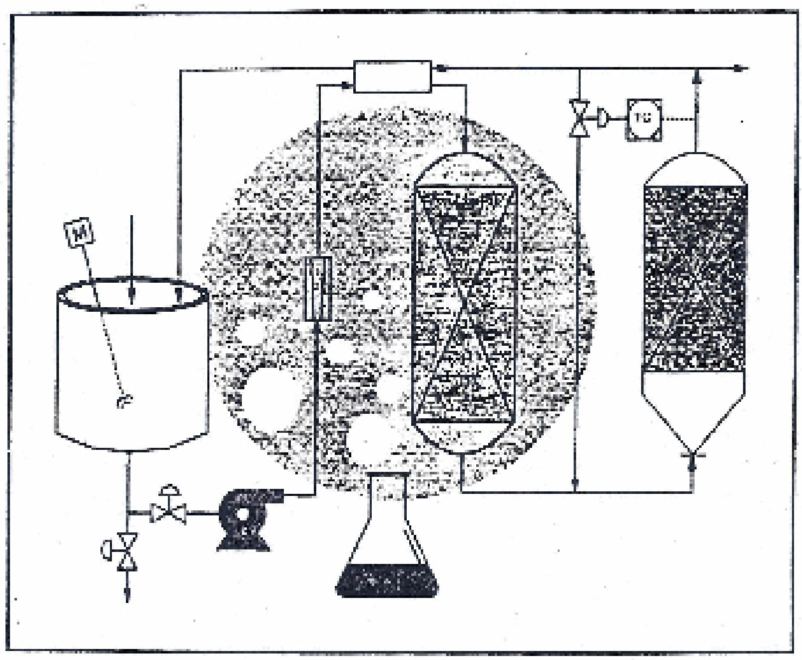
The Ronald E. McNair Post-Baccalaureate Achievement Program New Jersey Institute of Technology

Data Procurement

A Laboratory Manual For Fundamentals Of Engineering Design

Chemical Engineering Module:
Measurements Laboratory



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Second Edition

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Contents

Data Procurement

- **Introduction**

- **The manual was written to guide students to obtain the maximum benefit from our Freshman FED Course and our Senior laboratory course.**

- **Students are encouraged to use the state of the art electronic facilities to**
  - **Reduce calculation time for analysis of measured data.**

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- **Purpose**
  - **To put theory into practice, which will require independent, logical thinking on an open-ended research problem.**
  - **The problem will have more than one answer and your answer will depend on your assumptions.**
  - **Hopefully, the experience will encourage the student to enroll in Graduate School and eventually obtain a Ph. D. Degree and enter University teaching and research.**

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- **Safety First Before the Experiment**
  - **Laboratory Safety and Good Laboratory Practice**

  - **Each laboratory will have its safety rules and regulations. Be conscious of these rules and regulations**

    - **These rules were made to prevent accidents and for anyone, the experimenter or the observer from getting hurt.**

    - **The proper educational training in engineering must also develop a proper safety program and safety consciousness.**

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- **Always ask yourself the question in your work, "What will happen if I---?"**

- **For example, "What will happen if I---?"**
  - **Speed in my automobile**
  - **Open this valve**
  - **Raise the temperature**
  - **Start the pump**
  - **Open this electrical switch**

  Be extremely conscious of any action you take.

  STAY ALERT !

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Important considerations:

1. <u>Clothing:</u> Be sure that the clothing that you wear is <u>protective</u> and <u>appropriate</u> for your environment.

- **2 <u>Eye Protection:</u> Eye protection is mandatory in many laboratory settings.**

- **3. <u>Housekeeping:</u> All experimental areas should be in a clean orderly state at all times.**

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- **Important considerations: (Continued)**

- **4. <u>Horseplay:</u> Incidents of horseplay can lead to accidents and harm to individuals. No horseplay is tolerated in laboratories.**

  - **5. <u>Equipment difficulties:</u> You are encouraged to correct any minor equipment problems by working safely. However, any major difficulties should be reported to your mentor for appropriate correction.**

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- Important considerations: (continued)

- 6. <u>Tools:</u> Be sure that any tools that you use are appropriate and in good condition. Bring unsafe tools to the attention of your mentor.

- 7. <u>Electrical:</u> Many times extension chords are needed.
  - Do not use extension chords that are frayed.
  - Do not lay extension chords on the floor, but support them appropriately.
  - When working with electrical systems, be sure that your are in an area that is dry and you are not standing in water.

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- **Important considerations: (continued)**
  - **8. <u>Accidents:</u> Accidents happen even with the most safety precautions. Be conscious of the location of safety equipment. Report any accidents to your mentor.**
    - **In case of a serious accident immediately notify your mentor or call our Security Department at Extension 3111from a safety phone in your laboratory or 973-596-3111 from your cell phone.**
    - **Remember, there is a nurse in our gym. Entrance is first door to left upon entering the building.**

Data Procurement

- **Important considerations: (continued)**
  - **9. <u>Ventilation:</u> Be sure that any hoods you work in are functioning and the area you work in is properly ventilated.**

- **Finally, remember the motto:**

"WHEN IN DOUBT ASK!"

