Physics 1 Lab
Measuring With Precision Instruments

Physics Department

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Lab 1

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Question 1

Analyze the data in Table (3):

(a) Calculate the mean values, standard deviation, standard error, and standard deviation of the mean for the thickness of each pair of sheets. Express the thickness of each sheet in the form

$$d = \bar{d} \pm \alpha$$

where $\bar{d}$ and α are the mean and standard deviation of the mean, respectively.

(b) What errors exist in this stage? Are there random errors in this measurement? How does increasing the number of measurements affect the standard deviation and standard deviation of the mean?

Answer

Mean: $\overline{W} = \frac{1}{n}\sum_{i=1}^{n} W_i$

Standard Deviation: $\sigma = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(W_i - \overline{W})^2}$

SEM: $\alpha = \frac{\sigma}{\sqrt{n}}$

```

d1 = [ 4.18 4.22 4.37 4.19 4.17 4.18 4.21 4.18];
d2 = [ 5.32 5.33 5.26 5.27 5.33 5.34 5.28 5.33 ];

% Calculations for Sheet 1
mean_d1 = mean(d1);
std_d1 = std(d1);
var_d1 = var(d1);        % Variance added
sem_d1 = std_d1 / sqrt(length(d1));

% Calculations for Sheet 2
mean_d2 = mean(d2);
std_d2 = std(d2);
var_d2 = var(d2);        % Variance added
sem_d2 = std_d2 / sqrt(length(d2));

fprintf('Sheet 1:\n');

fprintf('Mean = %.4f\n', mean_d1);

fprintf('Standard Deviation = %.4f\n', std_d1);

fprintf('Variance = %.4f\n', var_d1);  % Variance displayed

fprintf('Standard Error (SEM) = %.4f\n', sem_d1);

fprintf('Thickness: d = %.4f \pm %.4f\n', mean_d1, sem_d1);
```

Sheet 1:
Mean = 4.2125 mm
Standard Deviation = 0.0658 mm
Variance = 0.0043 mm²
Standard Error (SEM) = 0.0233 mm
Thickness: $d = 4.2125 \pm 0.0233$ mm

```matlab

fprintf('Sheet 2:\n');

fprintf('Mean = %.4f\n', mean_d2);

fprintf('Standard Deviation = %.4f\n', std_d2);

fprintf('Variance = %.4f\n', var_d2);  % Variance displayed

fprintf('Standard Error (SEM) = %.4f\n', sem_d2);

fprintf('Thickness: d = %.4f \pm %.4f\n', mean_d2, sem_d2);
```

Sheet 2:
Mean = 5.3075 mm
Standard Deviation = 0.0320 mm
Variance = 0.0010 mm²
Standard Error (SEM) = 0.0113 mm
Thickness: $d = 5.3075 \pm 0.0113$ mm

In the case of systematic errors, only zero error exists, which is identifiable and can be corrected. Random errors, however, certainly exist (due to differences in the surface levels of various sheets). However given the proximity of measurement results, these errors are minor. By increasing the number of measurements, the values get closer to the actual mean and the standard deviation decreases. Considering the relation:

$$\sigma_m = \frac{\sigma}{\sqrt{N}}$$

with the reduction of standard deviation and an increase in the number of measurements, the standard deviation of the mean also decreases.

Question 2

Analyze the data in Table (4):

(a) Calculate the mean, standard deviation, and standard deviation of the mean for the diameter and length of the cylindrical shell. Express each of the diameter values (external and internal) and the length in the form

$$X = \bar{X} \pm \alpha$$

(b) Using the standard deviation of the mean as the error for these quantities, calculate the mean volume of the cylindrical shell and express it as

$$V = \bar{V} \pm \gamma$$

(c) What errors exist in this stage? Are there random errors in this measurement? How does increasing the number of measurements affect the results?

Answer

```
% Input data
outer_diameter = [20, 20, 20, 19.80, 19.82, 20.00, 19.82];
inner_diameter = [8, 8, 8, 7.98, 8, 8, 8];
length_L = [31.68, 31.60, 31.60, 31.62, 31.64, 31.58, 31.60];

% Outer Diameter Calculations
mean_outer = mean(outer_diameter);
std_outer = std(outer_diameter);
var_outer = var(outer_diameter);
sem_outer = std_outer / sqrt(length(outer_diameter));
```

Outer Diameter (a):
Mean = 19.9200 mm
Variance = 0.0100 mm²
Standard Deviation = 0.1000 mm
SEM (α) = 0.0378 mm
Result: $a = 19.920 \pm 0.038$ mm

```
% Inner Diameter Calculations
mean_inner = mean(inner_diameter);
std_inner = std(inner_diameter);
var_inner = var(inner_diameter);
sem_inner = std_inner / sqrt(length(inner_diameter));
```

Inner Diameter (y):
Mean = 7.9971 mm
Variance = 0.000057 mm²
Standard Deviation = 0.0076 mm
SEM (α) = 0.0029 mm
Result: $y = 7.997 \pm 0.003$ mm

```
% Length Calculations
mean_length = mean(length_L);
std_length = std(length_L);
var_length = var(length_L);
sem_length = std_length / sqrt(length(length_L));
```

