COMMUNICATING using MEASUREMENTS

In Engineering we use a great many measuring instruments.

Scales		
Verniers	ü	
Micrometers	ï ý	Length
Gauges	ï	
Comparators	þ	
Thermometers	ü	
Thermistors + Indicator	ï	
Thermocouples + Indicator	ý ï	Temperature
PRT's	þ	
Manometers	ü	
Piezometers	ý	Pressure
Pressure gauges	þ	
Tachometers		Rotational speed
Dynamometers		Torque & Force
Psychrometers		Relative Humidity
Anemometers		Air speed
Ammeters		
Voltmeters	ü ý	Electrical
Oscilloscopes	þ	

Transducers (of all kinds)

The QUALITY of a measuring instrument is assessed from its accuracy, precision, reliability, durability etc. all of which are related to its cost.

Instruments are expensive, and for any given application we would not normally want to select an instrument whose quality is higher than is strictly needed.

e.g. An instrument used to check the length of nails to ± 2mm; compared with one needed to measure the diameter of a refrigeration compressor's bore to ± 0.001 mm.

The ACCURACY of an instrument is a measure of how closely it indicates the 'true' value of the measurement.

Accuracy, however, is always relative. Ultimately the comparison is with International Standards.
The concept of traceability links any instrument to the International Standards via sub-standards etc.

[See Haywood: Appendix A]

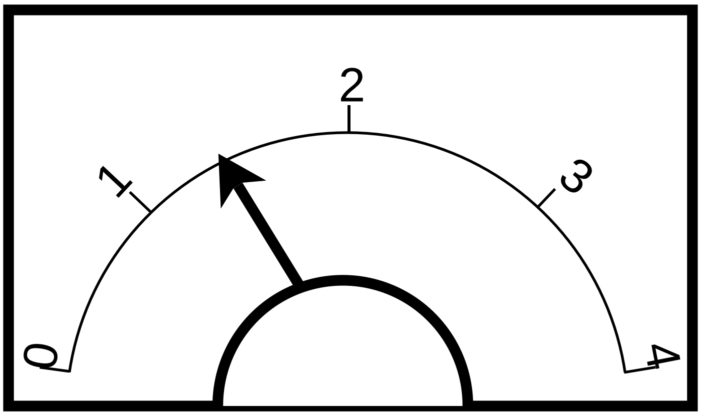
INSTRUMENT READOUT

<u>Analogue</u>

The indication is physically proportional to the quantity being measured.

e.g

A needle indicator -



Linear scales such as thermometers (MIG) & manometers

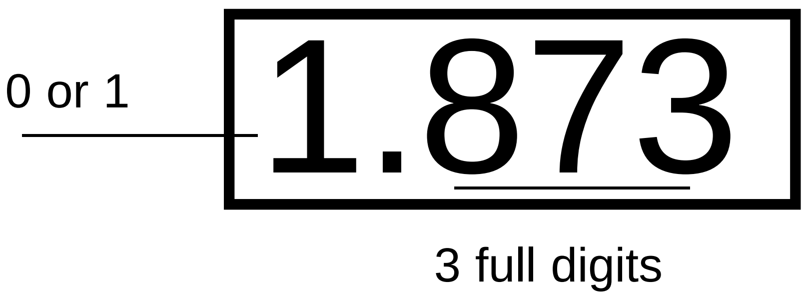
<u>Digital</u>

The indication is converted to a numerical form, and displayed in a given number of digits.

e.g

odometer

DVM's



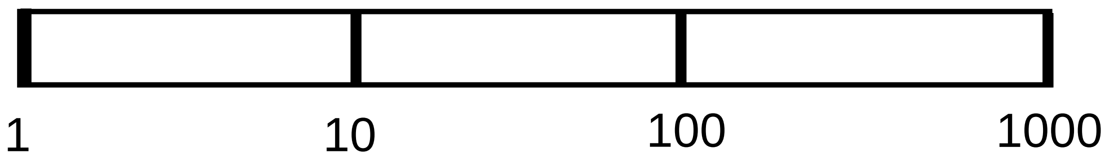
3½ digit display

Caution: Just because a digital display reads to 3 decimal places do not assume that it's accuracy is ± 0.001 digits!

Logarithmic

Physically similar to analogue indication but a log scale is used.

Care is needed in interpolating between divisions!



INSTRUMENT ACCURACY

Accuracy is often expressed as a percentage of full scale deflection (FSD).
e.g
If a voltmeter reads from 0 to 2 volts and has an accuracy of 2%, the reading at any point is ± 0.04 volts

So if the reading was 1V, it would be accurate to within ± 0.04 volts or **4% of the reading.**

Rule: Use the optimum (lowest) range for the measurement being taken.

CALIBRATION

Calibration is the means by which a measuring instrument is checked for accuracy. Its indication is compared with that of another instrument whose accuracy is **at least** an order magnitude better than the instrument being calibrated.

