What is “Measurement”? 

In general, it is the acquisition of information.

Classification of information leads to two different types of measurements:

- **Structural Information**: Information on the state or nature of a certain characteristic whose acquisition is called “Qualitative Measurement”.

- **Metric Information**: Information on the magnitude, amplitude or intensity of a certain characteristic whose acquisition is called “Quantitative Measurement”.

A qualitative measurement must be carried out before proceeding with a quantitative measurement. For example, if one needs to estimate the rate of loss of body liquid from a human face on a windy day, a qualitative measurement is needed first to determine which physical quantities affect the loss of body fluid (such as skin permeability, face area, air humidity, air temperature, air velocity, etc.) before attempting to determine their values.

When one refers to “Measurement” without actually specifying its type, it is usually meant the “Quantitative Measurement”.
“Whatever exists, exists in some amount”
Anonymous

Therefore, to be more specific, the “(Quantitative) Measurement” can also be defined as the “Determination of the amount of a quantity of interest in terms of a predefined scale”.

In engineering, the quantities of interest in measurements are physical or chemical

- **Material Properties** (density, thermal conductivity, magnetic permeability, viscosity, melting point, latent heat of evaporation, elastic modulus, solubility in water, etc.),

- **Component Parameters** (diameter, mass, spring constant, electrical inductance, fluid capacitance, thermal resistance, etc.), and

- **Variables of State** (position, force, voltage, pressure, temperature, diffusion rate, concentration, etc.).
Some Important Aspects of a Measurement:

1. A measurement must be "descriptive" with regard to that state or that phenomenon in the world around us which we are measuring. There must be a relationship between this state or phenomenon and the measurement result.

2. A measurement must be "selective". It should only provide information about what we wish to measure and not about any other of many states or phenomena around us.

3. A measurement must be "objective". The outcome of the measurement must be independent of an arbitrary observer.
Why to Measure?

The essential reason of performing a measurement is to provide information about the world around us, the observers. However, the need for such information may differ from one application to another. The following is a broad classification of reasons to measure:

- To observe natural phenomena in order to develop either theoretical or empirical models to represent these phenomena. In other words, the information gathered by simply “observing” our surrounding allows us to create models, to formulate laws, and to suggest theories to explain cause-effect relations of the phenomena involved. (Pure Sciences)

- To collect data for complementing, verifying, and improving these theoretical or empirical models, hypotheses, theorems, and laws by conducting “controlled experiments”. (Pure Sciences)

- To determine properties of a specific material, parameters of a specific object or a component, or the state or performance of a specific system including system identification. (Pure Sciences + Applied Sciences/Engineering + Daily Life)

- To design and to develop new products or processes or to improve the existing ones. The concept of “concurrent engineering” of modern era requires an integration of systematic experimental tests with all phases of product development processes starting from the design. (Engineering)
• To determine the states of engineering systems and processes in order to monitor and control them for their proper operation and maintenance. (Engineering)

• To perform acceptance testing of components or systems by authorized agencies to demonstrate their conformity with preset standards before their use. (Engineering)

**Engineering Experimentation & Experiment Design:**

In all branches of engineering, there exit two fundamental approaches to solving problems that arise in the discovery of knowledge and its application to society’s needs:

- Theoretical Modeling
- Experimental Measurement

While some problems can adequately be treated by using only theory, or only experimentation, most require a well balanced and complementing mix of these two techniques.
A comparative summary of basic features of theoretical and experimental methods are given in the following table: (Adapted from Figure 1.2 at page 6 of the reference: E.O. Doebelin, *Engineering Experimentation: Planning, Execution, Reporting*, McGraw-Hill, Inc., 1995.)

<table>
<thead>
<tr>
<th>THEORETICAL</th>
<th>EXPERIMENTAL</th>
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<tbody>
<tr>
<td>Study mathematical models of the real world</td>
<td>Study the real world without needing any</td>
</tr>
<tr>
<td>requiring simplifying assumptions.</td>
<td>simplifying assumptions.</td>
</tr>
<tr>
<td>Give general results for a whole class of</td>
<td>Give results specific to the apparatus studied.</td>
</tr>
<tr>
<td>problems.</td>
<td></td>
</tr>
<tr>
<td>Relaxation of assumptions leads to more</td>
<td>Higher accuracy measurements require more</td>
</tr>
<tr>
<td>complex mathematical models.</td>
<td>complex instrumentation.</td>
</tr>
<tr>
<td>Facilities needed may not be of top quality</td>
<td>Extensive (and expensive) laboratory facilities</td>
</tr>
<tr>
<td>(trained personnel plus “pencil and paper”).</td>
<td>may be needed.</td>
</tr>
<tr>
<td>Study can start immediately.</td>
<td>Time delays may occur in apparatus construction</td>
</tr>
<tr>
<td></td>
<td>and debugging.</td>
</tr>
<tr>
<td>STEP</td>
<td>QUESTION</td>
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</table>
| 1    | What is the objective of the experiment? | a) The problem may have been defined for you.  
     |                                       | b) Your experience may help you to define an objective.  
     |                                       | c) In an unfamiliar situation, try a few tentative tests from which an objective may suggest itself. | Objective of the experiment is defined and noted. |
| 2    | What are the important variables and are they defined? | a) The answer may be self evident. 
     |                                       | b) Step 1c may give a lead.  
     |                                       | c) Beware of including dependent variables. | The variables are selected and perhaps a hypothesis is made. |
| 3    | Will grouping the variables reduce the amount of testing? | a) Grouping can be based on physical arguments. 
     |                                       | b) Perform a dimensional analysis. | Any grouping are decided upon. |
| 4    | What apparatus is required? | a) You will have to work within the limitations of the apparatus available. You may forced to revise the conclusion of Step 2. 
     |                                       | b) Request additional facilities. | Necessary equipment are now available. |
| 5    | How will the test be organized? | a) Decide which quantities you will vary and in what order. 
     |                                       | b) Decide who is going to do what. | Test plan is drawn up and jobs are allocated. |
| 6    | How will the data appear on your notes? | a) Decide on the range over which each variable may change. Step 4a may impose a limitation. 
     |                                       | b) Prepare a table into which data can be entered. Is a reference test number needed? 
     |                                       | c) Decide whether accuracy of the measurements will ensure a meaningful result. 
<pre><code> |                                       | d) Prepare axes on which control curves can be plotted. | Notebooks are prepared. Test is performed. Data is recorded. Control curves are drawn. |
</code></pre>
<table>
<thead>
<tr>
<th>STEP</th>
<th>QUESTION</th>
<th>POSSIBLE ACTION</th>
<th>CONCLUSION</th>
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</table>
| 7    | What do the control curves show? | a) Take additional readings where bad points occur.  
b) Take additional readings in badly defined areas. | Data is now complete.                |
| 8    | How will the results be presented? | a) Decide between graphical, tabular, or formula presentation.  
b) If (a) demands it, perform a curve fitting exercise. | Results are presented.              |
| 9    | What do the results mean?        | a) Establish the validity or otherwise of the hypothesis made in Step 2.  
b) Establish the confidence which can be placed in the numerical results.  
c) Explain the nature of any trends.  
d) Explain deviations from any theoretical expectations. | Results are analyzed.  
Experimental errors are investigated.  
Discussion section is written. |
| 10   | Is the test finished?            | a) State the laws you have discovered.  
b) State any further investigations you consider necessary. | Conclusions are drawn and recommenda-  
tions are made.                      |
| 11   | Have you finished?               | a) Proceed as dictated by Step 10b.                                                               | Test continues or report is prepared. |