Chapter 3
Engineering Solutions

3.4 and 3.5 Problem Presentation

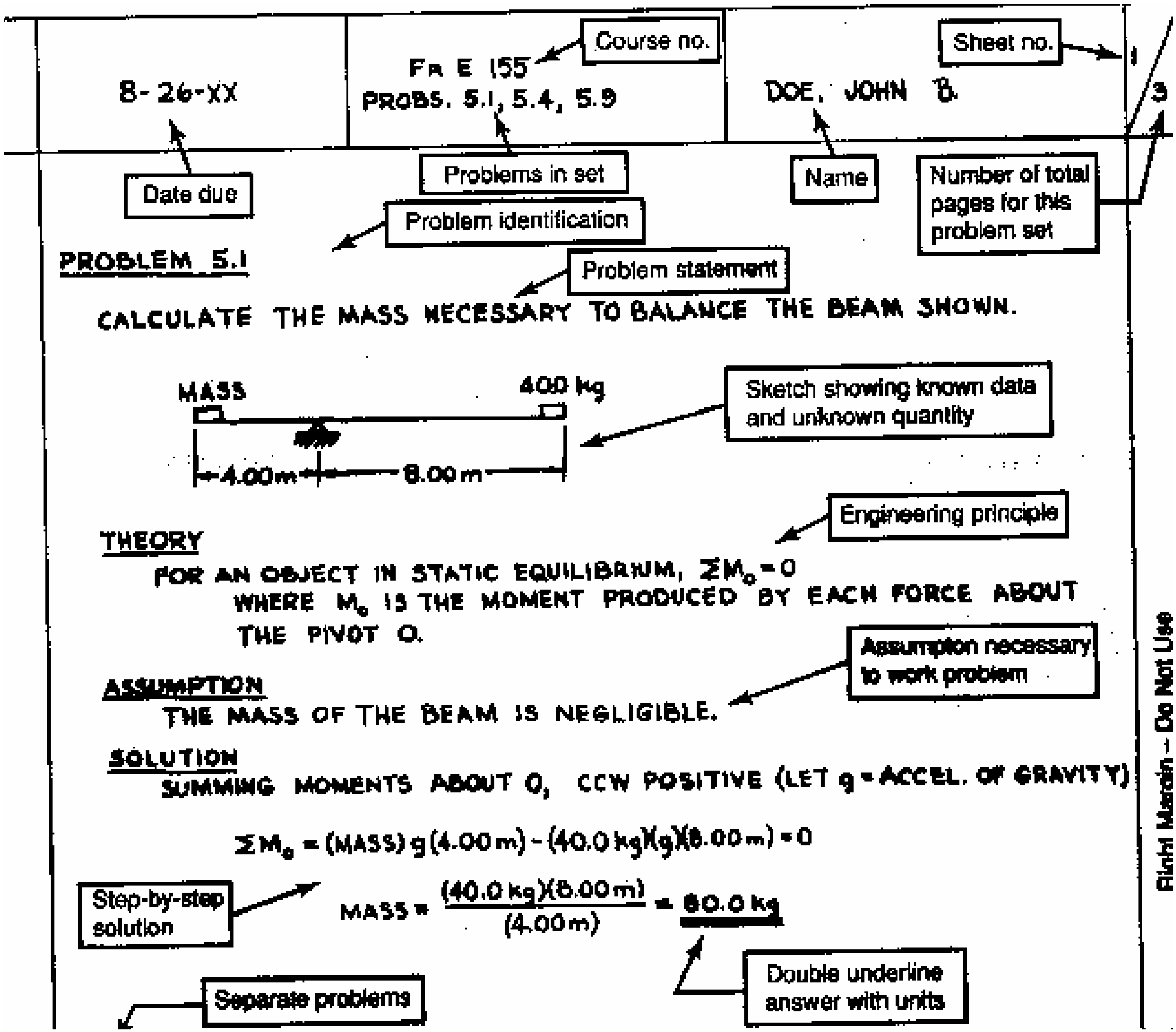
Organize your work as follows (see book):

Problem Statement

Theory and Assumptions

Solution

Verification



8-26-XX | FR E 155 PROBS. 5.1, 5.4, 5.9 | DOE, JOHN B. | 1/3

PROBLEM 5.1

CALCULATE THE MASS NECESSARY TO BALANCE THE BEAM SHOWN.

MASS — 400 kg — 4.00 m — 8.00 m

THEORY

FOR AN OBJECT IN STATIC EQUILIBRIUM, $\Sigma M_o = 0$ WHERE M_o IS THE MOMENT PRODUCED BY EACH FORCE ABOUT THE PIVOT O.

ASSUMPTION

THE MASS OF THE BEAM IS NEGLIGIBLE.

SOLUTION

SUMMING MOMENTS ABOUT O, CCW POSITIVE (LET g = ACCEL. OF GRAVITY)

$$\Sigma M_o = (\text{MASS})\,g\,(4.00\,\text{m}) - (40.0\,\text{kg})(g)(8.00\,\text{m}) = 0$$

$$\text{MASS} = \frac{(40.0\,\text{kg})(8.00\,\text{m})}{(4.00\,\text{m})} = \underline{\underline{80.0\,\text{kg}}}$$

Tools:

Pencil and Paper
See Fig. 3.1 in Book
or use
Analysis Software,
e.g. Mathcad

Tools:

Word Processor

See Fig. 3.3a and b in Book

Benefits:

Neater appearance

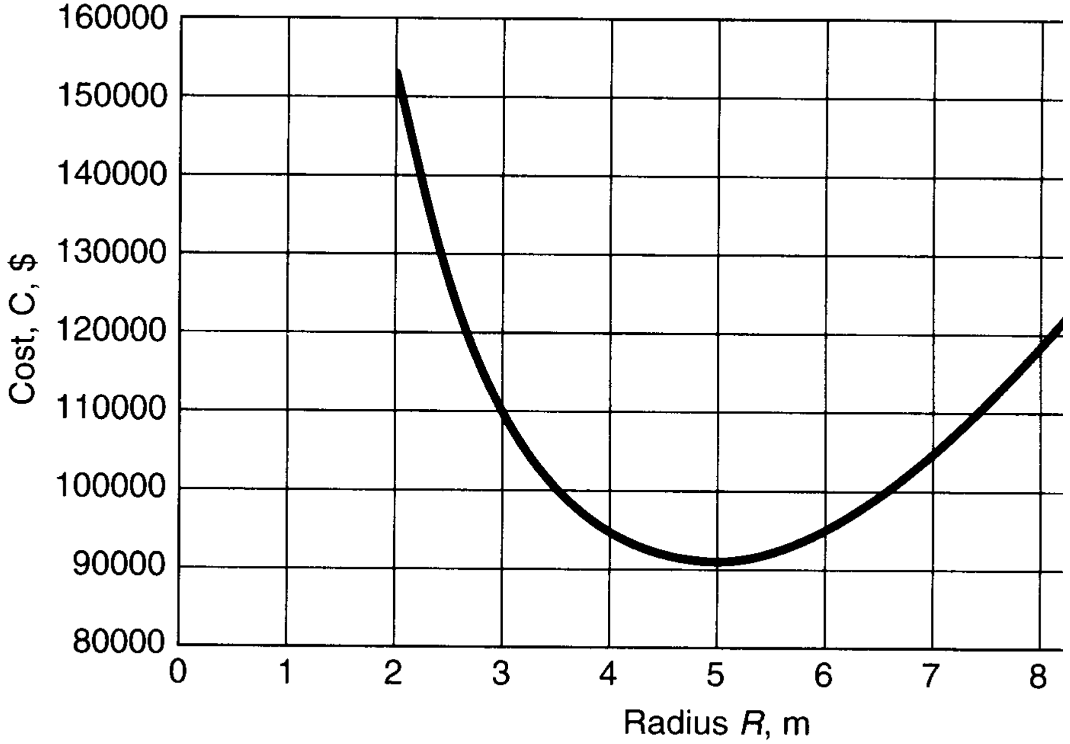
Import graphics

Import results from other tools, such as spread sheets

1. Express total volume in meters as a function of height and radius.

$$V_{Tank} = f(H, R)$$
$$= V_C + V_H$$
$$500 = \pi R^2 H + \frac{2\pi R^3}{3}$$

Note: $1\,\text{m}^3 = 1000$ L



Source: Eide, Fig. 3.3a

Analysis Software :

Advantages:

- Always clean and organized
- Numerics will be correct (assuming you entered correct equations)
- Automated graphing and presentation tools
- Superior error and plausibility checking

Analysis Software :

So why aren’t you using Math software yet?

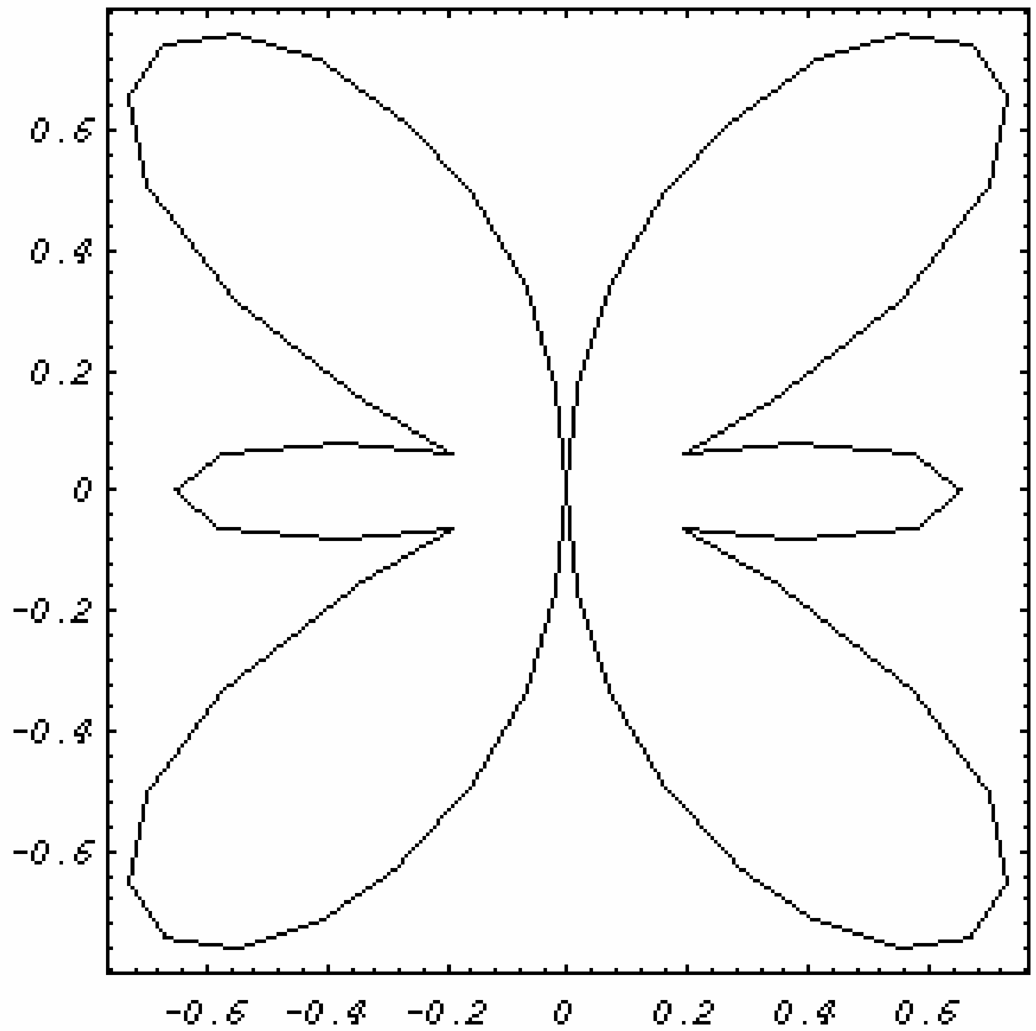
Examples of Analysis Software:

