The University of Jordan
Faculty of Engineering & Technology
Chemical Engineering Department

Chemical Engineering Principles (0905211)

Unit Conversion

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Content

- Unit and Dimensions
- System of Units
- Operations with Units
- Numerical Calculation and Estimation
- Dimensional Consistency and Dimensionless quantities
- Process data representation and analysis

All Measured Quantities Consist of a Number and a Unit.

unit
dimension
value

} What's the difference?

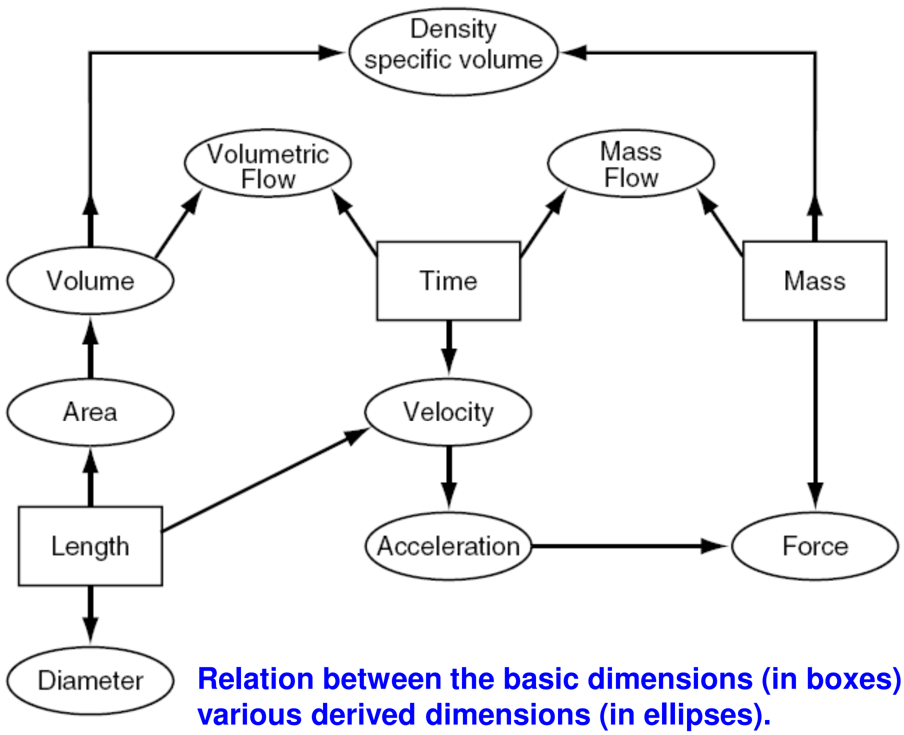
Unit and Dimensions

A **dimension** is a property that can be measured, such as length. time. mass. or calculated by multiplying or dividing other dimensions, such as length/time (velocity),

units are the means of expressing the dimensions, such as *feet* or *centimeters* for length, and *hours* or *seconds* for time

Dimensions and their respective units are classified as fundamental or derived:

- **Fundamental** (or basic) dimensions/units are those that can be measured independently and are sufficient to describe essential physical quantities.
- **Derived** dimensions/units are those that can be developed in terms of the fundamental dimensions/units.



Relation between the basic dimensions (in boxes) and various derived dimensions (in ellipses).

System of Units

A system of units has the following components:

1. ***Base units*** for mass, length, time, temperature, electrical current, and light intensity.

2. ***Multiple units,*** which are defined as multiples or fractions of base units such as minutes, hours, and milliseconds, all of which are defined in terms of the base unit of a second

3. ***Derived units,*** obtained in one of two ways:

a) By multiplying and dividing base or multiple units (cm^2, ft/min, $kg \cdot m/s^2$, etc.). **compound units.**

b) As defined equivalents of compound units (e.g., 1 erg $\equiv$ ($1 g \cdot cm/s^2$), 1 $lb_f \equiv 32.174\ lb_m \cdot ft/s^2$).