ERROR = ACTUAL READING - 'TRUE' READING

or

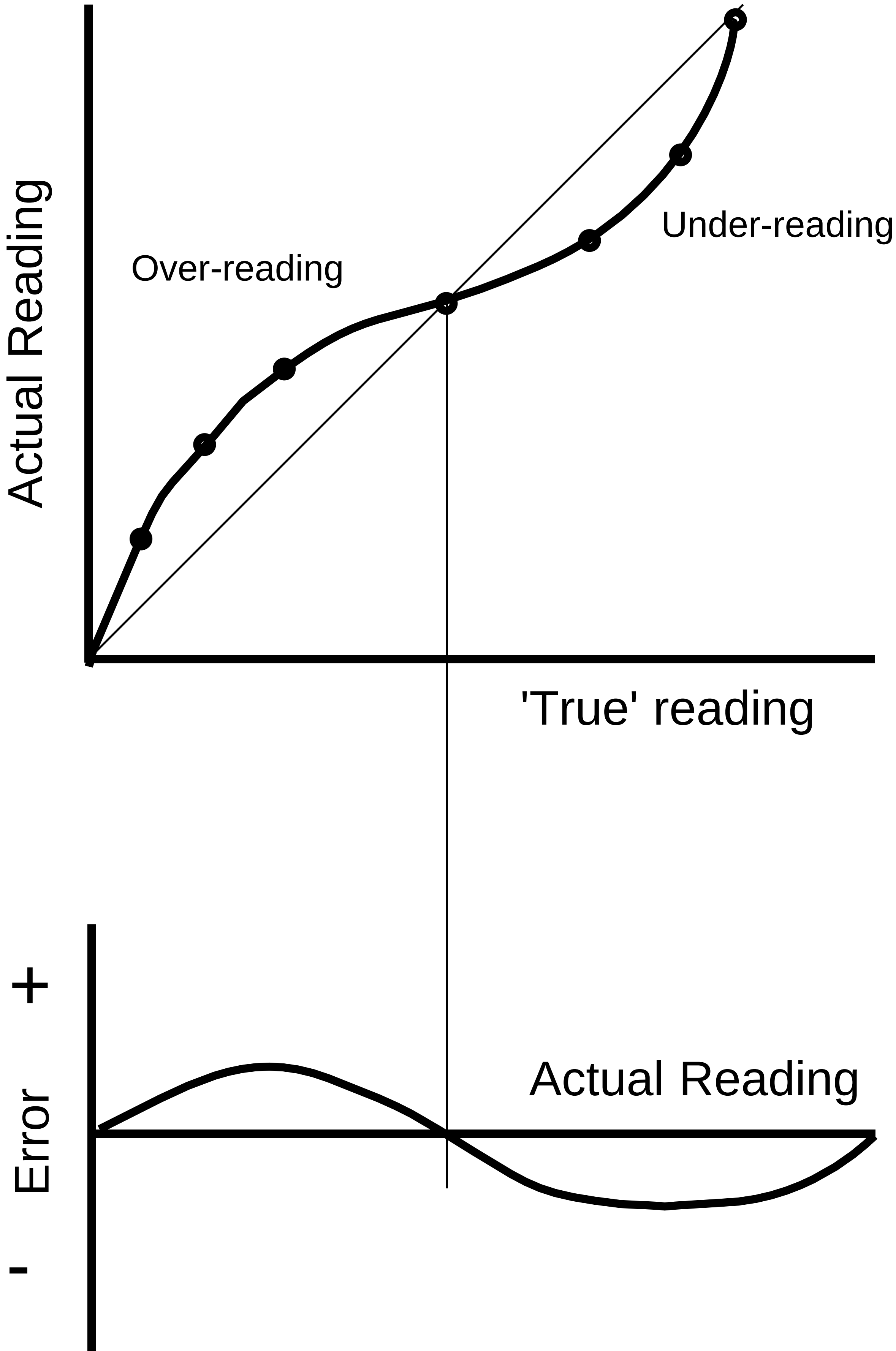
'TRUE' READING = ACTUAL READING + CORRECTION

It follows that the CORRECTION = - ERROR

To obtain a TRUE reading ADD a CORRECTION or SUBTRACT an ERROR.

Calibrated instruments are supplied with a calibration chart which enables its indication to be corrected at any point.

READING	CORRECTION


Actual Reading
Over-reading
Under-reading
'True' reading
+
Error
-
Actual Reading

DEALING WITH MEASUREMENT ERRORS

For valid evaluation of experimental results we must be aware of the effect of measurement errors.

The size of some errors will be vague, whereas others will be known - from the manufacturer or from experience.

Errors occur because of faults in:-
Apparatus
Instrumentation
Indicators

It is also important to distinguish between accuracy and precision.