Data Procurement

- **THE LABORATORY NOTEBOOK**

- **<u>Data Taking and Recording</u>**

- **In Industrial Research Centers, researchers are issued small, bound , <u>registered</u> notebooks that are assigned to them for data taking.**

- **The notebooks must be developed in an orderly procedure, which is mandated by the supervision.**

- **Research Data must never be recorded on scratches of paper or loose sheets. These are more likely to get lost than a bound notebook.**

Data Procurement

- **Well organized and maintained notebooks are required of all researchers because in the event of a patent dispute and resulting litigation, the notebook is the first line of defense of who had the patent idea first.**

- **These notebooks must be submitted to supervision when complete, or when the employee leaves the company.**

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- I am not privileged to know how long these notebooks are kept.

- I am also not familiar with current Industrial Practices since the advent of the computer although the computer existed while I was still active in the Industrial scene. I am sure things have changed.

Data Procurement

- **It will be your job when employed to determine what your employer wishes and what the conditions for acceptable data recording are at your place of employment.**

- **During your research at NJIT, you should consult with your Mentor should he /she have specific requirements. I strongly suggest a good, bound notebook with data also stored in two safe places (memory sticks) for your computer.**

Data Procurement

- **I am familiar with the following procedure in keeping a good notebook.**
  - **1. Title of Experiment and Date must appear at the top of each page.**
  - **2. Data must be recorded neatly, stating all units and dimensions and listing all conversion factors.**

Data Procurement

- 3. Data must be recorded in duplicate.

- 4. At the end of each period, experimenters must sign the bottom of each page. Two witnesses must also sign.

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- Example of a Proper Data Sheet in your Notebook

- Title of Experiment Date

A Study of Ohm's Law April 15, 2013

Then record your data clearly in the free space in an clear, organized manner, giving all units and dimensions for each number listed.

At the bottom of each page are the signatures.

Signature 1 Date

Print Name

Signature 2 Date

Print Name

Data Procurement

- **Basic Concepts of Measurement**

- **“Experimental methods and measurements require a basic terminology, definition of terms and measurement instruments”**

- **Holman, J. P. “Experimental Methods for Engineers”, Sixth Edition, McGraw-Hill, Inc., New York (1994)**

Data Procurement

- 1. Instruments
    - Measurements are made with instruments that range from simple to more complex. Examples are:
        - Meter stick
        - Ammeter
        - Gas Chromatograph and Recorder
        - On-line Computer Data Acquisition and Control

Data Procurement

- 2. Terminology and Definition of Terms

  - In working with these instruments a terminology has developed and these terms have been precisely defined. These are:

    a. Readability
    - b. Least Count
    - c. Sensitivity
    - d. Hysteresis
    - e. Accuracy
    - f. Precision
    - g. Calibration

Data Procurement

- 2. Terminology and Definition of Terms (continued)

  - a. <u>Readability</u>

    This term indicates to the Experimenter the closeness to which the scale of the instrument may be read.

  Example:

  A 12-inch scale has a higher readability than a 6-inch scale with the same range for the measurement. Reading 0-12 amps on a 12-inch scale is better then reading 0-12 amps on a 6-inch scale.

Data Procurement

- **2. Terminology and Definition of Terms (continued)**

- **b. <u>Least Count</u>**

  This term represents the smallest difference between two indications that can be detected on the instrument scale.

Example

1 millimeter an a meter stick
0.1 amps on an ammeter with a 12-inch scale.

DATA PROCUREMENT

- 2. Terminology and Definition of Terms (continued)
- Both Readability and Least Count depend on:
  - scale length
  - Spacing of graduations
  - Size of pointer or pen
  - Parallax effects (the apparent change in the position of an object (a pointer) resulting from the change in direction or position from which was viewed)

Data Procurement

- **2. Terminology and Definition of Terms (continued)**

  c. <u>Sensitivity</u>

  This term refers to the ratio of linear movement of the pointer (pen) on an analog instrument to the change in measured variable causing the motion.

Example:
one millivolt (mV) with a 25 centimeter scale on an analog instrument.

Sensitivity of linear scale is therefore,

25 cm/1mV = 25 cm/mV

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- **Terminology and Definition of Terms (continued)**

- **For digital instruments- the manufacturers specify sensitivity for a certain scale setting.**

- **Example:**

the specifications will read 100 nanoamperes (10^{-9} amps) on a 200 microamp scale range 200μ amps or 200 x 10^{-6} amps)

Data Procurement

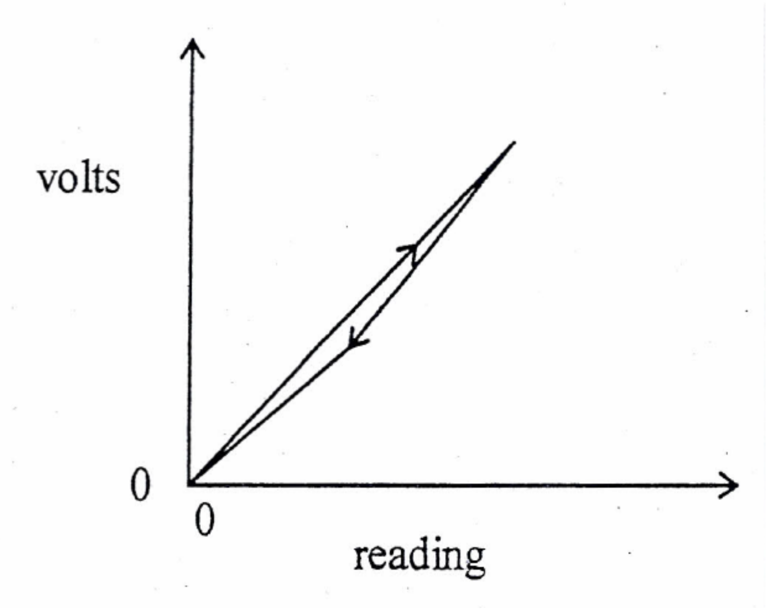
- Terminology and Definition of Terms (continued)

  - d. Hysteresis Some instruments are dependent upon the direction that is used. For example, one can measure voltage either in the increasing direction or the decreasing direction.