- **Mathematica (symbolic)**
- **Maple (symbolic)**
- **Mathcad (general and symbolic)**
- **Matlab (numerical)**
- **Numerous specialty products**

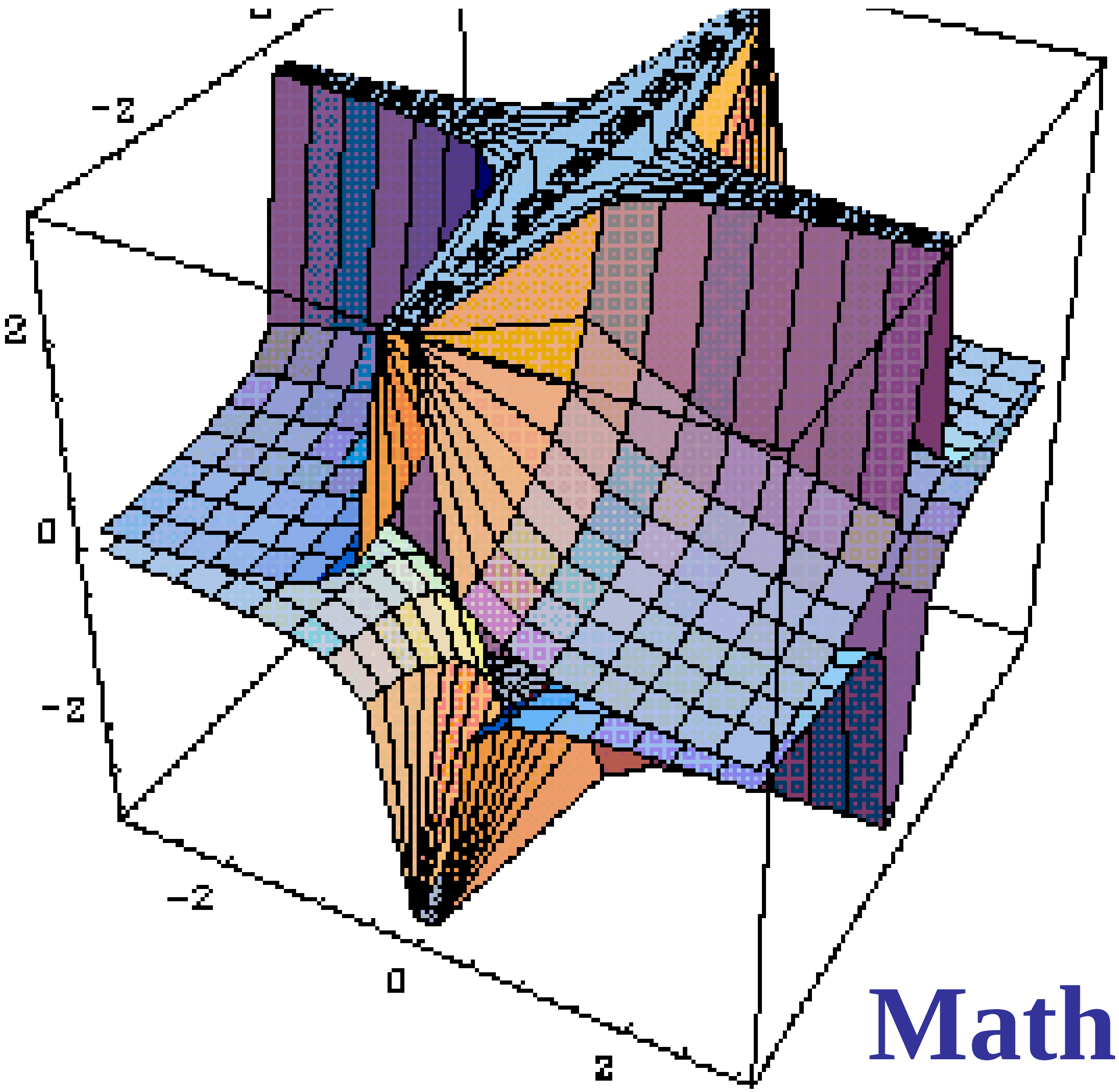
```
showfieldpattern[
   efieldtheta[N[Range[0, 2 Pi, Pi/30]],
       LinearSolve[
            ToeplitzMatrix[impedances[1.47, 0.005, 50]],
            -magneticfrill[1.47, 0.005, 2.23 * 0.005, 50]
       ],
       1.47]
]
```

Dipole (physics) analysis example

Mathematica



```
absgraph = InequalityPlot3D[Abs[x y z] < 1,
  {x, -3, 3}, {y, -3, 3}, {z, -3, 3}];
```

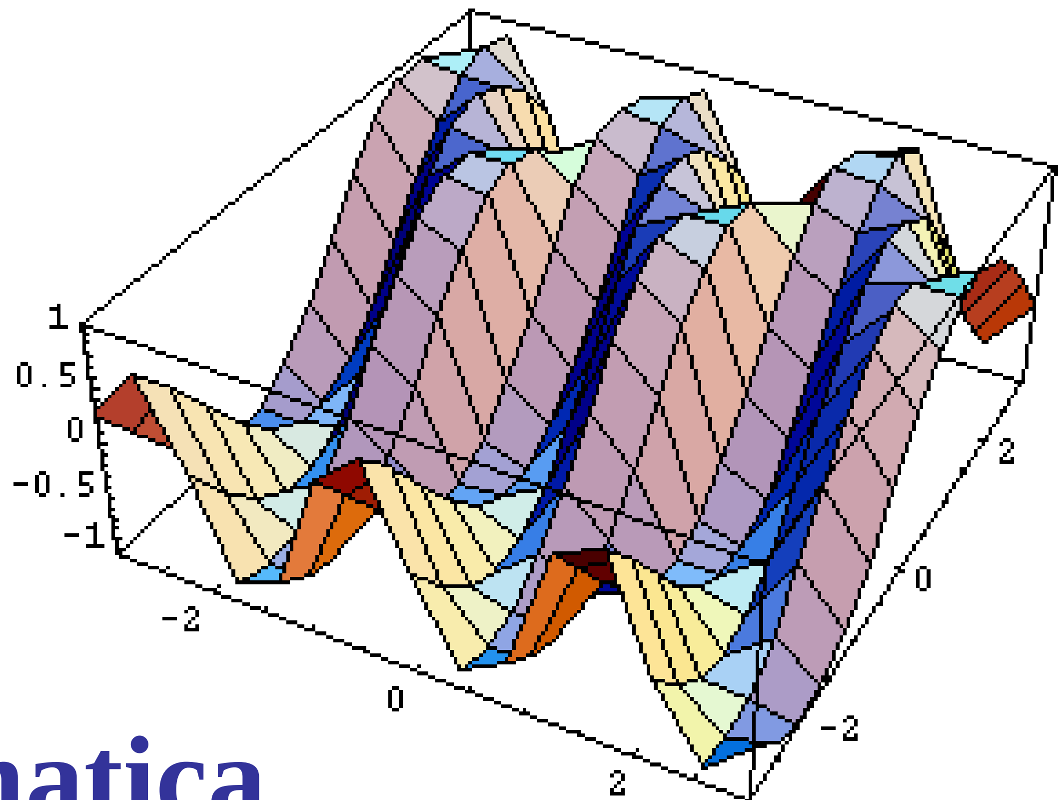


Mathematica

In[4]:= `Integrate[1/(x^3-1), x]`

Out[4]= $\left\{-\frac{\text{ArcTan}\left[\frac{1+2x}{\sqrt{3}}\right]}{\sqrt{3}}+\frac{1}{3}\text{Log}[-1+x]-\frac{1}{6}\text{Log}[1+x+x^2]\right\}$

In[5]:= `Plot3D[Sin[y + Sin[3 x]], {x, -3, 3}, {y, -3, 3}]`



Out[5]= - SurfaceGraphics -

Mathematica

Mathcad Calculus Example

Symbolics Example (Mathcad)

$$y(x) = \frac{x^3}{\sqrt{\frac{1 + x^2 + x^3}{\sin(3 \cdot x)}}}$$

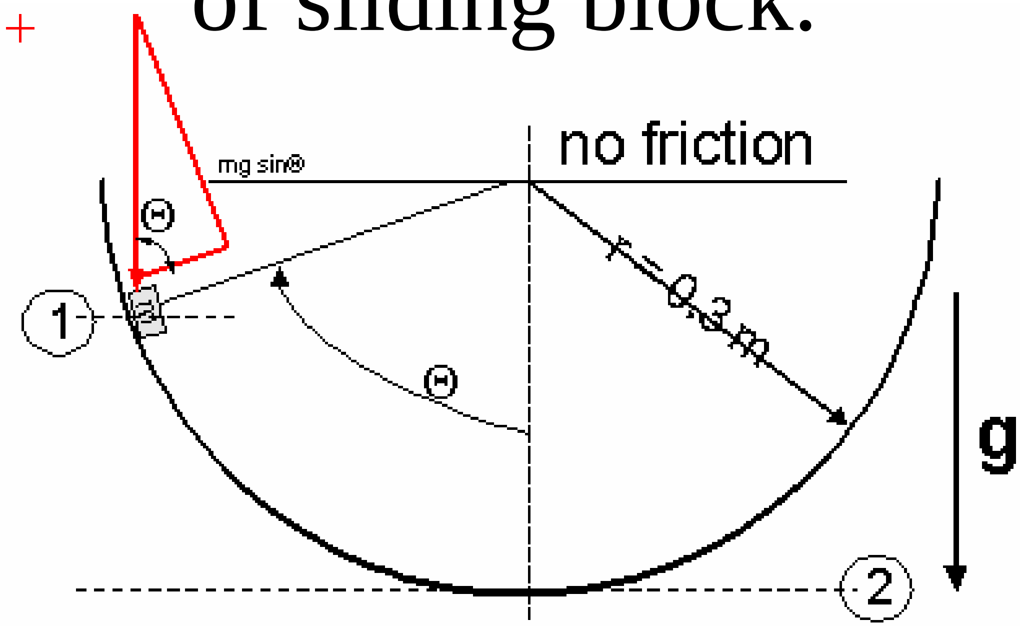
Maple Differentiation

$$\frac{d}{dx} y(x) = 3 \cdot \frac{x^2}{\left[\frac{\left(1 + x^2 + x^3\right)}{\sin(3 \cdot x)}\right]^{\frac{1}{2}}} - \frac{1}{2} \cdot \frac{x^3}{\left[\frac{\left(1 + x^2 + x^3\right)}{\sin(3 \cdot x)}\right]^{\frac{3}{2}}} \cdot a$$

with

$$a = \left[\frac{\left(2 \cdot x + 3 \cdot x^2\right)}{\sin(3 \cdot x)} - 3 \cdot \frac{\left(1 + x^2 + x^3\right)}{\sin(3 \cdot x)^2} \cdot \cos(3 \cdot x)\right]$$

Examples in Mathcad: compute motion of sliding block.