SI system of units

SI Base Units

...uantity (Dimension)	Unit Name	Unit Abbreviation
Mass	kilogram	kg
Length	meter	m
Time	second	s
Temperature	kelvin	K
Electric current	ampere	A
Amount of substance	mole	mol
Luminous intensity	candela	cd

Derived SI Units

Quantity	Definition of Quantity	SI unit
Area	Length squared	m^2
Volume	Length cubed	m^3
Density	Mass per unit volume	kg/m^3
Speed	Distance traveled per unit time	m/s
Acceleration	Change in speed per unit time	m/s^2
Force	Mass times acceleration of object	$kg\ m/s^2$ (= newton, N)
Pressure	Force per unit area	$kg/(m\ s^2)$ (= pascal, Pa)
Energy	Force times distance traveled	$kg\ m^2/s^2$ (= joule, J)

SI Prefixes

Factor	Prefix	Symbol	Factor	Prefix	Symbol
10^9	giga	G	10^{-1}	deci	d
10^6	mega	M	10^{-2}	centi	c
10^3	kilo	k	10^{-3}	milli	m
10^2	hecto	h	10^{-6}	micro	μ
10^1	deka	da	10^{-9}	nano	n

The **CGS system**

units of mass and length are grams (g) and centimeters (cm)

Table 2.3-1 SI and CGS Units

Base Units		
Quantity	Unit	Symbol
Length	meter (SI)	m
	centimeter (CGS)	cm
Mass	kilogram (SI)	kg
	gram (CGS)	g
Moles	gram-mole	mol or g-mole
Time	second	s
Temperature	kelvin	K
Electric current	ampere	A
Light intensity	candela	cd

Derived Units

Quantity	Unit	Symbol	Equivalent in Terms of Base Units
Volume	liter	L	$0.001\ m^3$ $1000\ cm^3$
Force	newton (SI) dyne (CGS)	N	$1\ kg \cdot m/s^2$ $1\ g \cdot cm/s^2$
Pressure	pascal (SI)	Pa	$1\ N/m^2$
Energy, work	joule (SI) erg (CGS) gram-calorie	J cal	$1\ N \cdot m = 1\ kg \cdot m^2/s^2$ $1\ dyne \cdot cm = 1\ g \cdot cm^2/s^2$ $4.184\ J = 4.184\ kg \cdot m^2/s^2$
Power	watt	W	$1\ J/s = 1\ kg \cdot m^2/s^3$

American engineering system

foot (ft) for length

the pound mass (lb_m) for mass,

the second (s) for time.

Common SI-English Equivalent Quantities

Quantity	SI	SI Equivalents	English Equivalents	English to SI Equivalent
Length	1 kilometer (km)	1000 (10^3) meters	0.6214 mile (mi)	1 mile = 1.609 km
	1 meter (m)	100 (10^2) centimeters	1.094 yards (yd)	1 yard = 0.9144 m
		1000 millimeters (mm)	39.37 inches (in)	1 foot (ft) = 0.3048 m
	1 centimeter (cm)	0.01 (10^{-2}) meter	0.3937 inch	1 inch = 2.54 cm (exactly)
Volume	1 cubic meter (m^3)	1,000,000 (10^6) cubic centimeters	35.31 cubic feet (ft^3)	1 cubic foot = 0.02832 m^3
	1 cubic decimeter (dm^3)	1000 cubic centimeters	0.2642 gallon (gal)	1 gallon = 3.785 dm^3
			1.057 quarts (qt)	1 quart = 0.9464 dm^3
	1 cubic centimeter (cm^3)	0.001 dm^3	0.03381 fluid ounce	1 quart = 946.4 cm^3 1 fluid ounce = 29.57 cm^3
Mass	1 kilogram (kg)	1000 grams	2.205 pounds (lb)	1 pound = 0.4536 kg
	1 gram (g)	1000 milligrams (mg)	0.03527 ounce (oz)	1 ounce = 28.35 g

Operations with Units

Addition, Subtraction, Equality

You can add, subtract, or equate numerical quantities only if the associated units of the quantities are the same.