    - An instrument will show hysteresis if there is a difference in reading depending upon if you are moving up scale or down scale

Data Procurement

- Terminology and Definition of Terms (continued)
- Example;



- Hysteresis is caused by:
  - Mechanical friction
  - Magnetic effects
  - Elastic deformation
  - Thermal effects

DATA PROCUREMENT

- Terminology and Definition of Terms (continued)

- e. <u>Accuracy</u> The term accuracy of an instrument indicates the deviation (error) of the reading from a known input, expressed as a percent of full scale reading.

- <u>Example:</u>

- A pressure gauge has a full scale Reading of 1000 kiloPascals (1000 kPa). If the accuracy is 1%, the instrument is accurate to ± 10 kPa for the full range. In this case, at full scale the accuracy is only good to ±10 kPa.

  The true accurate reading could therefore, range from 990 kPa to 1010 kPa. the error is ± 10kPa.

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Data Procurement

- **Terminology and Definition of Terms (continued)**
  - **f. Precision** Precision differs from accuracy in that this term indicates the ability of an instrument to reproduce a certain reading with a given accuracy.
  - **Example:**
  - **Consider voltmeters readings for a known voltage of 1000 volts (1000V). Repeated readings give the following data:**

Reading	Volts
1.	1010
2.	1020
3.	990
4.	980
5.	1005
Average	1001 V

Data Procurement

- **Terminology and Definition of Terms (continued).**
- **The Accuracy is 1020 – 1000 = +20V**
  - **980 -1000 = -20**
- **Therefore, the Accuracy is ± 20 volts**

20/1000 = 0.02 = 2%.

The precision is the maximum deviation from the mean. Hence, deviations from the mean are:

1020 - 1001 = +19

1010 – 1001 = + 9

1005 – 1001 = +4

990 – 1001 = - 11

980 – 1001 = - 21

The precision is, ± 21/1000 = 0.021 = 2.1%

Calibration of instruments improves the dependability of an instrument.

Data Procurement

- **Terminology and Definition of Terms (continued)**

- **g. Calibration**
  Calibration establishes the accuracy of an instrument. It is always wise to check the manufacturer's specifications and calibrations.

Data Procurement

- **Terminology and Definition of Terms (continued)**

- **Example:**
- **A manufacturer can state that a 100 percent scale reading on a flow meter (rotometer) is equal to 20 gallons per minute of liquid. The calibration curve may also be given with the instrument covering the entire range of 10-100 percent. This information must be checked.**

- **Calibrations compare the instrument with a known accurate standard. There are three methods that can be used to check the accuracy of this example.**

Data Procurement

- Terminology and Definition of Terms (continued)

- 1. Primary Standard
  - Calibrate flow meter by comparing it with a accurate standard flow measurement facility at the National Bureau of Standards, Washington, D.C.
- 2. Secondary Standard
  - A secondary standard has a higher accuracy than the available instrument to be calibrated. In this case, one can compare the available instrument with another flow meter of known accuracy.

Data Procurement

- **Terminology and Definition of Terms (continued)**
  - **3. A known, convenient source as a standard.**

- **In this particular case, the flow meter can be set at a finite percent reading and the outflow from the meter is collected in a container of known weight and the outflow is collected in the container over a period of time. Thus, for example, at 100 percent reading, 166.8 pounds of water (H_2O) are collected in one minute.**

- $$\frac{166.8 \text{ lbs } H_2O}{1.0 \text{ min}} \times \frac{1.0 \text{ gallon}}{8.34 \text{ lbs } H_2O}$$
  - **= 20 gallons per minute**
  - **= 20 gpm**

Data Procurement

- **Standards, Units and Dimensions**
  - **Standards, units and dimensions are important aspects of measurement.**
  - **Standards are needed and have been established to enable experimenters to compare the results of their experiments on a consistent basis.**

Data Procurement

- **Standards, Units and Dimensions (continued)**

  - **A dimension is a physical variable used to describe the nature of the system. For example, the length of a piece of wood is a dimension. The temperature of a gas is a dimension.**

  - **Units are the quantities by which the dimension is measured. For example, it may be stated that the piece of wood is 1.0 meter in length or 39.37 inches in length. The meter and the inches are the units of the dimension length.**

Data Procurement

- **Standards, Units and Dimensions**
- **(continued)**

- **The temperature can be 100 degrees Celsius (100^{o}C) or 212 degrees Fahrenheit (212^{o}F).**

- **There are two systems of Units. The old English of units is still widely used in the United States but most of the world is on the SI system of units (Systeme International d"Unites, established at the 11th General Conference on Weights and Measures).**

- **Units can be changed from one system to the other by conversion.**

Data Procurement

- Standards
  - For measurements to be meaningful, there must exist accepted standards for comparison.
  - 1. Standard units have been established for the dimensions:
    - Mass
    - Length
    - Time
    - Temperature
    - Electrical quantities

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- **Standards Continued**

The National Bureau of Standards has the primary responsibility in the USA and the National Physical Laboratory has the primary responsibility in the United Kingdom.

The United Nations has become involved to develop standards to allow for measurement comparison regardless of where in the world the measurement is made.