Problem C17-92

$m := 0.02$ $g := 9.81$

$r := 0.3$ $\theta 0 := 75 \cdot \frac{\pi}{180}$

$\theta 0 = 1.309$

We choose:
Datum line at bottom of Trough.
T1 =0, V(Θ) = -mgh*cosΘ
Energy equation:

$$-m \cdot g \cdot r \cdot \cos(\theta 0) + 0 = \frac{1}{2} \cdot \left(m \cdot v^2\right) - m \cdot g \cdot r \cdot \cos(\theta)$$

Symbolically solve for v: Place cursor at 'v', select Symbolics --> Variable --> Solve

$$\begin{bmatrix} -\sqrt{-2 \cdot g \cdot r \cdot (\cos(\theta 0) - \cos(\theta))} \\ \sqrt{-2 \cdot g \cdot r \cdot (\cos(\theta 0) - \cos(\theta))} \end{bmatrix}$$

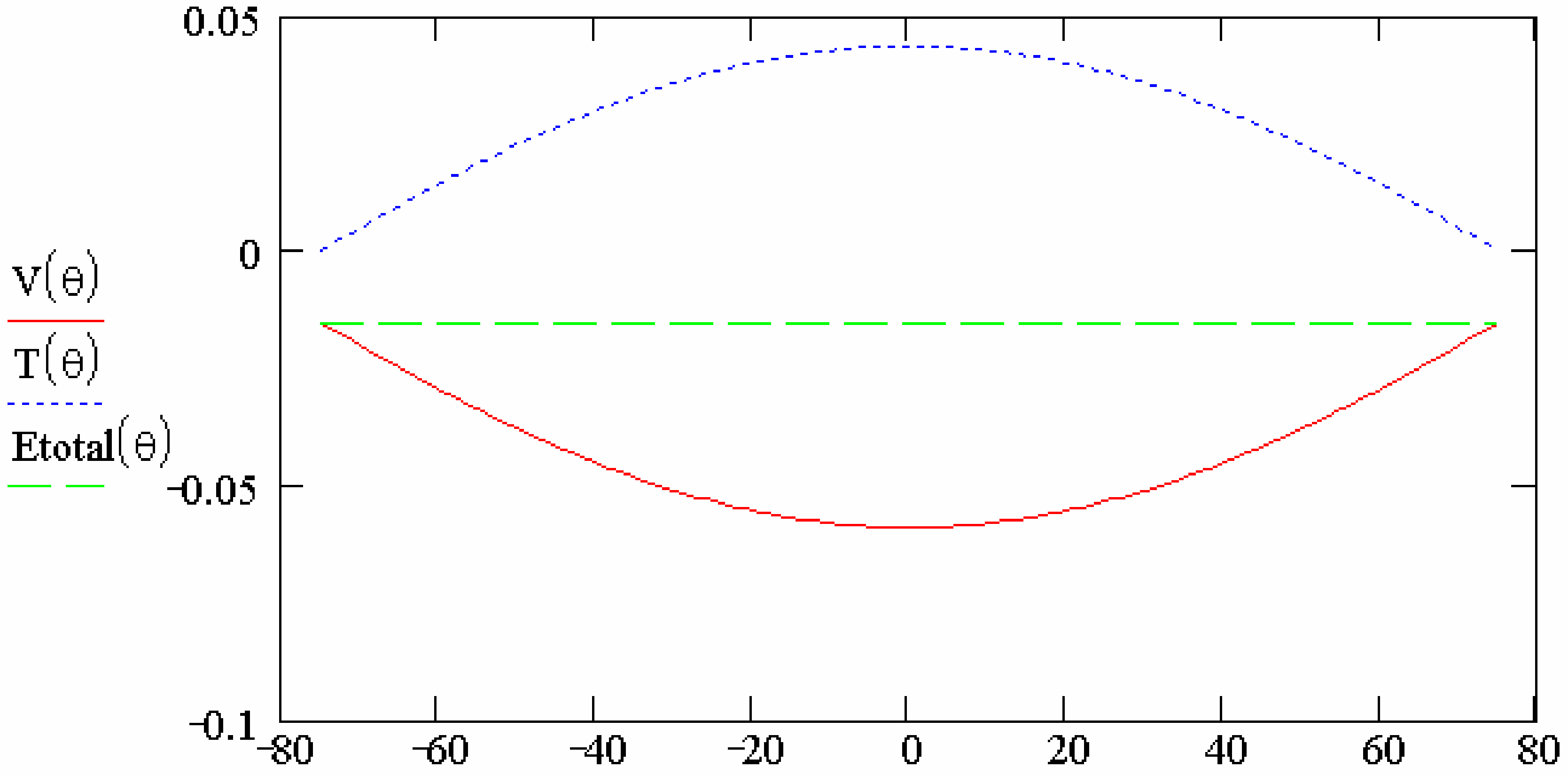
Motion of sliding block.

θ in radians!!

$$\theta := -75\cdot\frac{\pi}{180}, -74\cdot\frac{\pi}{180} .. 75\cdot\frac{\pi}{180} \quad v(\theta) := \sqrt{-2\cdot g\cdot r\cdot(\cos(\theta 0) - \cos(\theta))}$$

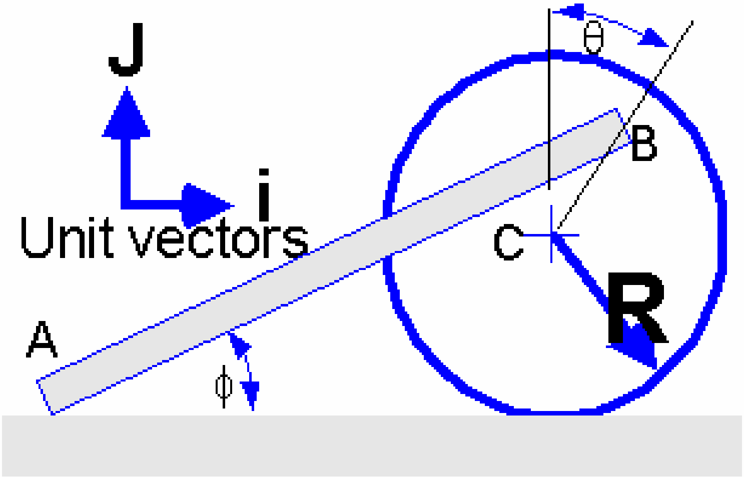
$$T(\theta) := \frac{1}{2}\cdot m\cdot v(\theta)^2 \quad V(\theta) := -(m\cdot g\cdot r\cdot\cos(\theta)) \quad Etotal(\theta) := V(\theta) + T(\theta)$$

$$Etotal(1) = -0.015$$



C14-68: Oscillating Arm

Arm AB is attached to the rolling wheel, causing AB to oscillate.
Find ω_{AB} and v_A



Data:

vC := 1.2   AB := 1   BC := 0.25   r := 0.3

Equations:

$t := 0, 0.1 .. 3 \qquad om := \frac{vC}{r} \qquad theta(t) := om \cdot t$

$$phi(t) := asin\left(\frac{r + BC \cdot cos(theta(t))}{AB}\right)$$

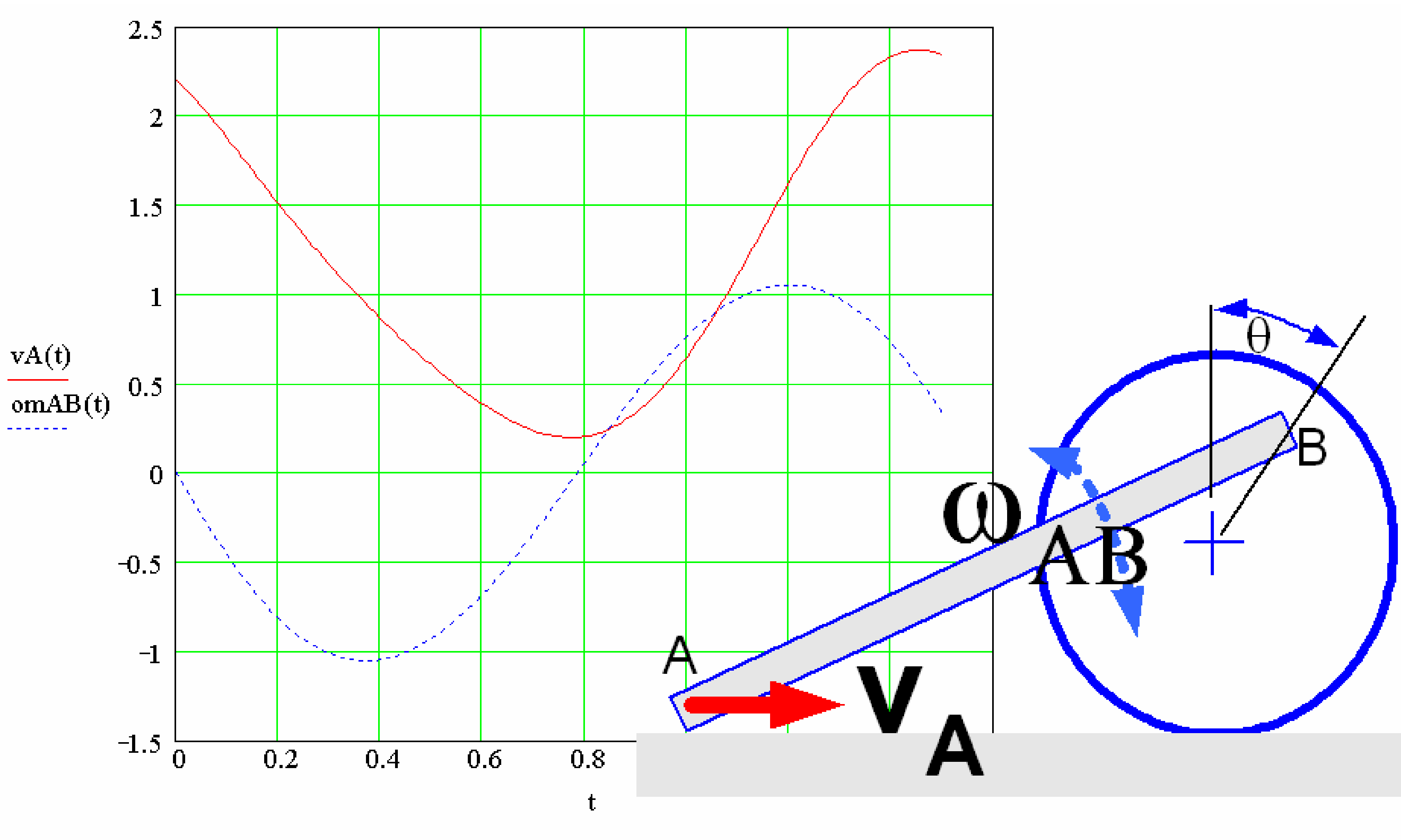
Dynamic system analysis example

Mathcad can find the solution by symbolic Equation solving:

$$\mathrm{omAB}(t) := \frac{-1}{\sqrt{1 - r^2 - 2\cdot r\cdot BC\cdot \cos\left(\frac{vC}{r}\cdot t\right) - BC^2\cdot \cos\left(\frac{vC}{r}\cdot t\right)^2}}\cdot BC\cdot \frac{vC}{r}\cdot \sin\left(\frac{vC}{r}\cdot t\right)$$

$$vA(t) := -vC\cdot\left(r + BC\cdot\cos\left(\frac{vC}{r}\cdot t\right)\right)\cdot\frac{\left(-\sqrt{1 - r^2 - 2\cdot r\cdot BC\cdot\cos\left(\frac{vC}{r}\cdot t\right) - BC^2\cdot\cos\left(\frac{vC}{r}\cdot t\right)^2} + BC\cdot\sin\left(\frac{vC}{r}\cdot t\right)\right)}{\left(\sqrt{1 - r^2 - 2\cdot r\cdot BC\cdot\cos\left(\frac{vC}{r}\cdot t\right) - BC^2\cdot\cos\left(\frac{vC}{r}\cdot t\right)^2}\cdot r\right)}$$

Dynamic system analysis example



Dynamic system analysis example

What is in it for me?

