Glossary of Technical Terms and Concepts

~ Terms and concepts that every scientifically literate student should know. ~

(Based on the work of PTE major Stephan Ommen; last updated 1/24/2007)

1. What is science?
Science is the process of using observable facts to draw conclusions; of learning, inventing, and testing laws, hypotheses, and theories that accurately describe the relationships between observable phenomena; of improving the accuracy of such findings; and of communicating with others about such findings.

2. What are some of the basic assumptions of science?
Scientists assume they will uncover rational or causal connections between observations. They assume that scientific laws have held true in the past and will hold true in the future, in every place in the universe. They assume that a simple explanation is better than a complex explanation as long as it still agrees with observations. They assume that there are certain observations that will not have any significant bearing on a situation.

3. What are some of the "appropriate" values (attitudes) for scientists?
Scientists typically value such personal qualities as curiosity, openness to new ideas, diligence, familiarity with scientific history, willingness to cooperate and share information, intellectual and academic honesty, objectivity, willingness to suspend judgment until suitable data are available for drawing tentative conclusions, and caution in drawing those conclusions.

4. Explain the statement, "Scientific conclusions are tentative."
Because new evidence can disprove even the most time-honored principles, laws, hypotheses, or even theories in science, and because new evidence can always be discovered, there is always the possibility of major revisions being made to science, and so, "scientific conclusions are tentative."

5. Explain the statement, "Science is empirical."
"Science is empirical" means that the conclusions of science are based upon repeatable, observable facts. If something cannot be observed (e.g., count the number of angels able to dance upon the head of a pin), then no scientific conclusions can be drawn. Observation is the hallmark of science. It is the final arbiter in helping scientists to decide the relative correctness of a principle, law, hypothesis, or theory.

6. What are data?
Data (plural, datum singular) are symbolic representations of events or states. Data are generally recorded as discrete bits of raw information. They are not interpretations of evidence; rather, they constitute the evidence itself. Data can be analyzed to produce facts or generate hypotheses.

7. What is a scientific fact? Give an example.
A scientific fact is generally an interpretive statement or conclusion based on evidence. A fact is something that any rational, well-informed group of observers would agree upon. An example of a fact is, "My car's engine contains four and a half quarts of oil." A simple measurement will show this to be the case, and NO ONE in his or her RIGHT mind would disagree in any meaningful way.

8. Do scientific facts ever change?

Yes, scientific facts will change if they are found to be incomplete, based on mistakes, lies, false assumptions, or in disagreement with new evidence. For instance, it once was a scientific fact that the Earth stood still.

9. Can scientific facts ever be contradictory and yet both be correct?

Under certain conditions, yes. For instance, consider observations made from two different inertial frames of reference (not accelerating with respect to one another). A person tossing a ball vertically inside a vehicle moving at a constant speed would see the ball go undergo linear motion – up and down. An external observer located on the ground would see the same ball undergo parabolic motion. The laws of physics would be the same nonetheless in both frames of reference.

10. What is a principle? Give an example.

A principle is a general rule or statement of a relationship seen in nature, in the operation of machine, or in a system. For example, Bernoulli's principle states that fluid in a moving stream has lower pressure than the surrounding fluid. When an object gets hotter it becomes brighter and whiter. Friction tends to oppose motion. Total energy is conserved. Momentum is conserved.

11. What is a scientific law? Give an example.

A time-tested, precise statement of a relation between particular variables or a sequence of events that always occurs under particular conditions. Newton's second law of motion ($F = ma$) is an example of a law because it states a precise relation between three variables (mass, acceleration, and net force) that always occurs under particular conditions (i.e. as long as those variables are describing the same object.)

12. What is a prediction? Give an example.

A prediction is a statement of what will happen in the future. An example of a prediction is, "When I increase the amount of pressure on the object, it will shrink in size."

13. What is a hypothesis? Give an example.

A hypothesis is a tentative explanation of a situation that can be tested thoroughly and that is intended to direct further investigation of the situation or discussion of the facts in the situation. An example of a hypothesis might be that a flashlight fails to work because its batteries are dead. To see if the hypothesis is correct, one might replace the supposedly bad batteries with fresh batteries. If that doesn't work, a new hypothesis is generated such as has to do with the possibility of a burned out light bulb.

14. What is a theory? Give an example.

A theory is an extremely well substantiated hypothesis. It is a precise statement that applies to a wide range of situations, and that has a track record of satisfactorily accounting for the known facts in those situations. It has a great predictive and explanatory power. An example of a theory is the special theory of relativity.

15. How does a hypothesis differ from a theory?

A hypothesis is created on the basis of a small amount of evidence; whereas a theory has been refined so that it accounts for a large amount of evidence. A theory is a well-substantiated hypothesis.

16. Are scientific theories always correct? Explain, providing an example.

Scientific theories have been shown to be incorrect. For example, the plum pudding model of the atom was falsified (shown to be false) because it could not account for the rebounding of alpha particles off of the atoms in gold foil.

17. What is meant by Popper's Principle of Falsifiability or, in other words, how does a scientific statement differ from a nonscientific statement?