Data Procurement

- 2. Some Standards
  - Standards are accepted by agreement and the conversions from one system of units to another is established by law.
  - For, example, the standard meter is the length of a platinum-iridium bar maintained at very accurate climate conditions at the International Bureau of Weights and Measures at Sevres, France.

Data Procurement

- **Some Standards (Continued)**
  - **The kilogram is the mass of a similar quantity of platinum-iridium kept at the same location.**
  - **Conversions are:**
  - **Mass**
  - **one pound mass =453.5924277 grams**

Data Procurement

- **Length**
  - **In 1960, at the General Conference on Weights and Measures , the length of one meter was defined.**
  - **1.0 meter = 1,650,753.73 wavelengths in a vacuum of the orange-red line in the spectrum of a Krypto-86 lamp.**
  - **In 1982, this was changed to the distance that light travels in 1/299, 292.54ths of a second.**

Data Procurement

- Time

- Standard units of time are measured from known frequencies of oscillation of a
  - Pendulum
  - Torsional vibrational system
  - Tuning fork
  - 60 Hz (Hertz) frequency of voltage.

Second = 1/86,400 of a solar day

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- **Time**

  Solar day is defined as the time interval that the sun passes a known Meridian on the Earth (probably, the Greenwich Meridian in England).

  The second was redefined in 1987 at 13th General Conference on Weights and Measures by the duration of 9,192,631,770 periods of the radiation corresponding to the transition between two hyperfine levels of the states of Cesium-135.

Data Procurement

- Temperature

  - Ordinary Temperature, as we know it, is measured in degrees Celsius, ^{o}C, in the SI System of units and in degrees Fahrenheit, ^{o}F, in the English system of units.

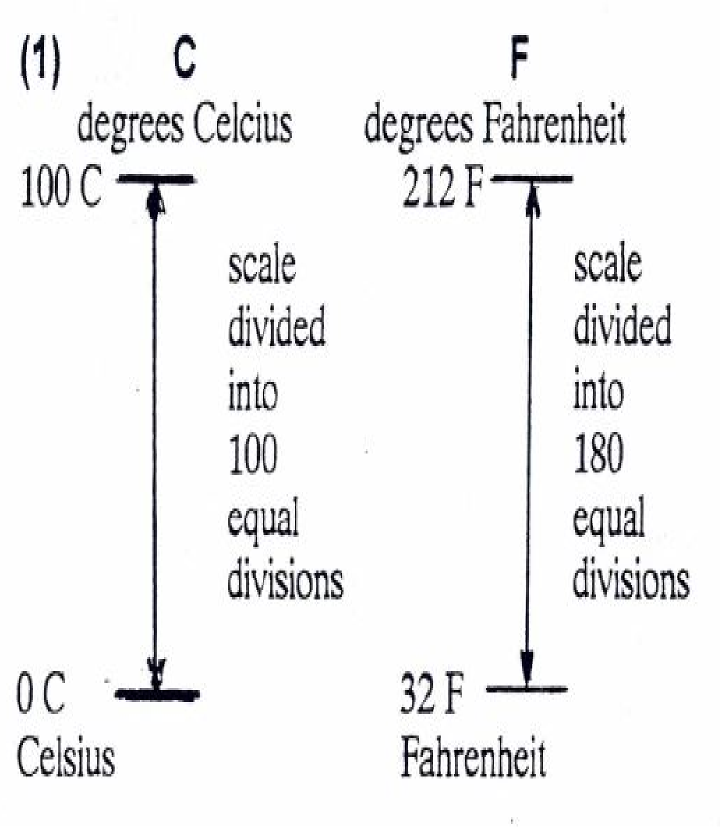
  - These scales are both based upon the height of a column of Mercury at the boiling point of water at sea level and 760 millimeters of Mercury Pressure (mm Hg) and for the freezing point of water at the same atmospheric conditions.

DATA PROCUREMENT

- Therefore, Δ 1.0 °C = Δ 1.8 °F

- **Boiling Point** water, sea level, 760 mmHg

- **Freezing Point** water, sea level, 760 mmHg



- The height of the Mercury columns is the same but the markings are different. Hence, 1.0 °C difference = Δ 1.8 °F difference.

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- **Absolute Temperature**
  - **In 1854, Lord Kelvin proposed an absolute temperature scale or, as known today, the Thermodynamic scale.**
  - **Thermodynamically, Lord Kelvin defined the absolute temperature, absolute zero, as the temperature when all molecular motion ceases.**
  - **This Absolute Zero was equivalent to**
    - **- 273.15 ^{o}C on the Celsius scale and**
    - **- 459.67 ^{o}F on the Fahrenheit scale**

Data Procurement

- **Absolute Temperature**

- **Therefore, degrees Kelvin**
- **$K = {}^{o}C + 273.15$**

- **And degrees Rankine**
- **$R = {}^{o}F + 459.67$**

- **Conversions are:**

- **${}^{o}F = 1.8\,{}^{o}C + 32$ or**
- **${}^{o}C = ({}^{o}F - 32)/1.8$**

  - **and hence, $R = 1.8\ K$**

Data Procurement

- Electrical Units
  - Standard units of electrical quantities are derived from mechanical units.
  - Basic electrical units are:
    - Volt
    - Ampere (Amp)
    - Ohm

Data Procurement

- Electrical Units (Continued)

  - Basic Units

	SI	English
Mass	kg	lb
Length	m	ft
Time	s	s
Temperature	^oC	^oF
Abs. Temp.	K	R
Electric	A	A