Yes, you will have to get used to the constraints imposed by the software. This will pass.
All learning is an investment for your future.

What is in it for me?

Benefits: You will be

Faster

More Efficient

More accurate.

Better presentation

Time is money.

What is in it for me?

Tools such as Mathcad allow you to create:

- **Better presentations**
- **Accurate results.**
- **Better design choices (play *what if?* scenarios)**

Conclusion Chapter 3

Plan for the long term.
Become familiar with those tools that will make you the most productive.
Your investment will pay off handsomely.

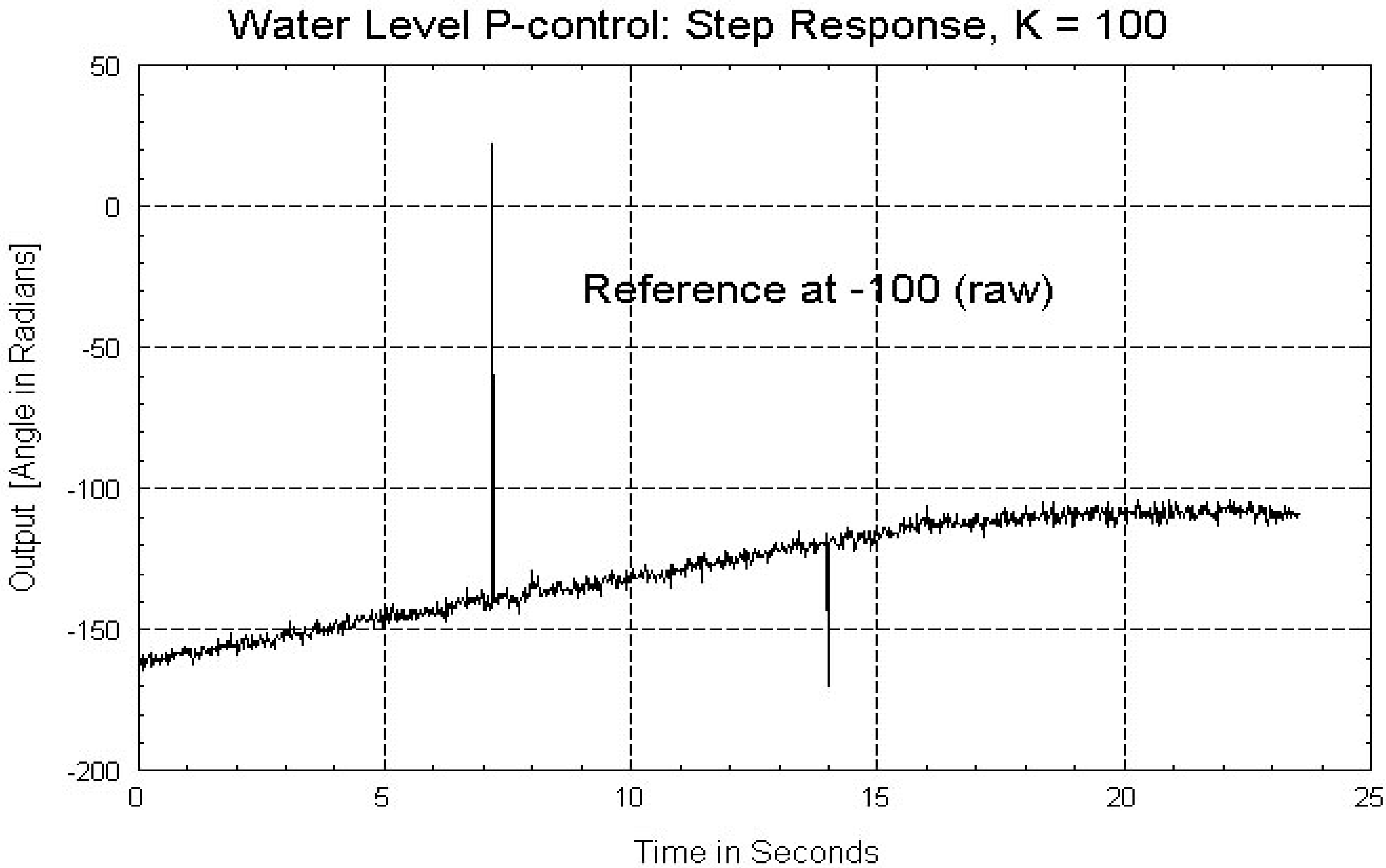
Chapter 4

Representation of Technical Information

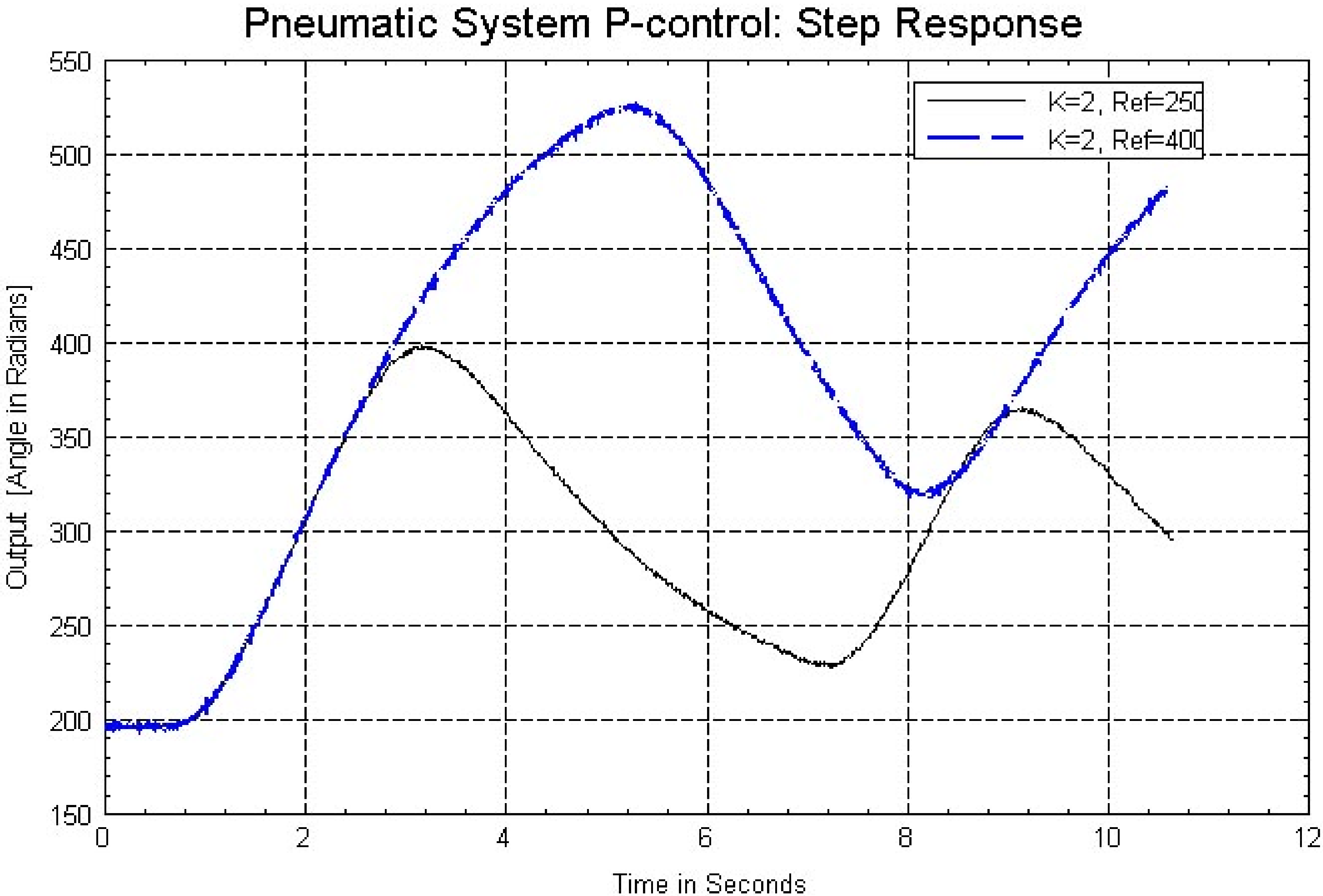
A Typical Scenario

We collected data in an experiment.

- **The data set might consist of a list, such as the one on page 143 in your book, or a computer data file.**
- **We plot the data.**



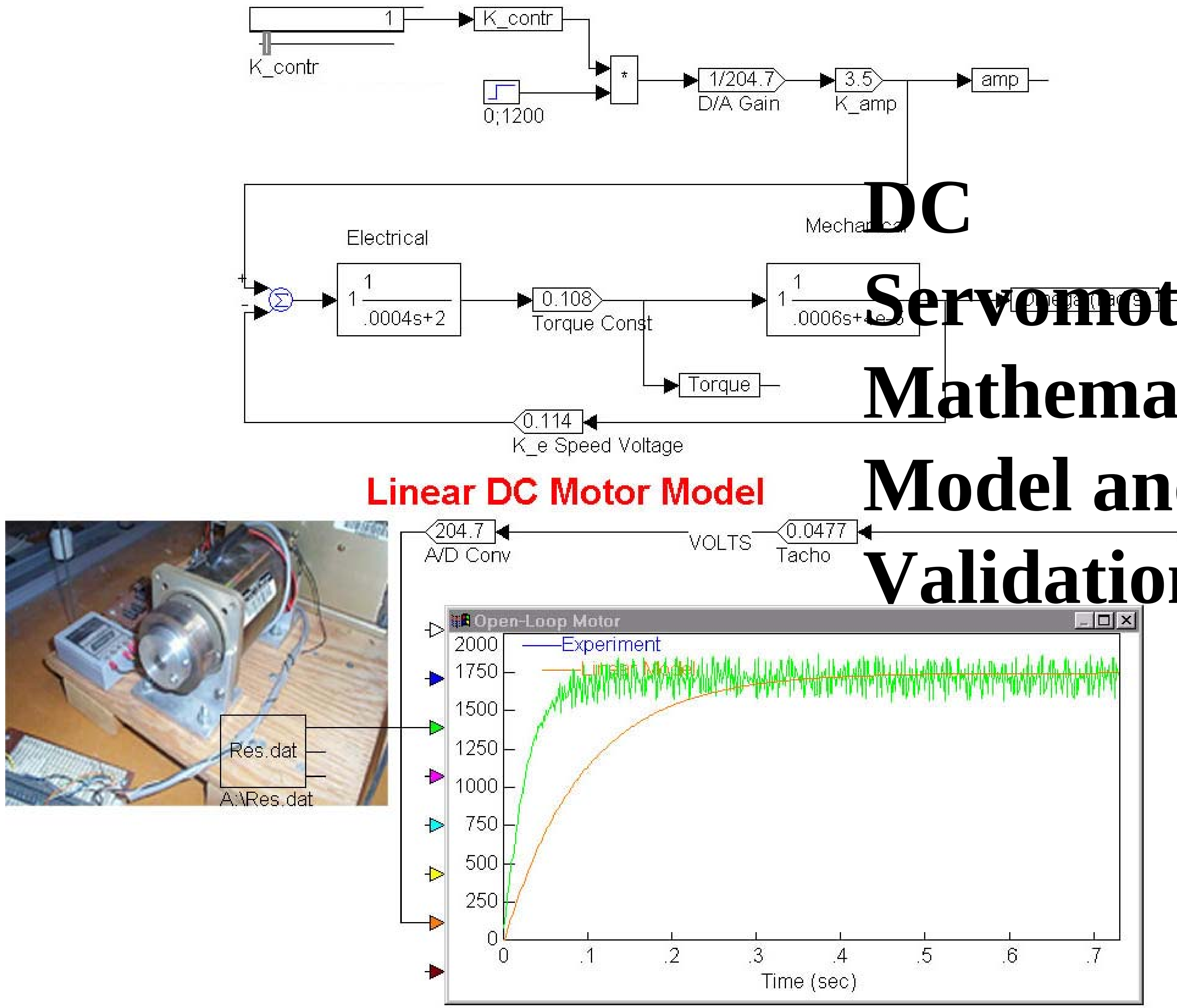
A Problem: **Noisy Data (Noise often results from poor quality measurements, or from interference (just try AM radio)**



How good is this control?