5 kilograms + 3 joules — cannot be carried out: Dimensions are different

$3\ \text{cm} - 1\ \text{mm (or 1 s)} = ?$ $(3x - y = ?)$ — Units are not different

10 pounds + 5 grams — dimensions are the same, mass

Units must be transformed to be the same, either pounds, grams

$3\ \text{cm} - 1\ \text{cm} = 2\ \text{cm}$ $(3x - x = 2x)$ — can be performed, *units are the same.*

The numerical values of two quantities may be added or subtracted only if the units are the same.

Multiplication and Division

You can multiply or divide unlike units, but you cannot cancel or merge units unless they are identical

$$3\ \text{N} \times 4\ \text{m} = 12\ \text{N}\cdot\text{m}$$

$$\frac{5.0\ \text{km}}{2.0\ \text{h}} = 2.5\ \text{km/h}$$

$$7.0\ \frac{\text{km}}{\text{h}} \times 4\ \text{h} = 28\ \text{km}$$

$$3\ \text{m} \times 4\ \text{m} = 12\ \text{m}^2$$

$$6\ \text{cm} \times 5\ \frac{\text{cm}}{\text{s}} = 30\ \text{cm}^2/\text{s}$$

$$\frac{6\ \text{g}}{2\ \text{g}} = 3 \quad \text{(3 is a } \textit{dimensionless} \text{ quantity)}$$

$$\left(5.0\ \frac{\text{kg}}{\text{s}}\right) \Big/ \left(0.20\ \frac{\text{kg}}{\text{m}^3}\right) = 25\ \text{m}^3/\text{s}$$

numerical values and their corresponding units may always be combined by multiplication or division.

Functions

Trigonometric functions can only have angular units (radians, degrees).
All other functions and function arguments, including exponentiation, powers, etc., must be dimensionless.

$$\left.\begin{array}{l}\log(16\text{m}^2) \\ 6^{(2\text{ft})} = ???\end{array}\right\} \quad \text{meaningless}$$

$$\sin\left(\frac{\pi}{2}\text{ ft}\right) \quad \text{is never defined}$$

For simplicity, a variable must be transformed or scaled to be dimensionless before applying nonlinear operations

For example

For a pipe of radius R with units of m, we would develop a dimensionless variable r*, a fraction, for a distance r from the axis also in m, to operate on

$$r^* = \frac{r\text{m}}{R\text{m}}$$

$$\log r^* = \log r + \log m - \log R - \log m = \log r - \log R = \log\frac{r}{R}$$

Conversion of Units

Dimensional analysis: A method that uses a conversion factor to convert a quantity expressed in one unit to an equivalent quantity in a different unit.

Conversion factor: States the relationship between two different units.

original quantity x conversion factor = equivalent quantity

$$\text{What you want} = \text{What you have} * \frac{\text{What you want}}{\text{What you have}}$$

How many meters is 8.72 cm?

How many feet is 39.37 inches?

How many kilometers is 15,000 decimeters?

How many seconds is 4.38 days?

FACTORS FOR UNIT CONVERSIONS

Quantity	Equivalent Values
Mass	1 kg = 1000 g = 0.001 metric ton = 2.20462 lb_m = 35.27392 oz 1 lb_m = 16 oz = 5×10^{-4} ton = 453.593 g = 0.453593 kg
Length	1 m = 100 cm = 1000 mm = 10^6 microns (μm) = 10^{10} angstroms (Å) = 39.37 in. = 3.2808 ft = 1.0936 yd = 0.0006214 mile 1 ft = 12 in. = 1/3 yd = 0.3048 m = 30.48 cm
Volume	1 m^3 = 1000 L = 10^6 cm^3 = 10^6 mL = 35.3145 ft^3 = 220.83 imperial gallons = 264.17 gal = 1056.68 qt 1 ft^3 = 1728 $in.^3$ = 7.4805 gal = 0.028317 m^3 = 28.317 L = 28,317 cm^3
Force	1 N = 1 kg·m/s^2 = 10^5 dynes = 10^5 g·cm/s^2 = 0.22481 lb_f 1 lb_f = 32.174 lb_m·ft/s^2 = 4.4482 N = 4.4482×10^5 dynes
Pressure	1 atm = 1.01325×10^5 N/m^2 (Pa) = 101.325 kPa = 1.01325 bar = 1.01325×10^6 dynes/cm^2 = 760 mm Hg at 0°C (torr) = 10.333 m H_2O at 4°C = 14.696 lb_f/$in.^2$ (psi) = 33.9 ft H_2O at 4°C = 29.921 in. Hg at 0°C
Energy	1 J = 1 N·m = 10^7 ergs = 10^7 dyne·cm = 2.778×10^{-7} kW·h = 0.23901 cal = 0.7376 ft-lb_f = 9.486×10^{-4} Btu
Power	1 W = 1 J/s = 0.23901 cal/s = 0.7376 ft·lb_f/s = 9.486×10^{-4} Btu/s = 1.341×10^{-3} hp