Hence, Newton’s First law, F = ma

- Force, Newton's, N:
- $N = (kg – m/s^2)$

Data Procurement

- **Electrical Units (Continued)**

  - The **Quantities are:**

    - **Volt**
    - **Coulomb**
    - **Ampere**
    - **Watts**
    - **Ohm**

- **<u>The Volt</u>**

- **The unit Volt was named after Alexandro Volta, an Italian Physicist, (1745-1827).**

- **It is based upon work done by a charge moving between two points which have a known potential drop between them.**

- **This potential drop is the voltage, V, and the charge, Q, is doing work (Energy), W.**

Data Procurement

- **Electrical Units (Continued)**

- **Therefore,**
  - **$W = QV$ or $V = E$ and**
  - **$W = QE$**

  - **$V = E = W/Q$**

  - **where , Q = charge in Coulombs**
    $V = E$ = Volts

  - **W = N-m = J = Joule, Energy (Heat)**
  - **$W = (kg - m/s^2) \times m = (kg\text{-}m^2) / s^2$**

  - **Hence, voltage, electrical force, or potential drop, is the work done by a unit charge ($Q = 1.0$) as the charge moves between two points.**

Data Procurement

- Electrical Units (Continued)

- <u>Coulomb and Ampere</u>

- The flow of electric charge is measured in coulombs and amperes.

- A coulomb is the quantity of electricity equal to 3×10^{9} electrostatic units (esu) of charge.

- Since 1 electron = 4.8×10^{-10} esu, the coulomb is the charge of a number of electrons. Hence,

- 1 coulomb = 3×10^{9} esu/ 4.8×10^{-10} esu per electron = 6.25×10^{18} electrons

- The coulomb was named after Charles A. Coulomb, a French Physicist (1736-1806)

Data Procurement

- Electrical Units (Continued)

- When electrons flow, there is a current which is the time rate of flow of the electric charge. This unit of flow is the transfer of one coulomb of charge past a given point in one second.

- This unit of flow is called the ampere (amp) and

  - Flow = I = Q/t = charge/time
  - charge = current x time

- The ampere was named after Andre M. Ampere, a French scientist (1775-1836)

Data Procurement

- **Electrical Units (Continued)**

- **work = voltage x charge**
- **charge = current x time**
- **Hence, work = voltage x current x time or**

- **W = EQ and Q = It and W = EIt,**

- **W = N-m = J (Joule) = Energy**

- **Power is defined as the work done per unit of time. Hence, P = W/t =EI**

- **Power = (N-m) /s = J/s =volts x amps = Watts**

- **The unit of power, watt, was named after the Scottish Engineer , James Watt (1736-1819) who also developed the Steam Engine.**

Data Procurement

- Electrical Units (Continued)

- Resistance

- All flow depends upon a driving force and a resistance.

- Fluid flow depends upon a pressure difference driving force and the resistance from friction.

- Heat flow, or Heat Transfer depends upon a temperature difference driving force and the resistance based on, in essence, thermal conductivity.

Data Procurement

- Electrical Units (Continued)

- Mass Transfer depends upon Concentration difference driving force and the resistance based on, in essence, the mass Diffusivity.

- Electrical flow depends upon the voltage difference driving force and the resistance in the conducting material.

- In electrical systems the dimension of flow is the ampere, I, and the dimension of resistance is the ohm.

Data Procurement

- **Electrical Units (Continued)**
- **Known as Ohm's law, it was named after Georg S. Ohm, a German physicist, (1787-1854).**
- **Notice the all these scientists were close to contemporaries, Volta, Coulomb, Ampere, Ohm**
- **In metallic current flow, the current, I, is proportional to the Voltage difference, E.**
- **The proportionality constant, is the reciprocal of the resistance, just as in Fluid Flow, Heat Flow, and Mass Flow.**

Data Procurement

- Electrical Units (Continued)
- Thus, $I = E/R$
    - where R is the resistance which has units of ohms.
- Thus, an ohm is the resistance in a system
- When the Voltage difference, E = 1.0 volts and the current flow, I = 1.0 ampere.
- When working with measurements, the investigator must become very familiar with the importance of conversion of units from system to system and from units to units.

Data Procurement and Correlations

- In modern times, correlations are best made using the computer program Excel. Data are fed into the program and Excel will determine the statistically best values of the slope and intercept and also determine the Correlation Coefficient , R^2
- The coefficient R^2 varies between 0 and 1.0. A value of zero means the correlation is a circle or no correlation at all. A value of 1.0 means a perfect linear correlation.
- The closer to one means the closer to a more perfect correlation.
- Some examples of what Excel would do are shown in the following correlations.