Another Example: Controlling a DC Servomotor

DC Servomotor: Mathematical Model and Validation



Engineers must

•Collect Information (Data)

•Create Records

•Analyze and display the information (e.g identify trends, create a mathematical model

The following test scores were earned by a class of first-year engineering students on a physics test.

40	70	77	80	85	59	90	67	47	70
87	61	73	88	70	58	70	67	62	75
65	90	58	69	99	83	63	72	95	62
79	80	68	100	75	58	69	60	72	88
64	52	65	77	72	70	31	93	79	72

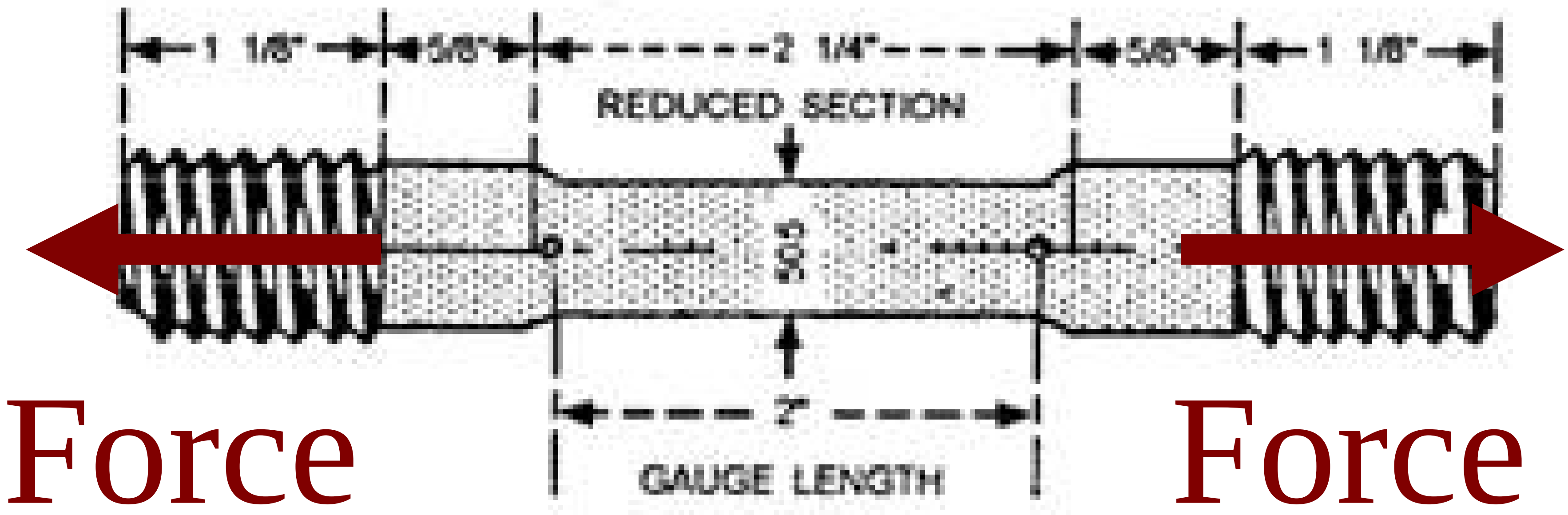
A set of data

An Example:

A sorted set of data from Tensile Testing of Materials

A Tensile Testing Machine

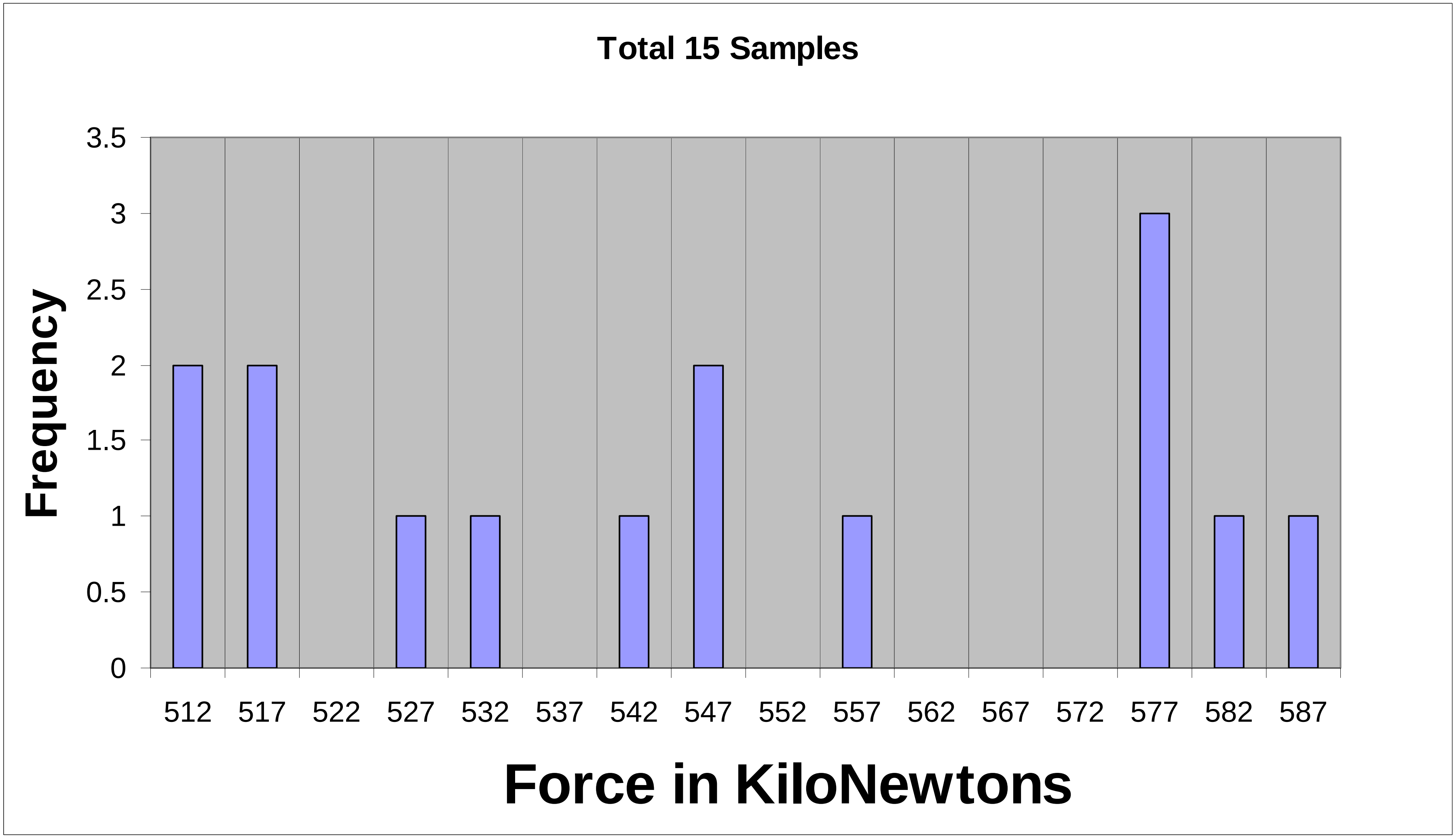
Material samples are inserted and the force to break the sample apart is recorded.


1 1/8"
5/8"
2 1/4"
5/8"
1 1/8"
REDUCED SECTION
505
2"
GAUGE LENGTH
Force
Force

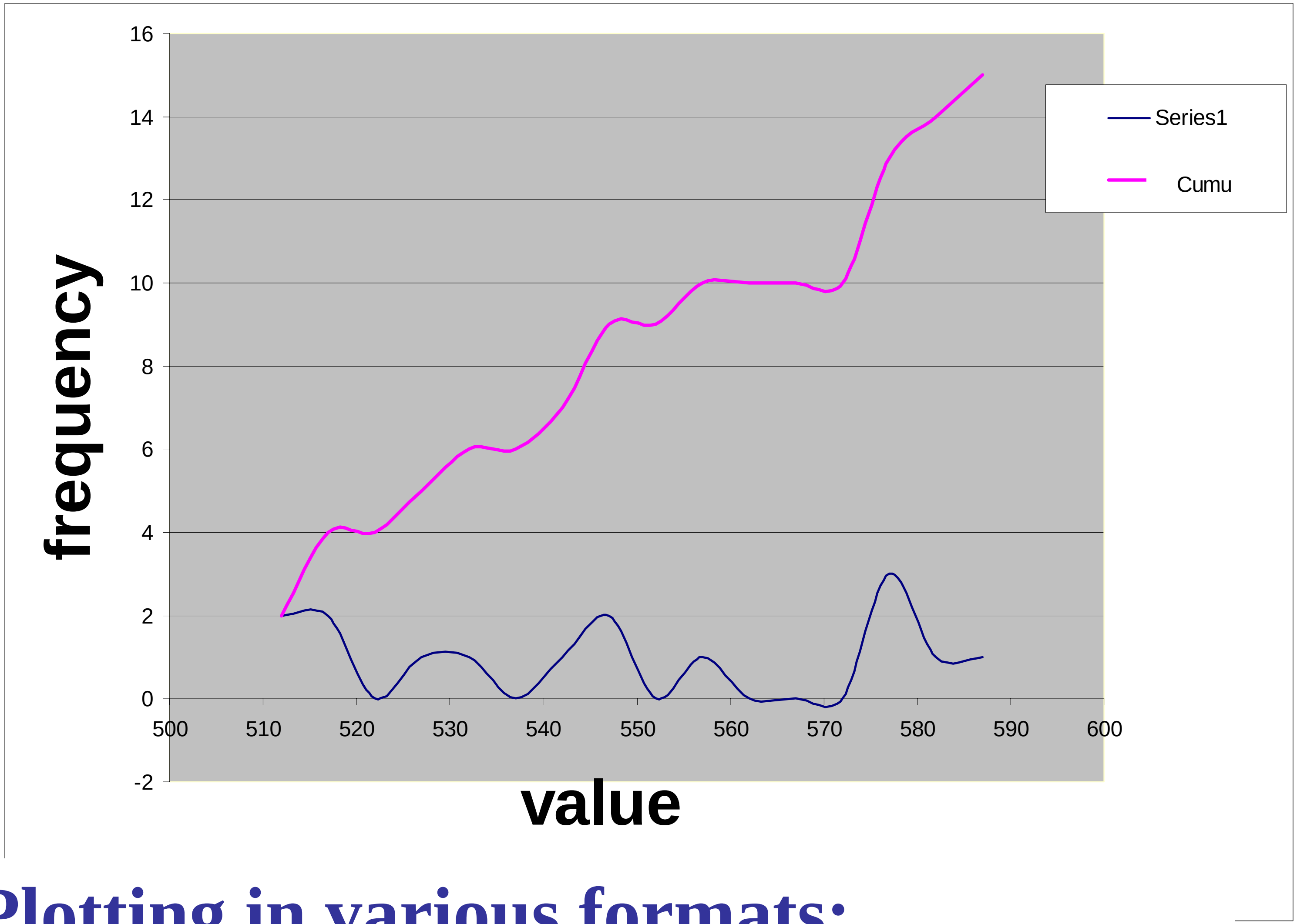
First Column: Force (in Kilo-Newtons) required to break the sample