Example: The factor to convert grams to lb_m is $\left(\frac{2.20462\ lb_m}{1000\ g}\right)$.

from chemistry class:

$$1 \text{ atm} = 760 \text{ mmHg} = 1.013 * 10^5 \text{ Pa} = 1.013 \text{ bar} = ...$$

$$\text{foot (International) ft} = 1/3 \text{ yd} = 0.3048 \text{ m}$$

Convert 800 mmHg into bars

36 mg to g

Convert an acceleration of 1 cm/s^2 to its equivalent in km/yr^2.

COMPLEX UNIT CONVERSIONS AND SIGNIFICANT FIGURES

A large sport utility vehicle moving at a speed of 125 km/h might use gasoline at a rate of 16 L per 100 km. What does this correspond to in mi/gal?

COMPLEX UNIT CONVERSIONS AND SIGNIFICANT FIGURES

The volcanic explosion that destroyed the Indonesian island of Krakatau on August 27, 1883, released an estimated 4.3 cubic miles (mi^3) of debris into the atmosphere and affected global weather for years. In SI units, how many cubic meters (m^3) of debris were released?

Conversion Between Systems of Units

Convert 2 km to miles.

Convert 400 $in.^3$/day to cm^3/min.

Convert 23 $lb_m \cdot ft/min^2$ to its equivalent in $kg \cdot cm/s^2$.

FORCE AND WEIGHT

From Newton's second law, $\sum F = ma$

force is proportional to the product of mass and acceleration (length/time^2).

Natural force units are,

$kg \cdot m/s^2$ (SI), $g \cdot cm/s^2$ (CGS), and $lb_m \cdot ft/s^2$ (American engineering).

In the metric systems,

$$1 \text{ newton (N)} \equiv 1 \text{ kg} \cdot \text{m/s}^2 \qquad 1 \text{ dyne} \equiv 1 \text{ g} \cdot \text{cm/s}^2$$

In the American engineering system, **pound-force** (lb_f)

the product of a unit mass (1 lb_m) and the acceleration of gravity at sea level and 45° latitude, which is 32.174 ft/s^2:

$$1 \text{ lb}_f \equiv 32.174 \text{ lb}_m \cdot \text{ft/s}^2$$

For example,

the force in newtons required to accelerate a mass of 4.00 kg at a rate of 9.00 m/s^2 is

The **weight** of an object is the force exerted on the object by gravitational attraction.

$$W = mg$$

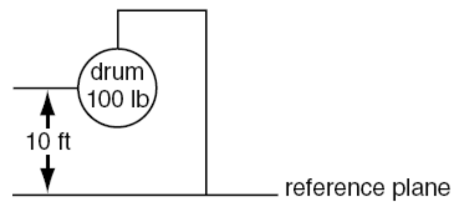
The value of g at sea level and 45° latitude is

$$g = 9.8066\ \text{m/s}^2 = 980.66\ \text{cm/s}^2 = 32.174\ \text{ft/s}^2$$

EXAMPLE

What is the potential energy in (ft)($1b_f$) of a 100 lb drum hanging 10 ft above the surface of the earth with reference to the surface of the earth?

g = acceleration of gravity = 32.2 ft/s^2.