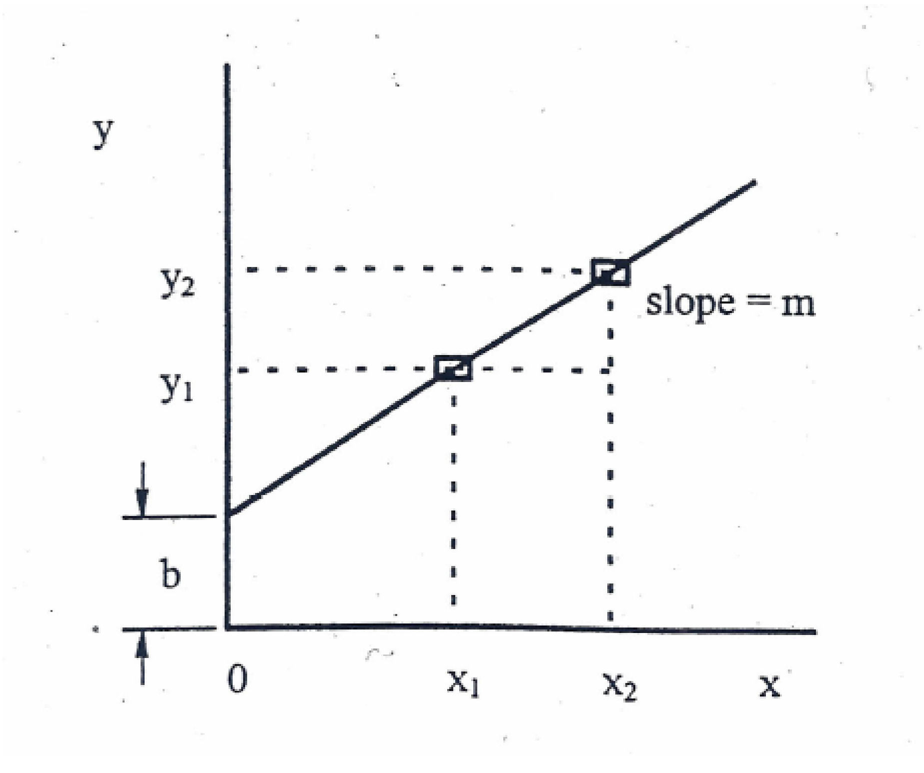
Data Procurement and Correlations

1. **Linear Graphs**

$y = mx + b$

m = slope = $(y_2 - y_1) / (x_2 - x_1)$

b = intercept is the value of y when $x = 0$



Data Procurement And Correlations

2. Semi-Logarithmic Graphs

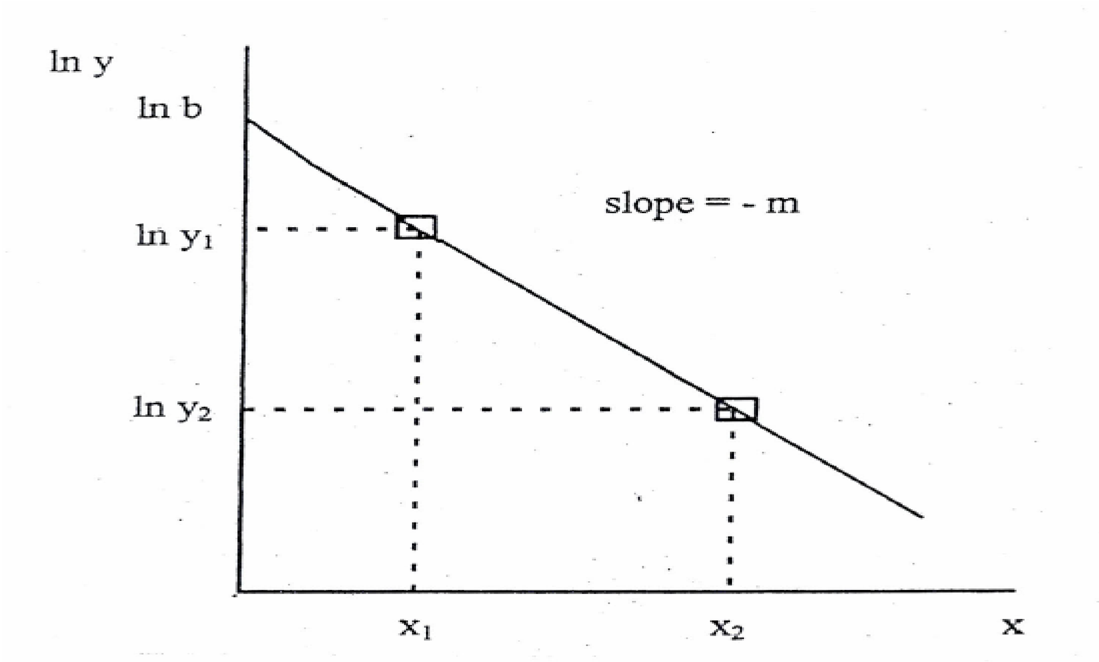
$$y = be^{-mx}$$

$$\ln y = \ln b - mx \ln e$$

$$\ln e = 1 \quad \text{or} \quad \ln y = \ln b - mx$$

$$m = \text{slope} = (\ln y_2 - \ln y_1) / (x_2 - x_1)$$

$\ln b = \ln y + mx$ **is the intercept**



Data Procurement And Correlations

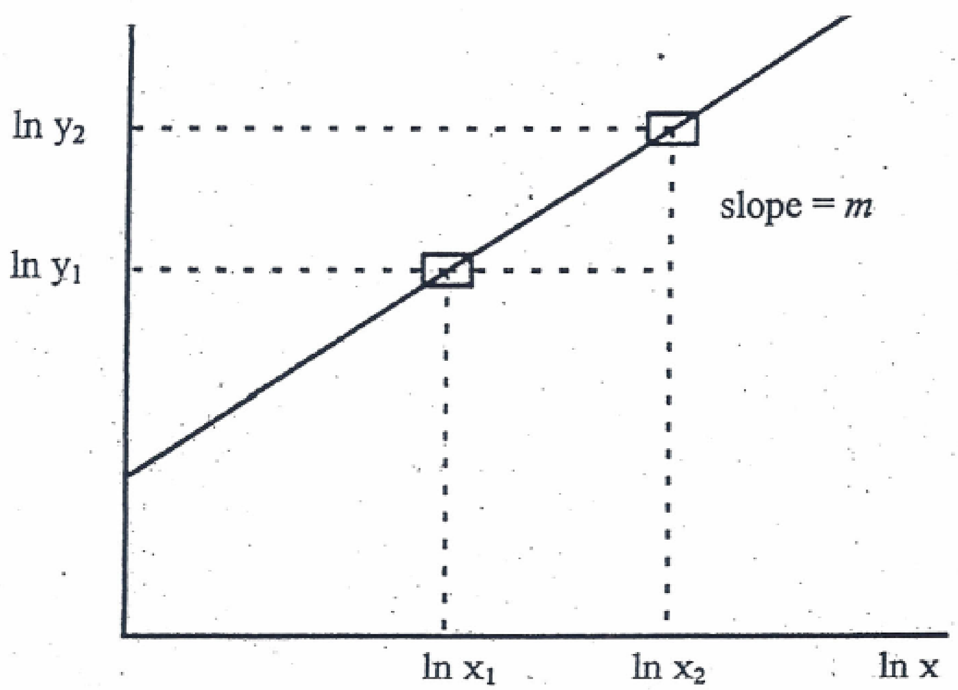
3. Logarithmic Graphs

$$y = bx^m$$

$$\ln y = \ln b + m \ln x$$

$$m = \text{slope} = (\ln y_2 - \ln y_1) / (\ln x_2 - \ln x_1)$$

$\ln b = \ln y + m \ln x$ **is the intercept**



DATA PROCUREMENT CORRELATIONS

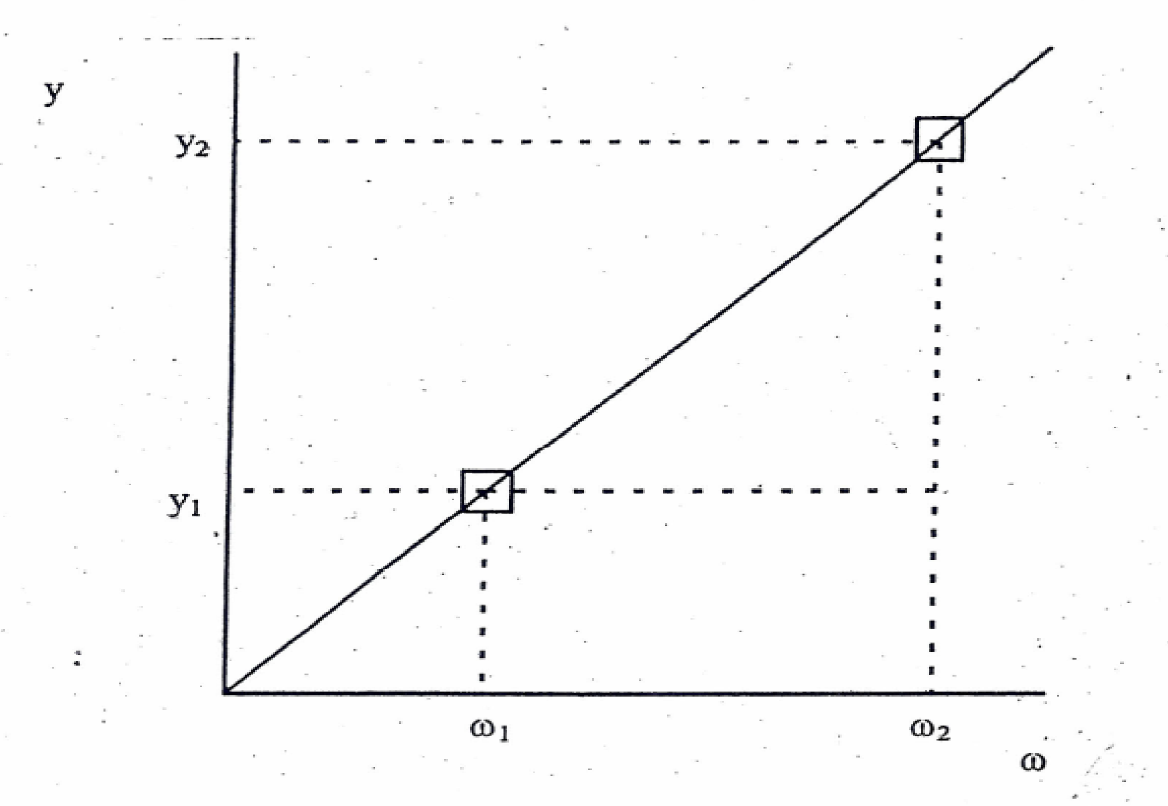
4. Linearization

The equation $y = mx^{1/2} + b$ can be linearized by defining $\omega = x^{1/2}$

hence, $y = m\omega + b$

m = slope = $(y_2 - y_1) / (\omega_2 - \omega_1)$

$b = y + m\omega$ = the intercept



Data Procurement and Correlations

4. Linearization

The equation $(y^2 - 1) = be^{m(x-2)}$

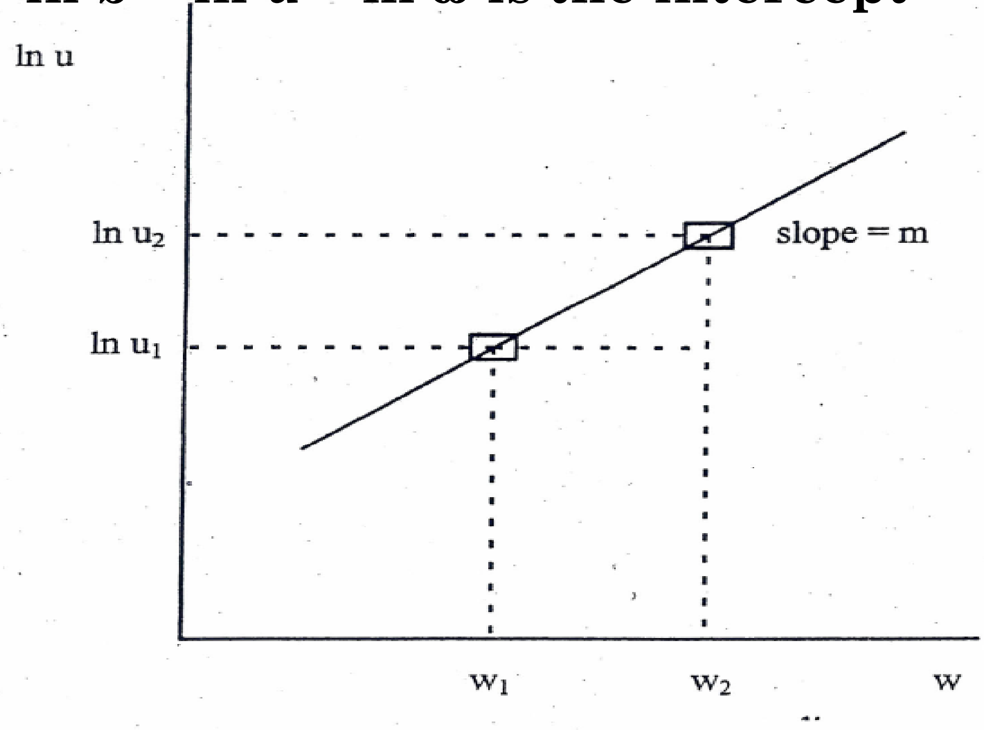
can be linearized by letting

$u = y^2 - 1$ and $\omega = x - 2$

hence $u = be^{m\omega}$ and $\ln u = \ln b - m\,\omega$

$m = \text{slope} = (\ln u_2 - \ln u_1) / (\omega_2 - \omega_1)$