Force	Number
512	2
517	2
522	0
527	1
532	1
537	0
542	1
547	2
552	0
557	1
562	0
567	0
572	0
577	3
582	1
587	1

Second Column: Number of samples broken at the respective Force Level



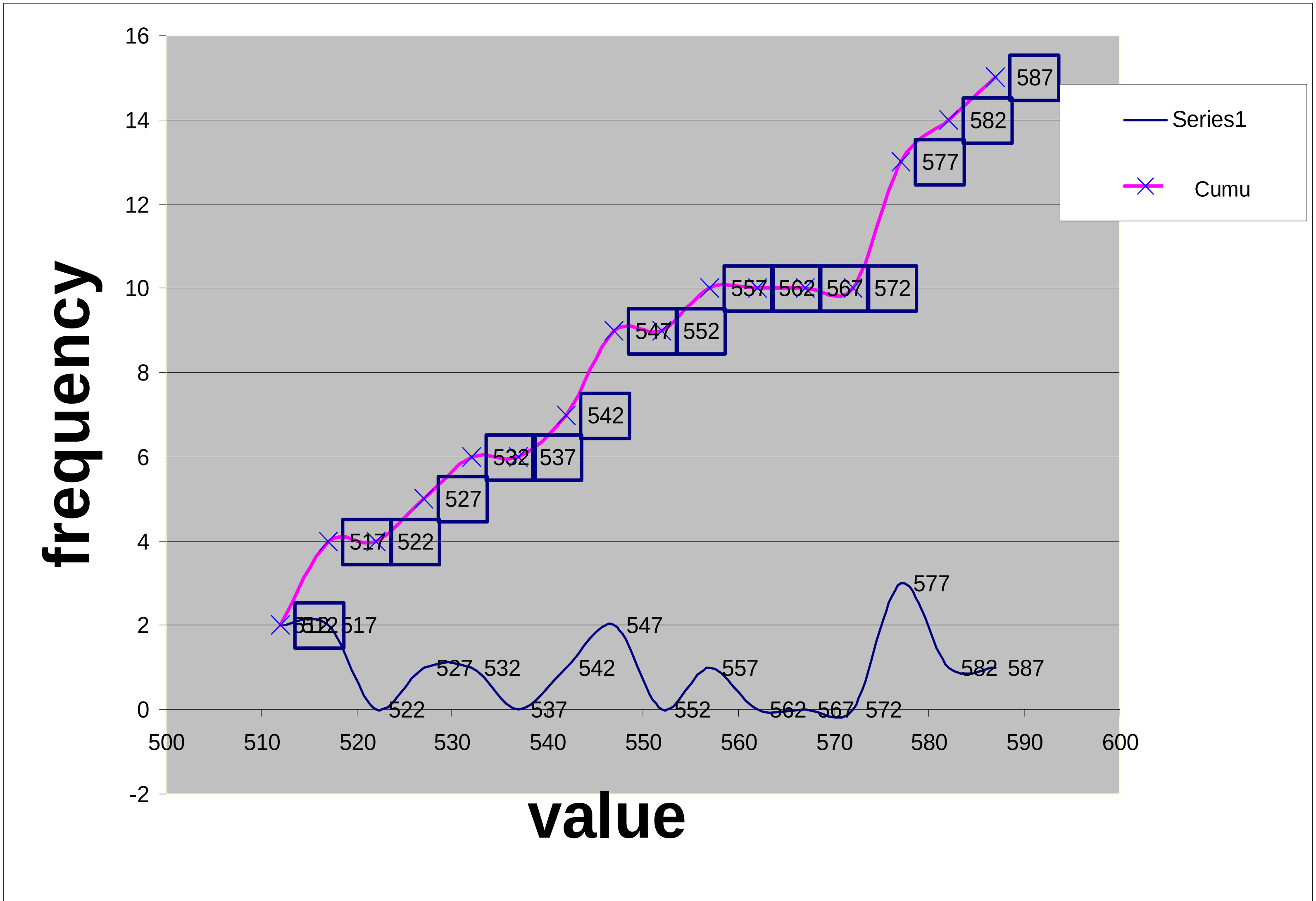
We can enter the data set into a spreadsheet program such as MS Excel, and plot the information in various formats.



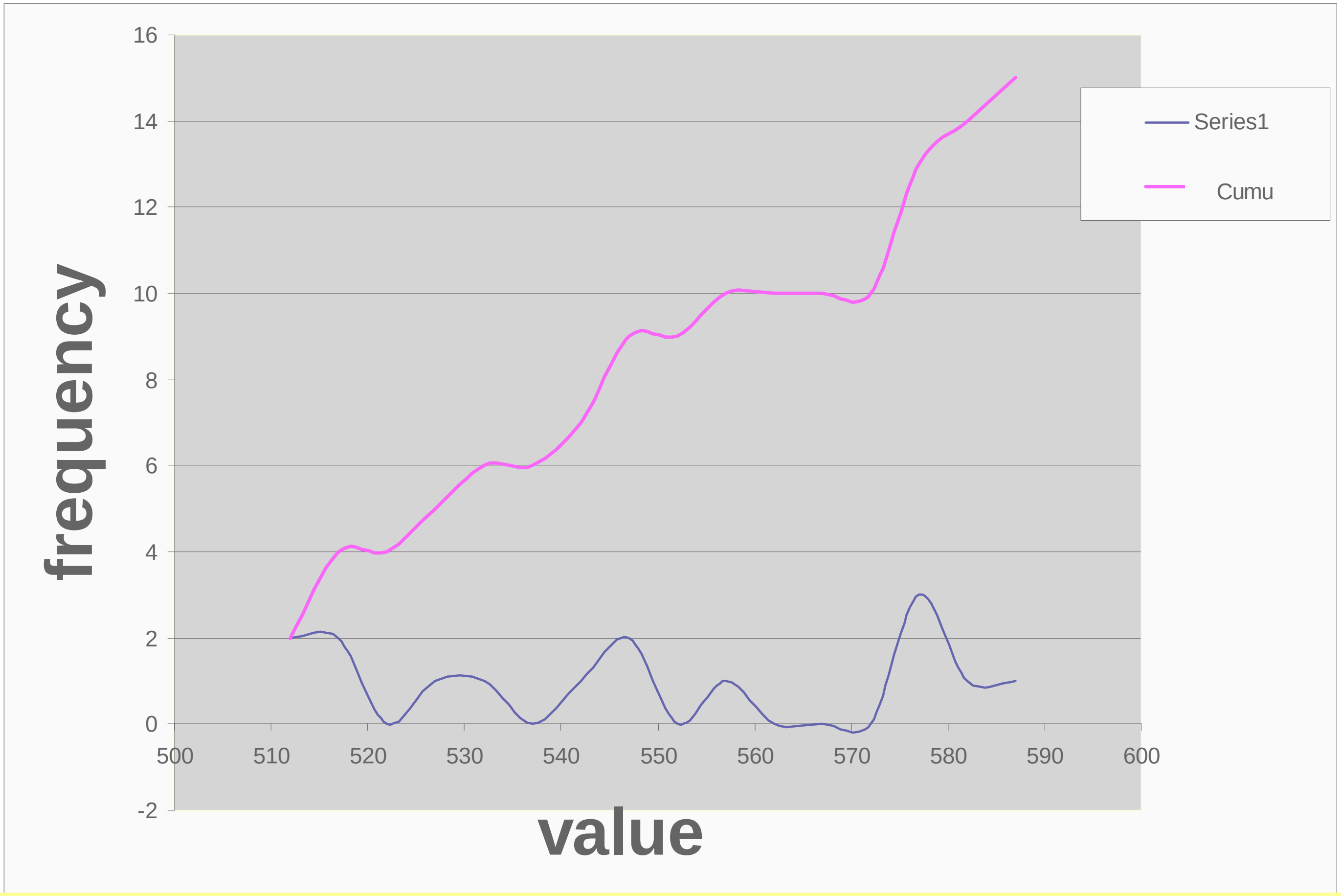
Plotting in various formats:

Same data, Line graph (in blue)

Cumulative (adding all samples) in red



You have various options to highlight data. Explore them and find out what works best.



For your Homework assignment:

Please use spreadsheet software or Mathcad! Explore the best options to present the information, and submit

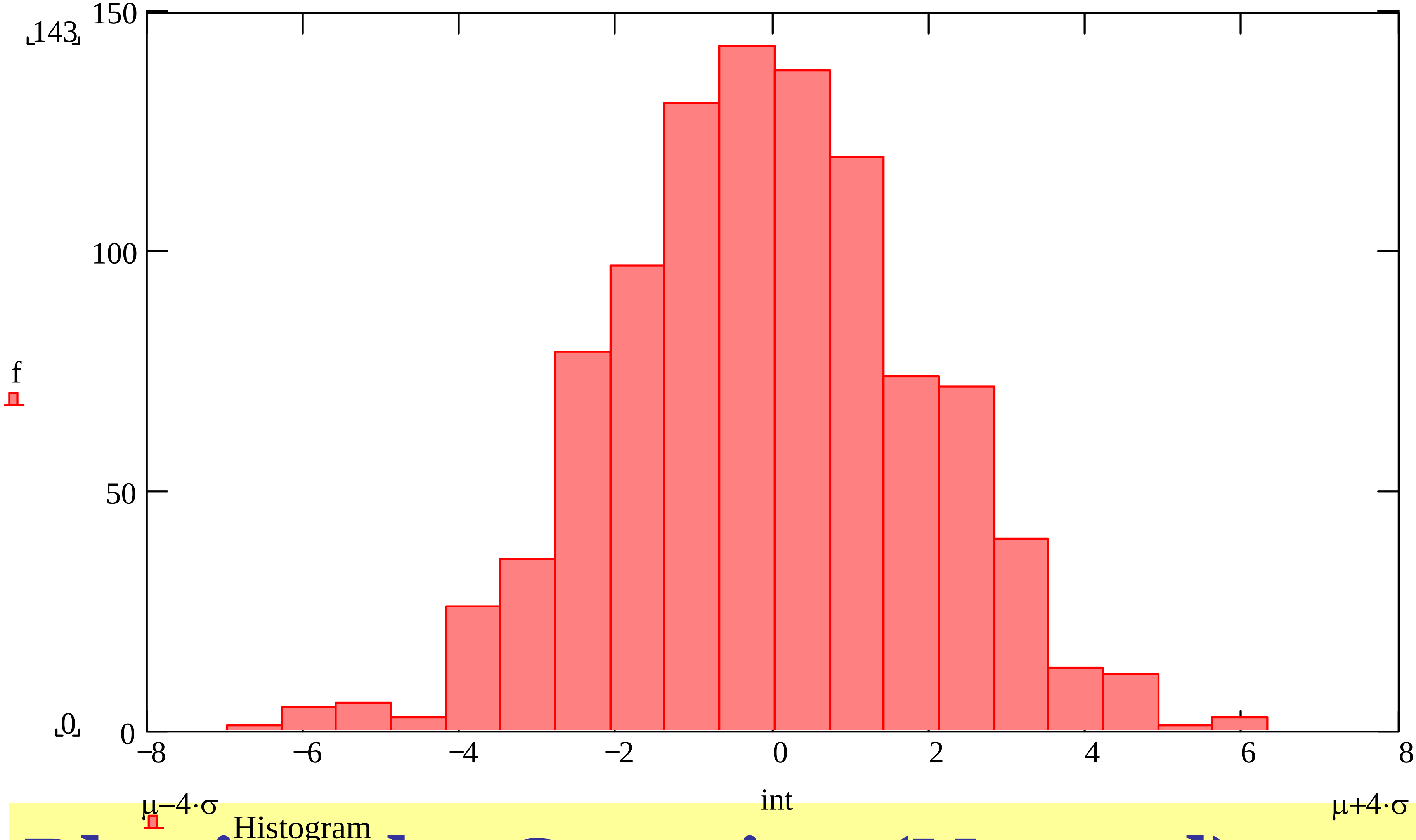
Mathcad Example:

A Gaussian (Normal) Distribution.