EXAMPLE

Water has a density of 62.4 lb_m/ft^3. How much does 2.000 ft^3 of water weigh (1) at sea level and 45° latitude and (2) in Denver, Colorado, where the altitude is 5374 ft and the gravitational acceleration is 32.139 ft/s^2?

EXAMPLE

In biological systems, enzymes are used to accelerate the rates of certain biological reactions. Glucoamylase is an enzyme that aids in the conversion of starch to glucose (a sugar that cells use for energy). Experiments show that 1 μg mol of glucoamylase in a 4% starch solution results in a production rate of glucose of 0.6 μg mol/(mL)(min). Determine the production rate of glucose for this system in the units of lb mol/(ft^3)(day).

Dimensional Consistency and Dimensionless quantities

Every valid equation must be dimensionally homogeneous: that is, all additive terms on both sides of the equation must have the same dimensions.

Dimensional considerations can be used to help identify the dimensions and units of terms or quantities in an equation.

$$u(\text{m/s}) = u_0(\text{m/s}) + g(\text{m/s}^2)t(\text{s})$$

This equation is dimensionally homogeneous,

each of the terms u, u_0, and gt has the same dimensions (length/time).

If an equation

is dimensionally homogeneous but its additive terms have inconsistent units, the terms (and hence the equation) may be made consistent simply by applying the appropriate conversion factors.

Assume that In the equation, $u = u_0 + gt$

$u(\text{m/s}) \quad u_0(\text{m/s}) \quad g(\text{m/s}^2) \quad \text{time } (t) \text{ in minutes}$

Then, the equation can be written as:

$$u(\text{m/s}) = u_0(\text{m/s}) + g(\text{m/s}^2)t(\text{min})(60 \text{ s/min})$$

$$u = u_0 + 60gt$$

EXAMPLE

Consider the equation $D(\text{ft}) = 3t(\text{s}) - 4$

1. If the equation is valid, what are the dimensions of the constants 3 and 4?

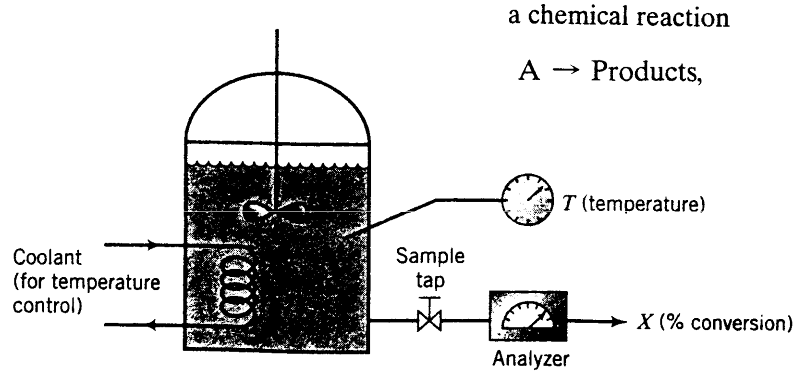
Exercise.

Numerical Calculation and Estimation

Estimation of Measured Values: Sample Mean

a chemical reaction

A → Products,



X, the percentage of the A fed that has reacted.

in a real reactor X is a *random variable,* changing in an unpredictable manner from one run to another at the same experimental

Run	1	2	3	4	5	6	7	8	9	10
$X(\%)$	67.1	73.1	69.6	67.4	71.0	68.2	69.4	68.2	68.7	70.2

Why don't we get the same value of X in each run?

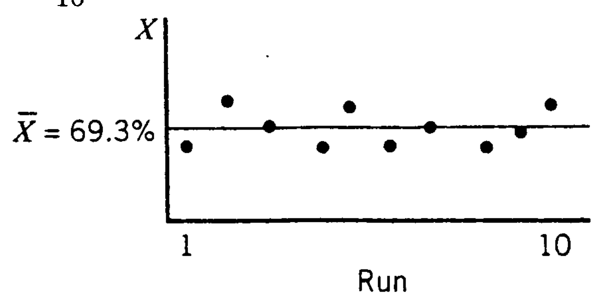
What is the true value of X?

How can we estimate of the true value of X?