$\ln b = \ln u + m\,\omega$ is the intercept



Data Procurement and correlations

- **Linearization**

- **Once the slope m, and the intercept b, are known, then**

$$(y^2 - 1) = b e^{m(x-2)}$$

then

$$y^2 = 1 + b e^{m(x-2)}$$

and

$$y = [1 + b e^{m(x-2)}]^{1/2}$$

In all cases, the process of linearization of the mathematical function followed by the determination of the slope and the intercept is the key to solving the problem.

Data Procurement

- **Dimensional Analysis**
  - **1.Dimensionless groups or, more appropriately, unit less groups are use in engineering correlations frequently. These are numbers that can be used more extensively to cover many situations in the laboratory and the same number would be used in a large scale plant operation. This scale-up is possible because the number is unit less.**

Data Procurement

- Dimensional Analysis (Continued)

  - Chemical and Mechanical Engineering
    Example for Heat Transfer

- Reynolds Number

- $N_{Re} = Dv\rho/\mu$

- where D = diameter of the pipe or tube, m

  v = velocity of fluid in pie or tube, m/s
  ρ = density of the fluid, kg/m^3

  μ = viscosity of the fluid, kg(m-s)

- hence, $N_{Re} = Dv\rho/\mu$

  $= [(m)(m/s)(kg/m^3)] / [kg/(m-s)]$

  = dimensionless number

Data Procurement

- **Dimensional Analysis (Continued)**
- **Nusselt Number**
- **N_{Nu}= hD/k**
- **where h = heat transfer coefficient, J/ (s- m^2 -K**
