal].$\boldsymbol{b}$x10^n; here, $1 \leq \boldsymbol{a} \leq 9$, $0 \leq \boldsymbol{b} \leq 9999$ ….[any number of digits based on precision of observations] , and $-999999 \ldots \leq \boldsymbol{n} \leq 9999$..[any number of digits based on order of magnitude brought out at para 1.3.1]. Scientific notation has advantage of retaining degree of precision viz. exact count of 1700 persons on the principle of Significant Digits has 2 SigFig resulting in approximation to hundreds, while in scientific notation it is 1.700x10^3 retains precision in count of person.

1.2.2.3. Least and Most Significant Digits: No instrument can give exact quantity to be measured.This is an implementation aspect of the Rules of SigFig and rightmost digit is Most Significant Digit (MSD) and leftmost digit is Least Significant Digit (LSD). Let us compare five typical length with measuring tools shown in the table below, using measurements articulated for a practical view. No instrument can give exact quantity to be measured.

1.2.2.3.1. Least Count of Instrument: It is the smallest measurement i.e. quantity on the scale of instrument that can be measured and is also called **accuracy of instrument**. Accordingly, in line with the rounding principles greatest possible error in instrument is half of the Least Count. Recording of a measurement from an instrument which is below the least count is a **wrong observation**. Likewise, if recording of measurement does not include least count then again it is wrong observation or a casual observation where **accuracy of instrument is not fully used**.

1.2.2.3.2. Rounding of Numbers: It is based on requirement of accuracy in data and measuring instrument. Since no instrument can give exact quantity is to be measured and hence observations are approximated to maximum possible error using the least count. This has given rise to concept of rounding of numbers to least significant digit (LSD). Most widely used principle of rounding is - t***o round a number find the place value you want to round, if the number to the right of it is less than five, the rounding number does not change, and if the number to the right is greater than or equal to five, then round the target number up.*** Rounding with significant digits underlined in pre rounded SigFigs are: 23.456≈23.45, 23.455≈23.45, 23.452≈23.45.

1.2.2.2.3 Rule of exception: There is another situation where one wishes to distribute pencils to 34 deprived students, and has a discounted offer only on pencil box each containing 10 pencils. While extending generosity it is obvious for the person to ensure no child is let out. In this situation the practical choice is to purchase 4 pencil boxes, be it even at extra cost, and leave surplus 6 pencils either for use of students in future or distribute additional pencil to most deserving students. This is engineering approach of handling not only numbers, rather the problems.

1.2.3. Arithmetical Operation and SigFigs: There is phrase – strength of a chain is that of its weakest link. Likewise reliability of a calculation is of the order of its least precise digit i.e. LSD. Arithmetic operations may involve measurement taken with different instruments having different least count and thus require rationalization of the results such that they are reliable. In light of this application of principles of SigFig in arithmetic operations have been simplified into a set of rules as under, and its applications are shown in Table 2. This principle is in use in electronic machines and can be verified on MS Excel, which is readily available, with a care that **Round Function** is used.

Rule 1: Sequence of arithmetic operations are as per BODMAS RULE.

Rule 2: Before Addition and Subtraction operation convert all operands into Decimal form with trailing Zeros to match rightmost digit.

Tule 3: Perform Addition and Subtraction operation and convert the result into least number of places among operands.

Rule 4: Before Division and Multiplication convert all quantities in scientific notation, retaining LSDs.

Rule 5: Perform Multiplication and Division, and convert result of operation into least precise operand.