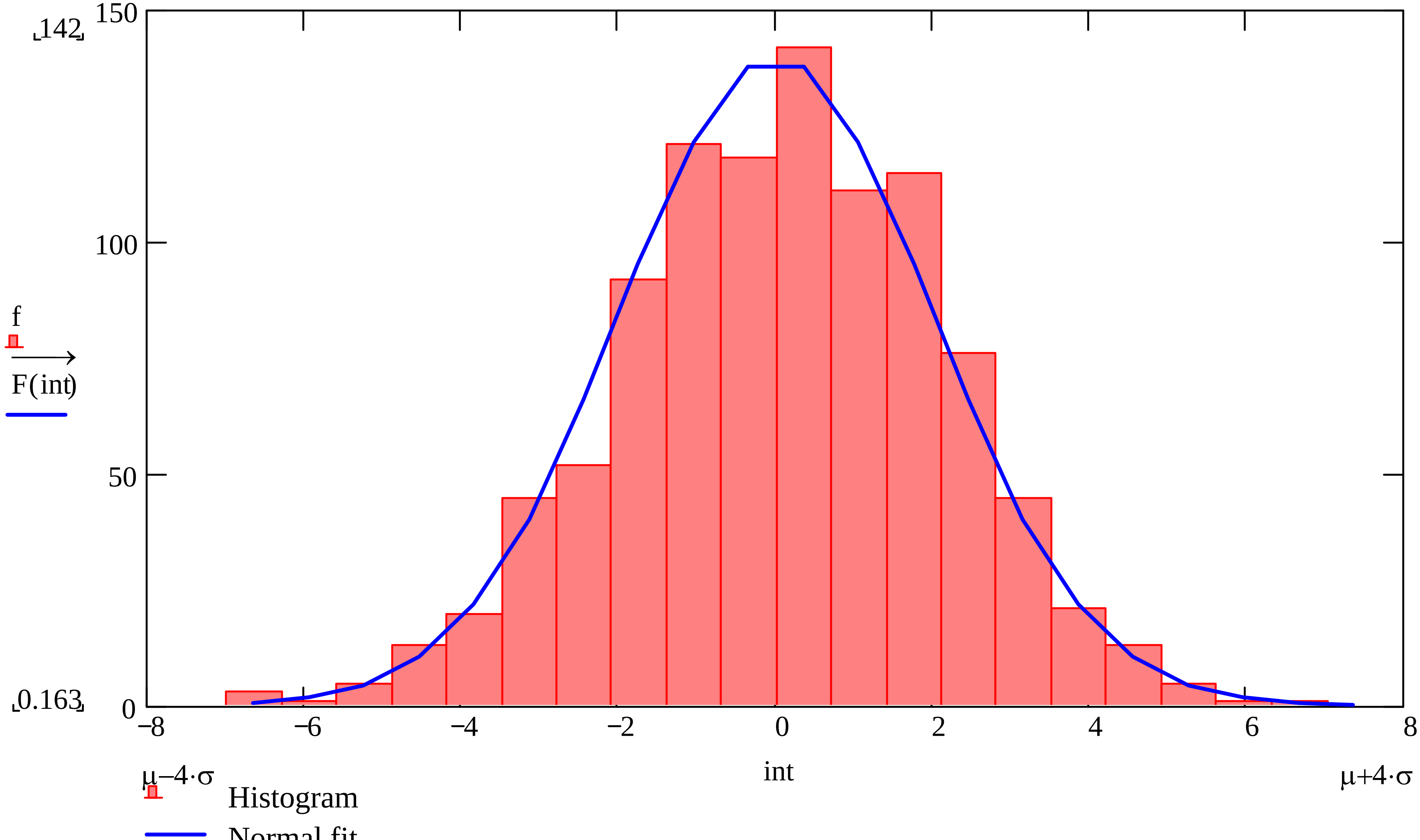
The numbers are shown at right.

f =

	0
0	1
1	5
2	6
3	3
4	26
5	36
6	79
7	97
8	131
9	143
10	138
11	120
12	74
13	72
14	40
15	13



Plotting the Gaussian (Normal) Distribution. (Histogram)



Compute the Normal Distribution.

(Blue Line)

Mathcad Commands:

Histogram: $f := \text{hist}(\text{int}, N)$

Gaussian Fitting Function:

$$F(x) := n \cdot h \cdot \text{dnorm}(x, \mu, \sigma)$$

For help in Mathcad, see Quick sheets → Statistics

Chapter 4.2 Collecting Data

- Manual (slow, inefficient, error-prone. don’t waste your time! Sometimes, of course, manual recording of data is expedient)
- Computer assisted (typically faster and more accurate) You can also buy special recorders (data loggers) that record very large quantities at very high rates.

Example:
During Nuclear testing at the Nevada Test Site, all data must be collected within about **100 nanoseconds** after triggering.
The instrumentation is destroyed by the explosion

Plotting Experimental Data:

A set of x/y data

$x =$	$y(x) =$
1	9.871
2	11.09
3	15.714
4	17.364
5	21.608
6	22.117
7	27.808
8	28.495
9	31.351
10	34.355

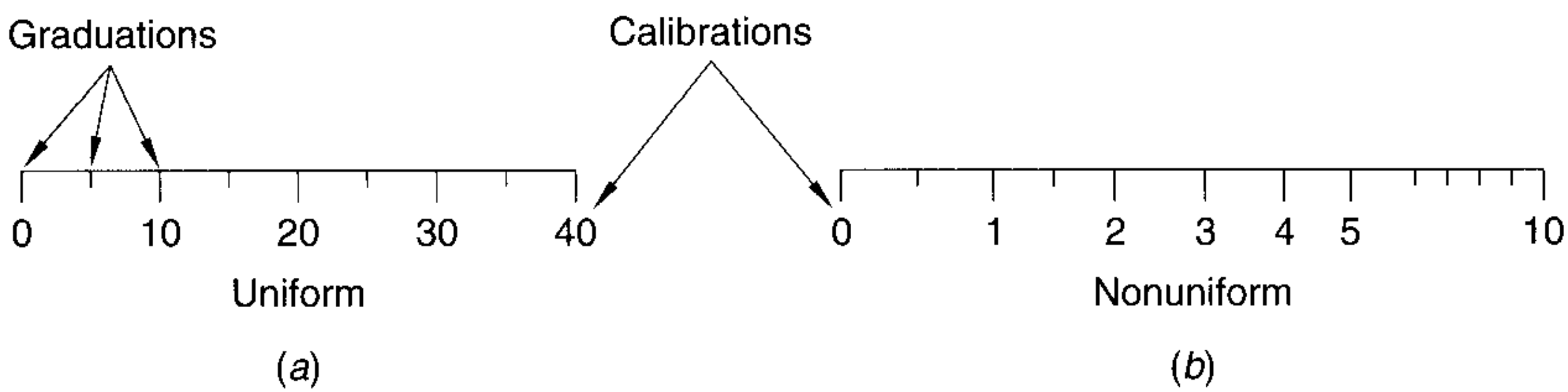
Plotting Experimental Data: Basics

- Present the information clearly and concisely!
- Each graph should speak for itself: **Label the axes!**
  Descriptive Title!

Eide,
Page 155
Fig. 4.9

Scaling the Axes

Figure 4.9



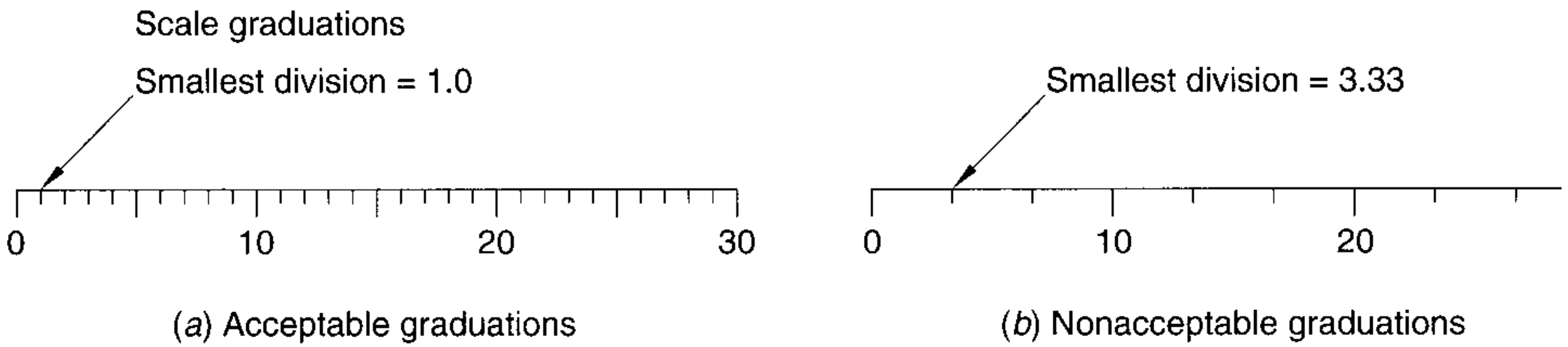
Scale graduations and calibrations.

Eide,

Page 155 Fig. 4.10

Please Read and apply!

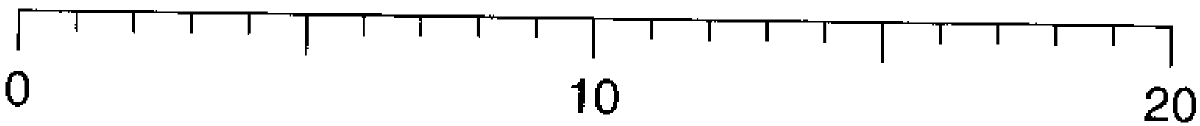
Figure 4.10



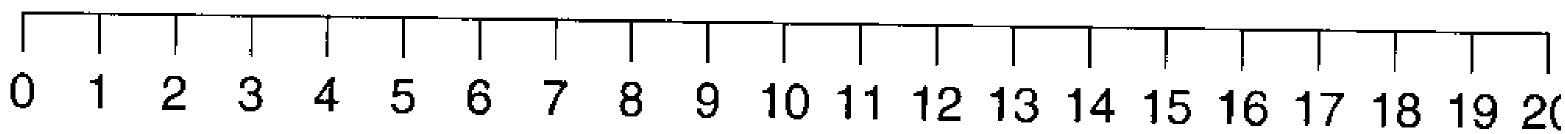
Acceptable and nonacceptable scale graduations.