Accuracy we defined earlier.

PRECISION has to do with repeatability. i.e. if we take the same measurement many times, a precise instrument will give the same reading each time. An imprecise instrument will give different readings.

So measuring devices can 'behave' in four possible ways:-

They can be:-

A - precise and inaccurate: repeated measurements are the same but not equal to the 'true' value.

B - imprecise and accurate: repeated measurements have different values but the average of repeated readings equals the 'true' value.

C - precise and accurate: repeated measurements give the same value which equals the 'true' value

D - imprecise and inaccurate:-

PRECISION ⇒ REPEATABILITY

ACCURACY ⇒ TRUE MEASURE

ERROR CLASSIFICATION

RANDOM	SYSTEMATIC (to do with the SYSTEM)
friction or stiction	bent needle on an indicator
human error	effect of instrument placement
parallax	use of an incorrect conversion factor
counting errors	zero errors
environmental effects (if neglected)	environmental effects (if included)
vibrational effects	lead or lag effects

NB systematic errors can be compensated or corrected for, whereas random errors can only be allowed for by statistical methods.

SPECIFYING ERRORS

A - In absolute terms:

e.g ± 0.5K; ± 1 mm

This method is satisfactory for specifying 'tolerances' but is not generally useful in terms of assessing the **significance** of the effect of the error.

B - In fractional (or percentage) terms:

If X_0 is the 'true' value and dX the error, the measured value (X) will be $X = X_0 \pm dX$

The true fractional error is : $\frac{dX}{X_0}$

Providing dX is small we may specify the fractional error as:

$$\frac{dX}{X}$$

As a percentage: $\frac{dX}{X}$ ´ 100 %

This method of error specification is much more useful because it gives the error relative to the quantities we are measuring.

THE EFFECT OF ERRORS ON DERIVED QUANTITIES

We often have to measure indirectly, and deduce quantities by calculation using more fundamental or base measurements.

e.g

Area = length x length

Volume = area x length

Heat energy = mass $\times$ specific heat capacity $\times$ ΔT

Work energy = force x distance or $\int F dx$

Momentum = mass x velocity

Total fluid energy = PE + KE + Presure-flow energy

etc

Clearly errors in base measurement will have effects on the derived measurements:

SUMS:

If $S = A + B$

& $A = A_0 + dA$

& $B = B_0 + dB$

then $S = A + dA + B + dB$

$= (A + B) + (dA + dB)$

Obviously $dS = dA + dB$

The error in the SUM equals the sum of the errors in the added components.

If $dA = dB$ (ie each measurement is to the <u>same tolerance</u>) the error in the SUM is TWICE the tolerance.

Hence on engineering drawings we dimension from a common datum - we do NOT chain dimensions!

PRODUCTS: If $P = A \times B$ then :

$P = (A_0 + dA) \times (B_0 + dB)$

$= A_0B_0 + AdB + BdA + dAdB$

Providing the errors are small we may ignore $dAdB$

$P = P_0 + AdB + BdA$

$dP = AdB + BdA$

therefore $$\frac{dP}{P} = \frac{(AdB + BdA)}{AB} = \frac{dA}{A} + \frac{dB}{B}$$

The fractional error in the PRODUCT is the sum of the fractional errors in the multiplied components.

e.g. in measuring area: if two lengths are measured to the same fractional error (**not** the same as the same tolerance) the fractional error in the area is TWICE that of the lengths.

ie The effect of errors in measurements which are used to derive other quantities is to **increase** the errors in the derived quantity.

We therefore need to ensure that our base measurements are measured sufficiently accurately to satisfy the accuracy we want in the derived quantity.

NB Differences & Quotients:-

Same result as for SUMS

Same result as for PRODUCTS

Example:

The length of heated bar is given by :- $L = L_0 [1 + a\ (T-T_0)]$

L_0 = 32mm ± 0.02mm; T_0 = 0°C; a = $2x10^{-4}$ ± 2%
and temperature is measured to ±5K

What is the error in L when the bar is heated to 100°C?

$$L = L_0 + L_0\ a\ (T-T_0)$$

The error in $T-T_0$ = twice error in each measurement = ±10K
Deal with the products next:

Fractional error in L_0 is 0.02/32 = 0.000625
Fractional error in $T-T_0$ is 10/100 = 0.1
Fractional error in a is 0.02 (given)

The fractional errors add, therefore the error in the second term is 0.000625 + 0.02 + 0.1 = ±0.121 mm

the value of the second term is

$$2x10^{-4} \text{ x } 32 \text{ x } 100 = 0.64\text{mm}$$

therefore the error = 0.121 x 0.64 = ±0.076 mm

the SUMMATION errors add
therefore the final error = 0.020 + 0.076 = ± 0.096 mm

NB: The large temperature error swamps the measurement error!