TABLE 1 : Measurement vis-à-vis SigFigs

Range of Scale	Range in Length	Minimum Graduation (division)	Least Count	Range of Measurements	Measurement: Measured Values	GPE*	LSD#	MSD$	SigFig
Micrometre	0-5 cm	Main Scale : 1 mm Circular Scale: 1 mm:100 Div.	0.01mm or 10 µm	0-0.00001 to 0.05 m	0.07mm		7	7	1
					0.73 mm		3	7	2
					2.04 mm	0.005 mm	4	2	3
					3.15 mm		5	3	3
					4.60 cm		0	6	3
					4.6 cm^	0.05 cm	6	4	2
Vernier Calliper	0-10 cm	Main Scale:1 mm, Sliding scale division : 9 mm: 10 Div.	0.1 mm	0.0001 to 0.1 m	0.3 mm		3	3	1
					1.6 mm		6	1	2
					5.2 mm	0.05 mm	2	5	2
					2.39 cm		9	2	3
					9.05 cm		5	9	3
					9.1 cm^	0.5 mm	1	9	2
					9 cm^	5 mm	9	9	1
Measuring Rod	0-1 m	1 cm	5 mm	0.01 to 1 m	25 cm		5	2	2
					60 cm	2.5 cm	6	6	1
					60.0 cm@	-	-	-	-
Measuring Tape	0-10 m	1 cm	0.1 cm	0.01 to 10 m	5 mm@	-	-	-	-
					3.7 cm^		7	3	2
					5.0 cm	0.5 cm	0	5	2
					20.6 cm		6	2	3
					7.34 m^	0.05 cm	4	7	3
					7.30 m^		0	7	3
					7.3 m^	5 cm	3	7	2
					5 m^	0.5 m	5	5	1
Surveying Chain	0-100 m	10 cm	5 cm	0.1 to 100 m	40.0 cm@	-	-	-	-
					40 cm	5 cm	0	4	1
					1.70 m@	-	-	-	-
					1.7 m		7	1	2
					63.8 m	5 cm	8	6	3
					83.0 m		0	8	3
					78 m	0.5 m	8	7	2
					90 m		9	9	1

***- Greatest Possible Error, # - Least Significant Digit, $ - Most Significant Digit, ^ - Full accuracy of instrument not used, @ - Incorrect Measurement**

Table 2: Basic Arithmetic Operations and SigFigs

Particulars	Basic Arithmetic Operations			
	Additions	**Subtraction**	**Multiplication**	**Division**
Given data set	2.346172, **21.14**, 0.790003, 7.562	**52.309**, -3.42987	i) **5.1349**x(8.79345x10^{-4}) ii) (**79.35**x10^{3})(5.6379x10^{-9})	{5.1349x(8.79345x10^{-4})}÷{(**79.35**x10^{3})(5.6379x10^{-9})}
Actual operation	2.346172 +21.140000 + 0.790003 + 7.562000 Sum= 31.838175	52.30900 - 1.42987 Difference = 50.87913	Product: i) = **4.5153**86405x10^{-3} ii) = **4.4737**x10^{-4}	Division: 4.5154x 10^{-3}÷ 4.474x10^{-4} =**1.009**249x10^{-1}
Answer to be reported	**Sum**=31.84	**Difference** = 50.879	**Product:** i) = 4.5154x 10^{-3} ii) = 4.474x10^{-4}	**Division:** = 1.009x10^{-1}
Analysis of reported answer	Least accurate data is in 2nd decimal place, which is 3 and digit right of it is 8≥5 and least accurate place is rounded up.	Least accurate data is in 3rd decimal place, which is 9 and digit right of it is 1<5 and hence it shall remain as such.	i) First operand is precise is least precise upto Four Decimal places, hence, so also the result ii) First operand is precise upto Two Decimal Places, hence so also the result.	In this operand 79.35 is least precise upto 2nd Decimal place and hence result is converted in to Two Decimal places.

1.3. Magnitude: Any physical quantity has a magnitude and could be significantly different for different physical entities viz. radius of electron is 2.8179403267x10^{-15} m, diameter of hair (17 to 181 μm), length of book 20 cm, distance between home and school 1.5 km, distance between Kashmir to Kanyakumari is 3,884 km, radius of the Earth 6.37x10^{3} km, mean distance between the Earth and the Sun is 1.5x10^{8} km, while in astronomical scale the Hydra Super-cluster is about 100 million light years long, and the galaxy clusters within it range from about 105 to 160 million light years away from us; here light year is the distance travelled by light in one year; velocity of light is 2.99792458x10^{8}m/s. Analysis of these magnitudes breaks down into few more concepts: **a)** Order of magnitude**,** and **b)** Nature of quantity – *i) Dimensions, ii) Scalar Quantity and iii) Vector Quantity*. These are conceptualized as above.