Sample Mean:

$$\overline{X} = \frac{1}{N}(X_1 + X_2 + \cdots + X_N) = \frac{1}{N}\sum_{j=1}^{N} X_j$$

$$\overline{X} = \frac{1}{10}(67.1\% + 73.1\% + \cdots + 70.2\%) = 69.3\%$$



Sample Variance of Scattered Data

Range:

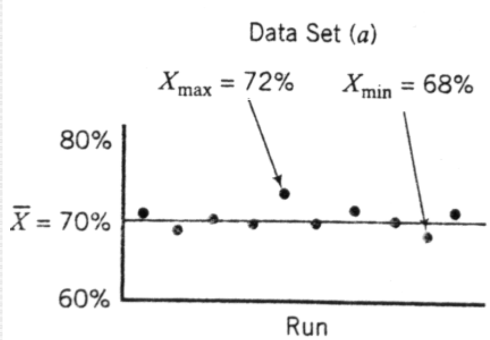
$$R = X_{max} - X_{min}$$

Sample Variance:

$$s_X^2 = \frac{1}{N-1}[(X_1 - \overline{X})^2 + (X_2 - \overline{X})^2 + \cdots + (X_N - \overline{X})^2]$$

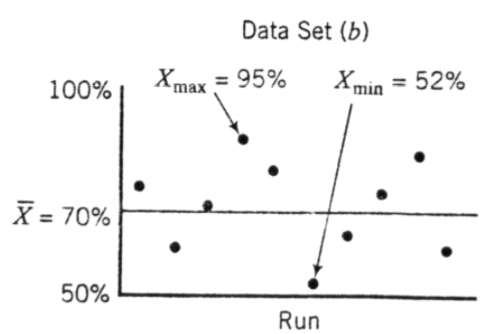
Sample Standard Deviation:

$$s_X = \sqrt{s_X^2}$$



$R = 5\%$

$(s_X^2 = 0.30, s_X = 0.55)$



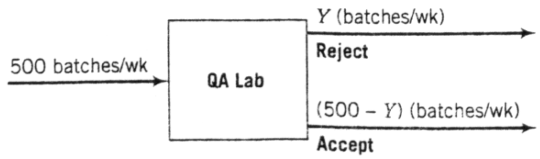
$R = 43\%$

$(s_X^2 = 50, s_X = 7.1)$

EXAMPLE

Five hundred batches of a pigment are produced each week. In the plant's quality assurance (QA) program, each batch is subjected to a precise color analysis test. If a batch does not pass the test, it is rejected and sent back for reformulation.

Let Y be the number of bad batches produced per week, and suppose that QA test results for a 12-week base period are as follows:



The company policy is to regard the process operation as normal as long as the number of bad batches produced in a week is no more than three standard deviations above the mean value for the base period (i.e., as long as $Y \leq \overline{Y} + 3s_Y$). If Y exceeds this value, the process is shut down for remedial maintenance (a long and costly procedure).

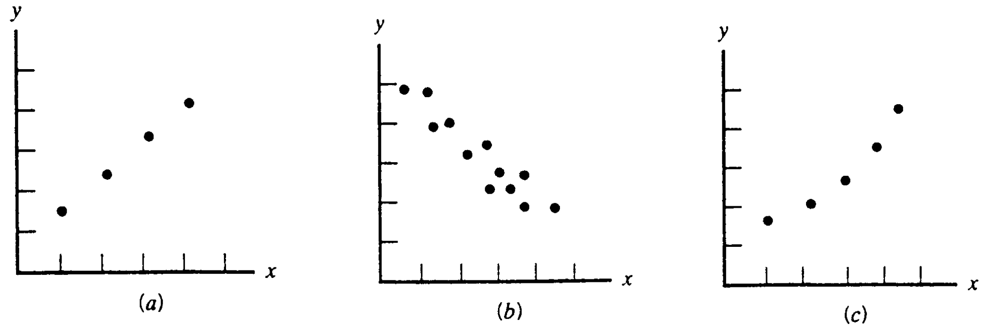
1. How many bad batches in a week would it take to shut down the process?