The principle of falsifiability says, in essence, that for a statement to be scientific it must be testable. A scientific statement is not necessary correct. "Ten angles can dance on the head of a pin" is NOT a scientific statement; it cannot be tested. However, "The acceleration due to gravity at the Earth's surface is 1.5 m/s^2" is a scientific statement. It is testable. In this case it just happens to be wrong. A scientific statement so defined does not have to be correct, just testable.

18. What is causality? Give an example.

Causality is the relation of cause and effect, or the degree of cause that can be attributed to some effect. An example of causality is, "I increased the force on the object, and this caused it to accelerate." Causality must never be confused with correlation or coincidence. Birds flying south during the autumn is not the cause of winter; just because a particular person was at the scene of a crime does not mean that this person was responsible for the crime.

19. What is deduction? Give an example.

Deduction is making a specific conclusion on the basis of a general principle. For example, "When objects get hotter, they tend to expand. Hence, heating air will cause it to expand."

20. What is induction? Give an example.

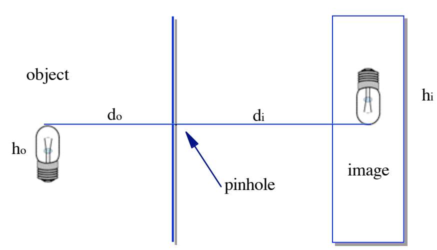
Induction is making a general conclusion on the basis of specific cases. For example, "Whenever I drop both light and heavy objects to the surface of the Earth in the absence of friction, they have an acceleration of 9.8 m/s^2. Therefore, all objects when dropped will accelerate at 9.8 m/s^2."

21. What is logic? Give an example.

Logic is the science of correctly drawing conclusions from propositions. For example, it is logical to conclude that a seat is part of a car, but it is illogical to conclude that a person is part of a car. A logical argument in favor of the first conclusion might be, "Something that is incomplete is missing one or more parts. A car is incomplete without all the seats. Therefore a seat is part of a car."

22. What is a proof? Give an example.

A proof is a confirmation of a fact using other statements or other evidence. An example is, "The power to the circuit is off because I checked the voltages between both lines and from both lines to ground, and all the readings were zero. Plus I verified that the meter was working by using it to check the voltage on an energized circuit both before and after checking the voltage on the de-energized circuit."



23. What is an independent variable? Give an example.

An independent variable is a factor that is externally adjustable without regard to other factors. In the above example, to find the relationship between d_o and h_i, d_i is held constant while d_o is varied.

24. What is a controlled variable? Give an example.

A controlled variable is one that has been held to a specific value for the sake of an experiment. For instance, consider the pinhole projector above. It is used to form an image of a clear light bulb that that has a height, h_o. In this adjustable pinhole projection system, the distance between a the light source and the pinhole (d_o) can vary, in which the distance between the pinhole and the image screen can vary (d_i), and in which the size of the image formed by the pinhole (h_i) can vary. When one wants to find the relationship between d_o and h_i, then d_i must be held constant. In the case with a particular light bulb of fixed height, d_i is in this case a controlled variable.

25. What is a dependent variable? Give an example.

A dependent variable is a factor that changes because of a change in another factor. In the above example, as d_o is varied, h_i also varies in a way that depends only upon d_o. h_i is then the dependent variable as its value depends only upon the value of the independent variable, d_o.

26. What is a parameter? Give an example.

A parameter is a value of a controlled variable. In the above example, the value of d_i constitutes one of the parameters of the system. Another parameter is the height of the light bulb filament, h_o. Yet another would be the size of the pinhole. Together the values of controlled variables define the state of a given experimental system.

27. What is an extraneous variable? Give an example.

An extraneous variable is a factor that has no relationship with other factors being considered. In the above example, the color of the pinhole camera is extraneous. It doesn't matter if the camera is green, red, or black. The same results would occur independent of the color of this extraneous variable.

28. What is a model? Give an example.

A model is a diagrammatic description or a representation of relations between phenomena. For instance, the Bohr atom is a typical model.

29. What is a system?

A system is a single entity, or one or more related entities, that can be studied in isolation from or in simple relation to the surroundings.

30. What is error?

When dealing with error analysis, it is a good idea to know what we really mean by error. To begin with, lets talk about what error is not. Error is not a ***blunder*** such as forgetting to put the decimal point in right place, using the wrong units, transposing number, or any other silly mistake. Error is not your lab partner breaking your equipment. Error isn't even the difference between your own measurement and some generally accepted value. (That is a ***discrepancy***.) Accepted values also have errors associated with them, they are just better measurements than you will be able to make in a three hour undergraduate physics lab. What we really mean by error has to do with uncertainty in measurements. Not everyone in lab will come up with the same measurements that you do and yet (with some obvious exceptions due to blunders) we may not give preference to one person's results over another's. Thus we need to classify types of errors.

31. What is random error?

Random errors are produced by any one of a number of unpredictable and unknown variations in the experiment. Examples might include fluctuations in room temperature, fluctuations in line voltage, mechanical vibrations, cosmic rays, etc. Experiments with very small random errors are said to have a high degree of ***precision***. Because random errors produce variations both above and below some average value, we may generally quantify their significance using statistical techniques.