1.3.1. Order of Magnitude – Various magnitudes stated above are in different order but representation of radius of electron, radius of the earth, mean distance between sun to earth and velocity of light are expressed in same form as $\boldsymbol{a}.\boldsymbol{b} \times 10^{n}$. Here '$\boldsymbol{a}$' is a digit such $1 \leq \boldsymbol{a} \leq 9$, '$\boldsymbol{b}$' is number, having any number of digits depending on accuracy of measurement, and '$\boldsymbol{n}$' is an integer and is called **order of magnitude**. Each quantity depending upon magnitude is defined by its order, of the unit used, and some of those generally encountered are pico (10-12), nano (10-9), micro (10-6), milli (10-3), centi (10-2), deci (10-1), deca (101), hecta (102), kilo (103), mega (106), giga (109) etc.

1.4. Nature of quantity (Dimensions): It is defining dimension a quantity in terms of its basic constituents. This has given rise to elemental dimensions or basic dimensions viz. Mass [M], Length [L], Time [T], Temperature [θ], Luminous Intensity [J], Amount of substance [N], Current [I]. These basic dimensions are used to obtain compound or derived dimension, viz. Area =[Length]x[Breadth]=L^2]; since both length, breadth and height, being of same nature, have dimension [L], volume [L^3], velocity = $\frac{[Displacement]}{[Time]}$ = [LT^{-1}], speed = $\frac{[Distance]}{[Time]}$ = [LT^{-1}], acceleration $= \frac{[Change\ in\ Velocity]}{[Duration\ of\ Change\ ,in\ time]}$ =[LT^{-2}], force =$[Mass] \times [Acceleration]$ MLT^{-2}], work = $[Force] \times [Displacement\ in\ the\ Direction\ of\ Force]$=[$ML^2T^{-2}$], power = $\frac{[Work\ Done]}{[Duration\ of\ Work,\ \ in\ Ttime\}} =$ [ML^2T^{-3}], energy= $[Power]x[Duration\ of\ Use\ of\ Power]$ = [ML^2T^{-2}] .

1.4.1. It may be noted that dimensions of velocity and speed are same, likewise that of energy and work are also same. As study of physics proceeds different physical quantities shall be encountered and at that point dimensional analysis of such new quantities shall carried out as an integral part of conceptual study.

1.5 Classification of Quantity: There is one more aspect of a quantity that is its behaviour, it could be either exclusive magnitude or magnitude with direction. Quantities that have only magnitude are called **Scalar Quantity** viz. mass, length, distance, work, power, energy etc. while those quantities having both magnitude and direction, as essential parameters, are called **Vector Quantity,** viz. Acceleration, Force, Surface Area, etc. All arithmetic operations (+, -, × and ÷ are applicable on Scalar quantities. Whereas, Vectors quantities follow + and – operations as usual but × operation is applicable in different manner with restriction on ÷ operation. These operations on vector quantities shall be taken up separately in this column, in the e-Bulletins to follow.

2. Conclusions: Mechanics, being realizable in immediate surroundings, is the first step in study of Physics. Moreover, measurements form premise for all scientific discoveries. Mechanics would find its applications in other branches of physics viz. electricity, magnetics, heat, sound, and optics. Accordingly, it would be conceptualized in correlation as we progress. However, a good amount of practice is required to make the quantification of measurement intuitive, which is, otherwise, a zone of common error. ***Such errors, despite correct applications of laws of physics and calculations may lead to error in answer or results and thus retard growth of an individual with concepts.***