What would be the limiting value of Y if two standard deviations instead of three were used

Process data representation and analysis

The operation of any chemical process depends on several variables: Temperature, pressure, flow rate and species concentration.
Usually indirect techniques are used to measure these variables, hot wire anemometry for flow rate measurement, thermal or electrical conductivity for concentration measurement or temperature measurement.

In this case, you measure a variable **X** that is coupled with the variable (T, P, F or C) with a certain relation.
The relation between X and the variable is defined in a separate calibration experiment



Representative plots of experimental data.

The calibration data can be then used to estimate the value of the variable (y) for a value of X between tabulated point (interpolation) or outside the data range (extrapolation)

A number of interpolation and extrapolation methods are commonly used, including two-point linear interpolation, graphical interpolation, and curve fitting.

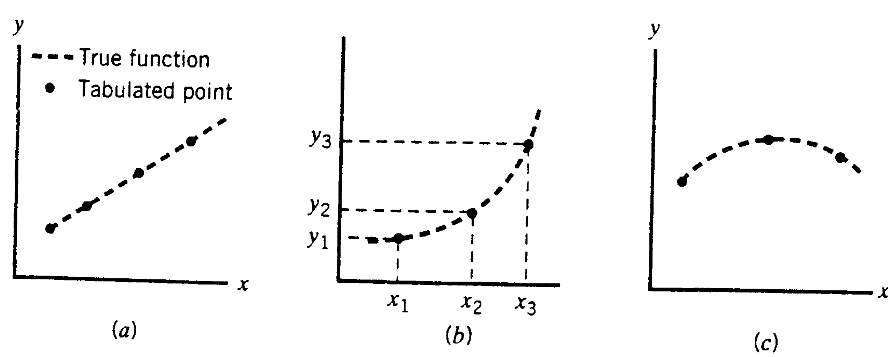
Two-Point Linear Interpolation

The equation of the line through (x_1, y_1) and (x_2, y_2) on a plot of y versus x is

$$y = y_1 + \frac{x - x_1}{x_2 - x_1}(y_2 - y_1)$$

to estimate y for an x between x_1 and x_2;

to estimate y for an x outside of this range



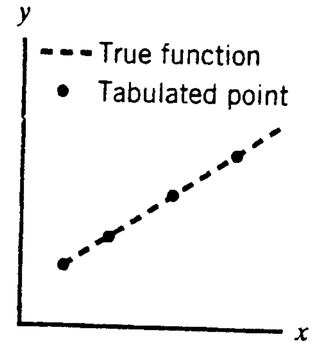
EXAMPLE

Fitting a Straight Line to Flowmeter Calibration Data

Flow Rate $\dot{V}$(L/min)	Rotameter Reading R
20.0	10
52.1	30
84.6	50
118.3	70
151.0	90

1. Draw a calibration curve and determine an equation for $\dot{V}(R)$.

Fitting Nonlinear Data



linear equation

$$y = ax + b$$

Fitting a nonlinear equation is usually much harder

$$y^2 = ax^3 + b.$$

$$y = ax^2 + b.$$

$$y^2 = \frac{a}{x} + b.$$

$$\frac{1}{y} = a(x + 3) + b.$$

$$\sin y = a(x^2 - 4).$$

$$y = \frac{1}{C_1 x - C_2}$$

$$y = 1 + x(mx^2 + n)^{1/2}$$

(Quantity 1) = a (Quantity 2) + b

linear equation

slope a and intercept b.

$y^2 = ax^3 + b. \implies$ Plot y^2 versus x^3

$y = ax^2 + b. \implies$ Plot y versus x^2.

$y^2 = \frac{a}{x} + b. \implies$ Plot y^2 versus $\frac{1}{x}$

$\frac{1}{y} = a(x + 3) + b. \implies$ Plot $\frac{1}{y}$ versus $(x + 3)$

$\sin y = a(x^2 - 4). \implies$ Plot $\sin y$ versus $(x^2 - 4)$.