- **D = diameter of the pipe or tube, m**
- **k = fluid thermal conductivity, J/ (s- m -K**
- **hence,**
- **N_{Nu}= hD/k**
- **= {([J/ (s- m^2 -K)(m/s)]}/[J/ (s- m -K)]**
- **= dimensionless number**

Data Procurement

- **Dimensional Analysis (Continued)**
- **Prandtl Number**
- $N_{Pr} = c_p\mu/k$
- **where** c_p **= heat capacity of the fluid, J/ (kg –K)**
- μ **= viscosity of the fluid, kg(m-s)**
- **k = fluid thermal conductivity, J/ (s- m -K**
- **hence,**
- $N_{Pr} = c_p\mu/k$

= [(J/ (kg-K)(kg(m-s)]/[J/ (s- m -K)]

= dimensionless number

Data Procurement

- Dimensional Analysis (Continued)

- 2. Dimensionless groups can be correlated to give a generalized correlation which will apply in the laboratory or on a plant scale.

- Example:

  - $N_{Nu} = a\, N^{m}_{Re}\, N^{n}_{Nu}$

- Linearizing yields

- $\ln N_{Nu} = \ln a + m \ln N_{Re} + n \ln N_{nu}$

Data Procurement

- **Dimensional Analysis (Continued)**

- **Which is in the form of**
- $y = a + b\, x_1 + c\, x_2$

- **This is a two variable linear regression equation.**

Submitting experimentally determined values of N_{nu} , N_{Re} and N_{Pr} into the Excel program will give the best statistical values of a, m, and n for the constants in the correlation and also the Correlation Coefficient, R^2.

These empirical equations are very useful in the design and analysis of engineering problems.