Error in Measurement

- Error = $\varepsilon \equiv x_{\text{meas}} - x_{\text{true}}$
  - Error is present in every measurement
  - Best we can do is estimate a bound on $\varepsilon$ with some level of certainty
    - $-u \leq \varepsilon \leq u$ (n:1)
  where $u$ is the uncertainty estimated at odds of n:1, or equivalently,
    - $x_{\text{meas}} - u \leq x_{\text{true}} \leq x_{\text{meas}} + u$ (n:1)
  - Wider interval at higher odds
  - Narrower interval at lower odds
The Goal

- Statements of uncertainty associated with measurement results
  - “A measurement result is complete only when accompanied by a quantitative statement of its uncertainty.”
  

- Example
  - \( Y = y \pm u_c(y) \) 95% confidence or (n:1) odds

Probability and Odds

- Probability \(\equiv\) the likelihood of a particular event taking place measured with reference to all possible events.
  - The probability of rolling 'snake eyes' [••] with a pair of dice is 1/36

- Odds \(\equiv\) the ratio of the probability of an event to the probability that it does not happen:
  - Odds = \( p/(1-p) \)
  - The odds of rolling snake eyes with a pair of dice is \( (1/36)/(35/36) \Rightarrow 1 \) in 35
  - Helpful in magnifying small or large probabilities by expressing them as a ratio of whole numbers.
  - What probability does odds of 19:1 correspond to?
Important Definitions

♦ **Calibration** = the process of applying known values of a measurand to determine the response of a measurement system
  - *Static* Calibration = calibration using a constant measurand
    • Ex. Weights applied to a scale
  - *Dynamic* Calibration = calibration using a time-dependent measurand
    • Ex. Sinusoidal, step, impact

♦ **Sensitivity** = the change of output (measured value) per unit of input (measurand). Sensitivity is the slope of the static calibration curve at a given value of the input.

Calibration, Sensitivity, and Linearity

**Graph:**

- **Sensor Calibration**
- **Measurand input, x units**
- **Output, y units**
- **K = sensitivity**
**Important Definitions, cont.**

- **Accuracy** = the closeness of a measured value to the actual value being measured
- **Repeatability (precision)** = the ability of an instrument to repeat an output when measuring a given quantity under identical conditions
- **Resolution** = the smallest increment of change in the measured value that can be determined from the readout or recording instrument

**Accuracy, Repeatability, and Systematic Error**
Components of Uncertainty

- **Random effects (random or precision errors)**
  - Occur differently for each measurement
  - Creates a distribution of values
  - Arise from uncontrolled variables, e.g., ________________
  - Can use statistical methods to estimate the likely range that the true value lies in

- **Systematic effects (systematic or bias errors)**
  - Occur the same way for each measurement
    - Ex: 1st down measurement chain – too many links
    - Ex: Bubble level - vial misaligned
  - Arise from:
    - Calibration error
    - Loading error
    - Measurement disturbance
    - Aging of components in measurement equipment
    - Uncontrolled variables
Components of Uncertainty, cont.

- Systematic effects, cont.
  - In general, need more than statistical methods to determine
    - Can estimate using:
      - Comparison with more accurate standards
      - Compare with a different method of measuring the same variable
      - Self-calibration (reversal) sometimes
      - Inter-laboratory comparison
      - Experience

Calibration and Hysteresis

![Sensor Calibration with Hysteresis diagram](image_url)
References