$y = \frac{1}{C_1 x - C_2} \implies \frac{1}{y} = C_1 x - C_2$

$\implies$ Plot $\frac{1}{y}$ versus x. Slope $= C_1$, intercept $= -C_2$.

$y = 1 + x(mx^2 + n)^{1/2} \implies \frac{(y-1)^2}{x^2} = mx^2 + n$

Plot $\frac{(y-1)^2}{x^2}$ versus x^2. Slope $= m$, intercept $= n$

In summary

For an (x,y) data to be fitted with an equation of the form

$$f(x,y) = ag(x,y) + b,$$

1. Calculate $f(x,y)$ and $g(x,y)$ for each tabulated (x,y) point, and plot f versus g.

2. If the plotted points fall on a straight line, the equation fits the data.

3. Select two point on the line (g_1, f_1) and (g_2, f_2) and calculate a and b

$$a = \frac{f_2 - f_1}{g_2 - g_1} \qquad b = f_1 - ag_1 \quad \text{or} \quad b = f_2 - ag_2$$

EXAMPLE

Linear Curve-Fitting of Nonlinear Data

A mass flow rate $\dot{m}$(g/s) is measured as a function of temperature T(°C).

T	10	20	40	80
$\dot{m}$	14.76	20.14	27.73	38.47

Show if $$\dot{m} = aT^{1/2} + b$$

exponential function,

$y = ae^{bx}$

power law,

$y = ax^b$

$$P = e^Q \Longleftrightarrow \ln P = Q$$

$$\ln[e^Q] = Q \quad \text{and} \quad e^{\ln P} = P$$

$$y = ax \Longleftrightarrow \ln y = \ln a + \ln x,$$

$$y = x^b \Longleftrightarrow \ln y = b \ln x.$$

$$y = a \exp(bx) \Longleftrightarrow \ln y = \ln a + bx$$

Plot $\ln y$ versus x. Slope $= b$, intercept $= \ln a$.

$$y = ax^b \Longleftrightarrow \ln y = \ln a + b \ln x$$

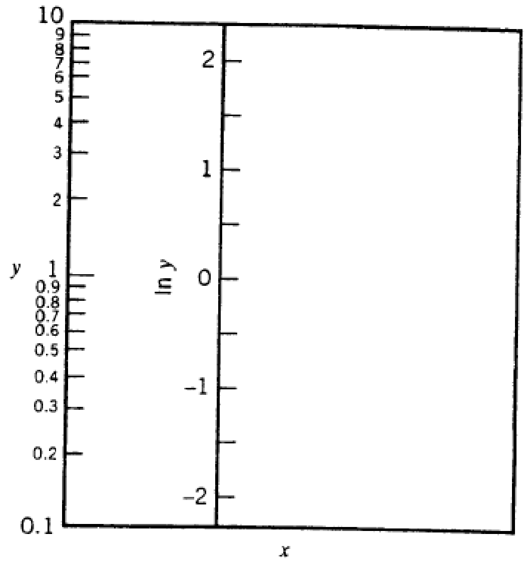
Plot $\ln y$ versus $\ln x$. Slope $= b$, intercept $= \ln a$.

Logarithmic Coordinates

to fit (x, y) data.

$$y = a \exp(bx)$$

$$y = ax^b$$



Suppose that an additional scale were drawn parallel to the ***ln(y)*** axis, on which values of y were shown adjacent to the corresponding values of ***ln (y)*** on the first scale

Log paper is graph paper with logarithmic scales on both axes. $y = ax^b$

semilog paper has one logarithmic axis and one rectangular axis. $y = ae^{bx}$

$$b = \frac{\ln y_2 - \ln y_1}{x_2 - x_1} = \frac{\ln(y_2/y_1)}{x_2 - x_1}$$

$$\ln a = \ln y_1 - bx_1 \implies [a = \exp(\ln a)]$$

EXAMPLE

Curve Fitting on Semilog and Log Plots

A plot of F versus t yields a line that passes through the points $(t_1 = 15, F_1 = 0.298)$ and $(t_2 = 30, F_2 = 0.0527)$ on (1) a semilog plot and (2) a log plot. For each case, calculate the equation that relates F and t.