Length (L):
Mean = 31.6171 mm
Variance = 0.0011 mm²
Standard Deviation = 0.0335 mm
SEM (α) = 0.0127 mm
Result: $L = 31.617 \pm 0.013$ mm

```
syms D_outer D_inner L
V = pi * L * ((D_outer/2)^2 - (D_inner/2)^2);  % Shell volume formula

dV_dDouter = diff(V, D_outer);
dV_dDinner = diff(V, D_inner);
dV_dL = diff(V, L);

error_V = sqrt(...
    (dV_dDouter * sem_outer)^2 + ...
    (dV_dDinner * sem_inner)^2 + ...
    (dV_dL * sem_length)^2 ...
);

V_mean = double(subs(V, [D_outer, D_inner, L], [mean_outer, mean_inner,
   mean_length]));
error_V = double(subs(error_V, [D_outer, D_inner, L], [mean_outer,
   mean_inner, mean_length]));
```

Cylindrical Shell Volume (V):
Mean Volume = 8265.40 mm³
Volume Error (γ) = 37.56 mm³
Result: $V = 8265.40 \pm 37.56$ mm³

Due to the zero-error nature of the **Coulisse caliper**, no systematic zero error is present in this case. However, variations in measurements taken from different regions of the cylinder lead to discrepancies in the recorded values. Since these variations are subject to **random errors**, their impact is more pronounced when considering **standard deviation** relative to numerical values (as referenced in Table 3). Nevertheless, because of the **consistency** in thickness measurements across different sheets, the overall measurement error remains relatively small.

Question 3

Analyze the data in Table (5): Calculate the mean, standard deviation, and standard deviation of the mean for the mass. Express the mass in the form

$$W = \bar{W} \pm \alpha$$

Answer

```
mass_data = [71.6 71.6 71.7 71.7 71.5];

mean_mass = mean(mass_data);
std_mass = std(mass_data);
sem_mass = std_mass / sqrt(length(mass_data));
```

Mass Analysis:
Mean ($\overline{W}$) = 71.6200 g
Standard Deviation (σ) = 0.0837 g
Standard Error of the Mean (SEM/α) = 0.0374 g
Final Result: $W = 71.620 \pm 0.037$ g

Question 4

Analyze the data in Table (6): Calculate the mean, standard deviation, and standard deviation of the mean for the height differences of the fixed and moving axes and the distances of the fixed and moving concave gauge. Express them in the form

$$r = \bar{r} \pm \eta \quad \text{and} \quad h = \bar{h} \pm \mu$$

Calculate the radius of curvature of the desired surface and express it in the form

$$R = \bar{R} \pm \sigma$$

Answer

```
r_data = [22.21, 21.96, 22.22];
h_data = [2.16, 2.06, 2.12, 2.13, 2.04];

mean_r = mean(r_data);
std_r = std(r_data);
sem_r = std_r / sqrt(length(r_data));

mean_h = mean(h_data);
std_h = std(h_data);
sem_h = std_h / sqrt(length(h_data));
```

Distance between axes (r):
Mean = 22.1300 $\pm$ 0.0850 mm

Height difference (h):
Mean = 2.1020 $\pm$ 0.0224 mm

```
% Formula: R = (r^2 + h^2)/(2h)
syms r h
R_mean = (mean_r^2 + mean_h^2)/(2*mean_h);

dR_dr = diff((r^2 + h^2)/(2*h), r);
dR_dh = diff((r^2 + h^2)/(2*h), h);

dRdr_val = double(subs(dR_dr, [r, h], [mean_r, mean_h]));
dRdh_val = double(subs(dR_dh, [r, h], [mean_r, mean_h]));

R_error = sqrt( (dRdr_val^2 * sem_r^2) + (dRdh_val^2 * sem_h^2) );
```

Spherical Radius (R):
Mean Radius = 117.54 mm
Standard Error (σ) = 1.52 mm
Final Result: $R = 117.54 \pm 1.52$ mm

Tables for Experiment 1

Table 1 - Zero Errors

Vernier Caliper Zero Error	0.00 mm	0.00	0.00	0.00	0.00	mean = 0.00
Micrometer Zero Error	0.37 mm	0.36	0.37	0.37	0.37	mean = 0.37

Table 2 - Sample Numbers (Omitted)

This table has been crossed out.

Table 3 - Sheet Thickness Measurement

Sample	Thickness of Metal Sheet (a)	Thickness of Plastic Sheet (b)
1	4.18	5.32
2	4.22	5.33
3	4.37	5.26
4	4.19	5.27
5	4.17	5.33
6	4.18	5.34
7	4.21	5.28
8	4.18	5.33

Table 4 - Measurement of Cylindrical Sample Dimensions

Sample	Outer Diameter (mm)	Inner Diameter (mm)	Length (mm)
1	20.00	8.00	31.68
2	20.00	8.00	31.60
3	20.00	8.00	31.60
4	19.80	7.98	31.62
5	19.82	8.00	31.64
6	20.00	8.00	31.58
7	19.82	8.00	31.60

Table 5 - Mass Measurement of Cylindrical Samples

Sample	Mass (g)
1	71.60
2	71.60
3	71.70
4	71.70
5	71.5

Table 6 - Measurement of Fixed Axis Distance and Deviation

Fixed and movable axis distance	22.21	21.96	22.22		
Height difference of fixed and movable axes of the concave meter	2.16	2.06	2.12	2.13	2.04