32. What is experimental error?
Generally speaking, there are two type of experimental error: 1) ***systematic errors*** and 2) ***random errors***. Systematic error are errors that are constant and always of the same sign and thus may not be reduced by averaging over a lot of data. Examples of systematic errors would be time measurements by a clock that runs to fast or slow, distance measurements by an inaccurately marked meter stick, Current measurements by inaccurately calibrated ammeters, etc. Generally speaking, systematic errors are hard to identify with a single experiment. In cases where it is important, systematic errors may be isolated by performing experiments using different procedures and comparing results. If the procedures are truly different, the systematic errors should also be different and hopefully easily identified. An experiment that has very small systematic errors is said to have a high degree of ***accuracy***.

33. What is instrumental error?
Instrumental error is the error that is specific to the measuring instrument itself. Instrumental error comes in two forms: 1) ***zero error*** (a.k.a. calibration error), and 2) ***least error.*** Both must be corrected or otherwise accounted for in a given experiment. Zero error occurs, for instance, in a caliper when the jaws of the caliper are closed but the value read does not zero. A correction must be applied to bring this value to zero, and also applied to each value measured that will be off to the same extent. Least error occurs when the measuring precision of an instrument has been reached. For instance, a meter stick is often marked in millimeters. The meter stick gives limited precision at distances shorter than one millimeter. One millimeter is therefore the least error of this instrument. When using a measuring instrument, it is important to ***calibrate*** it (e.g., check for zero error) before use.

34. What are measures of central tendency?
An average is a value that typifies a set of data. Because typical values tend to lie centrally within a set of data arranged according to size, averages are called measures of central tendency. The ***arithmetic mean*** (one of several types of averages such a weighted mean, harmonic mean, geometric mean, root mean square, etc.), median, and mode are probably the most familiar measures of central tendency, though there is a variety of others. We all should know how to calculate arithmetic means. The ***median*** is the middle value (or mean of two middle values) of a sequentially arranged set of measures. The ***mode*** is that value among a set of data that represents the greatest frequency of the number.

35. What is root mean square?
Root mean square in introductory labs (and as provided in the computer program *Graphical Analysis*) will be associated with error (***RMSE***) – a mathematical assessment of how well a regression line fits data. The y deviation of a data point from a best-fit regression line is the deviation. Squaring all such y values, summing them, and taking the square root suggests how much the data points deviate as a group from the best-fit line. An RMSE of 0 implies a perfect fit.

36. What are measures of dispersion?
Dispersion is the degree to which data tend to spread out around the average value. Dispersion is also known as the variation of the data. There are several common measures of dispersion such as the range, semi-interquartile range, the average or mean deviation, and the standard deviation. The ***range*** of a set of numbers is the difference between the largest and smallest numbers of the set. The average deviation or ***mean deviation*** is the sum of all absolute values of the differences from the mean divided by the number of data points. The ***standard deviation*** of a set of numbers is the root mean square deviation. The mean and standard deviations are defined using mathematical symbolism as follows:

$$M.D. = \frac{\sum_{j=1}^{N} \left| X_j - \overline{X} \right|}{N} \qquad\qquad s = \sqrt{\frac{\sum_{j=1}^{N} \left(X_j - \overline{X} \right)^2}{N}}$$

Q37. How does one interpret standard deviation of a set of numbers?
If a set of numbers are normally distributed around the mean (e.g., a bell-shaped frequency distribution of, say, 30 or more data points), then there is a 68.27% probability that any given data point will lie within plus or minus one standard deviation of the arithmetic mean (e.g., included in the interval $\overline{X} - s$ and $\overline{X} + s$). There is a 95.45% chance that a randomly chosen data point will lie within plus or minus two standard deviations of the arithmetic mean, and there is a 99.73% the data point is within plus or minus three standard deviations of the mean.

Q38. What is a physical interpretation of a model?
This makes reference to a physical interpretation of an algebraic model. For instance, say that a person plots a graph force versus acceleration. Due to measurement errors the best-fit line of the data suggests a form of the relationship $F = ma + 0.3 newtons$. Clearly, if acceleration equals zero, then force must also be zero, and <u>not</u> $0.3 newtons$. A best-fit line <u>must</u> pass through the origin of the graph. It is better to fit the data with the regression equation $y = ax$ than $y = ax + b$. This forces the y-intercept to be zero, which is consistent with a physical interpretation. A physical interpretation of data is to be favored over a merely algebraic model.

Q39. What is a fundamental unit?
A fundamental unit is an arbitrarily defined unit used in the measurement of certain important quantities. For instance, the kilogram, the meter, and the second are all arbitrary quantities. For instance, the meter is ostensibly 1/10,000,000 the distance from the equator to the north pole as measured along the Paris meridian. The meter was redefined in 1983 as the distance traveled by light in a vacuum in 1/299,792,458 of a second.

Q40. What is a derived unit?
A derived unit is a unit defined on the basis of fundamental units. For instance, the Newton – the unit for force – is a derived unit that is a combination of kilograms, meters, and seconds.