Axes Graduations

Eide,
Page 157
Fig. 4.12



(*a*) Easy to read



(*b*) Too crowded

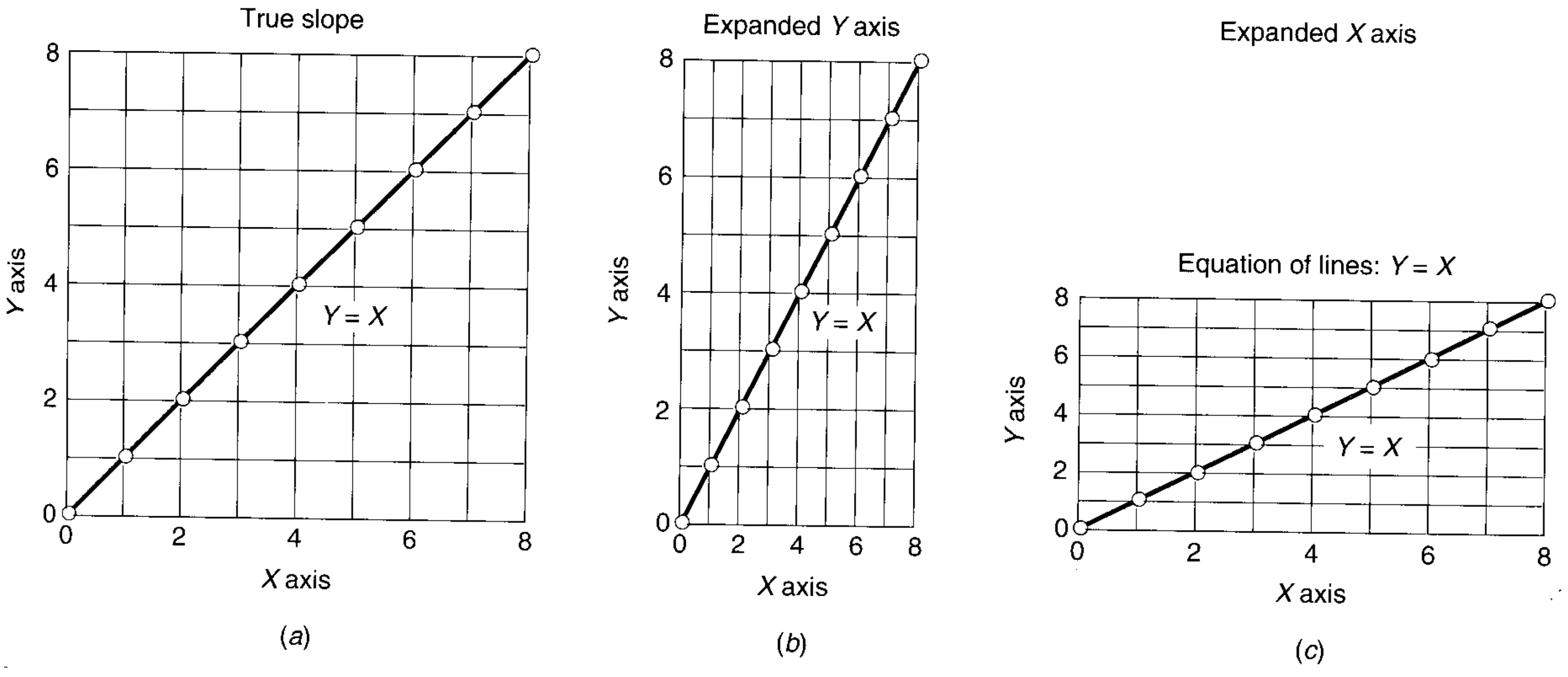
Acceptable and nonacceptable scale calibrations.

Eide,

Page 157 Fig. 4.13

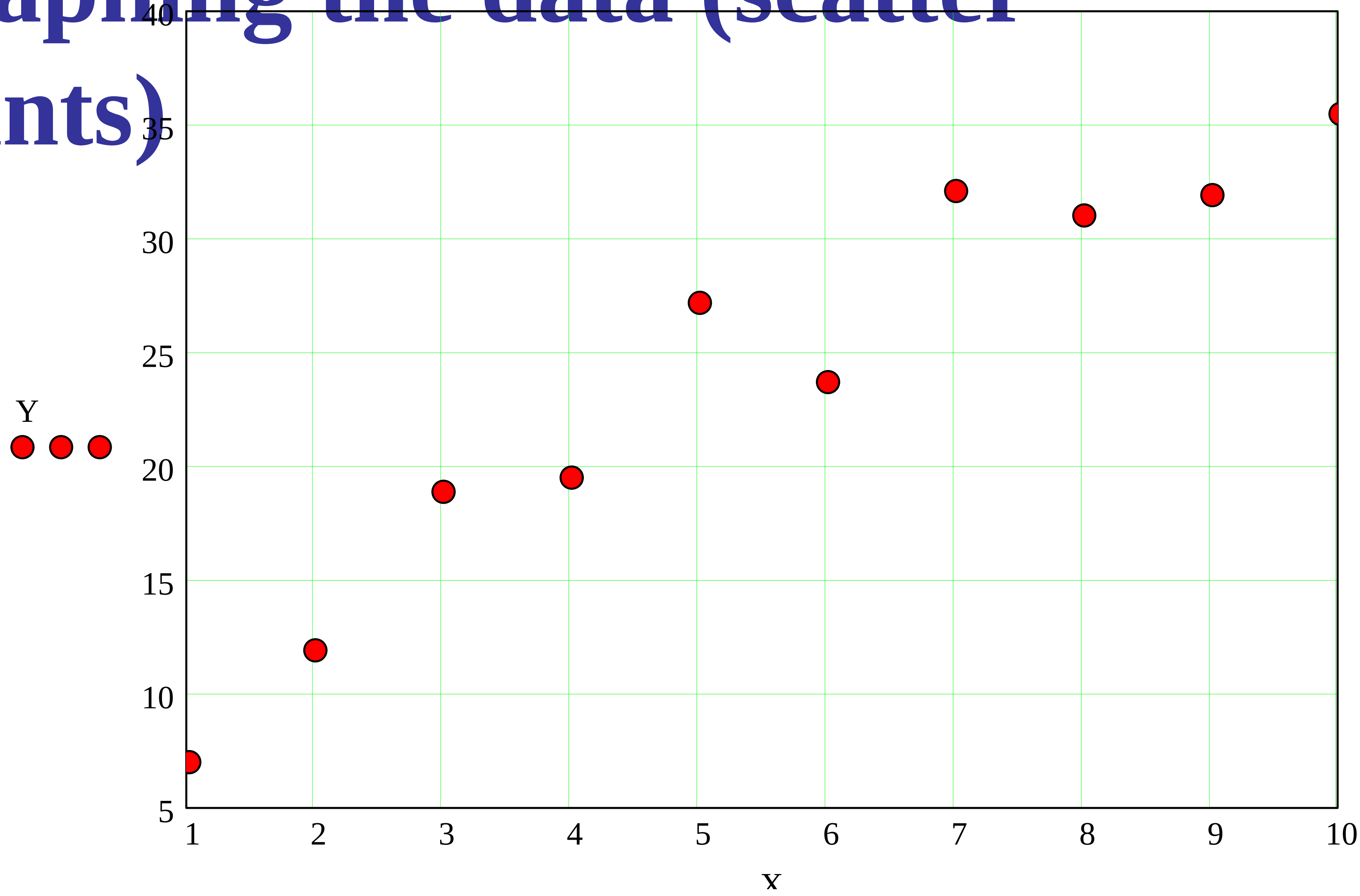
Proper Representation of Data

You choose.



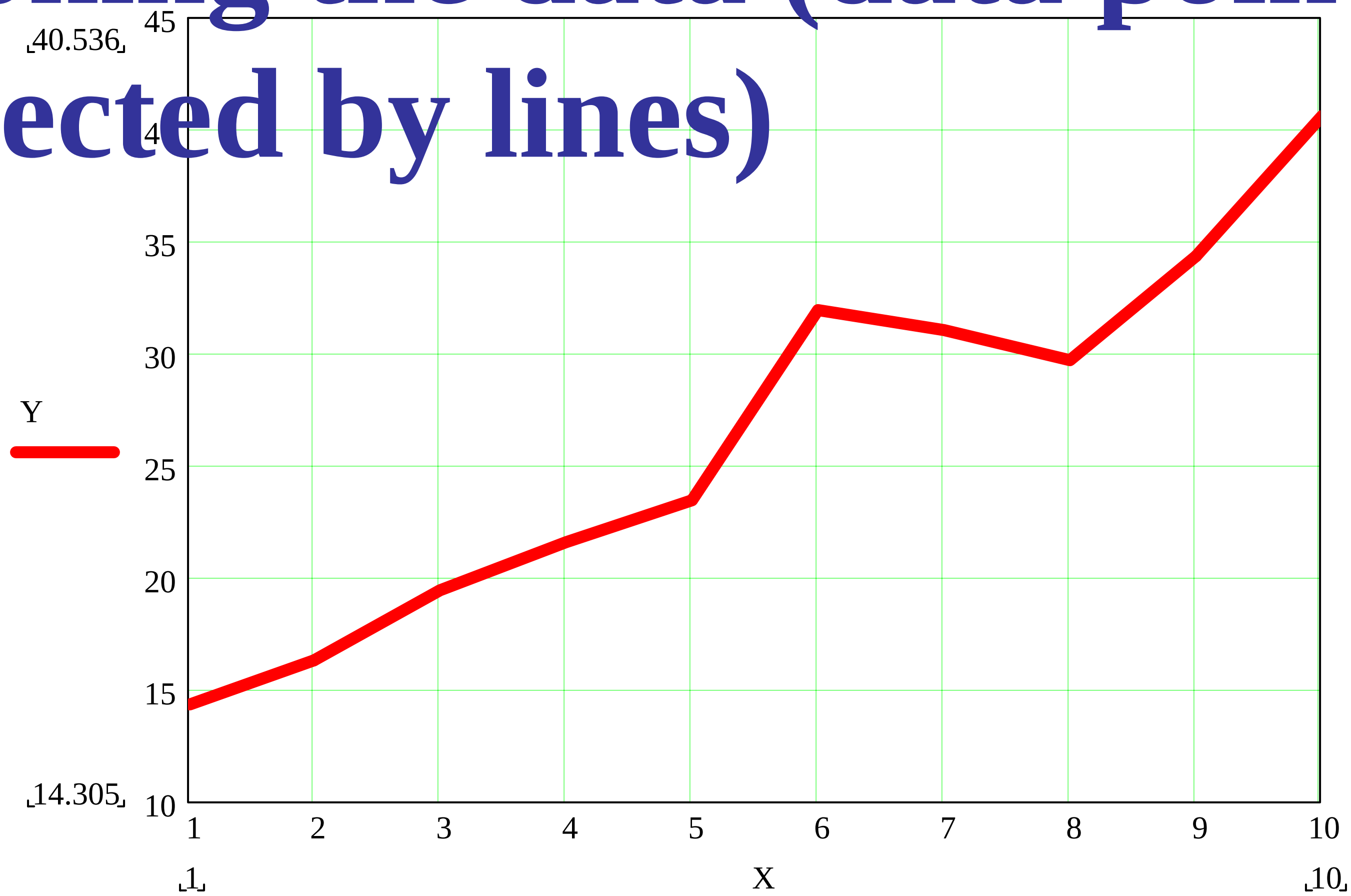
Plotting Experimental Data:

Graphing the data (scatter points)

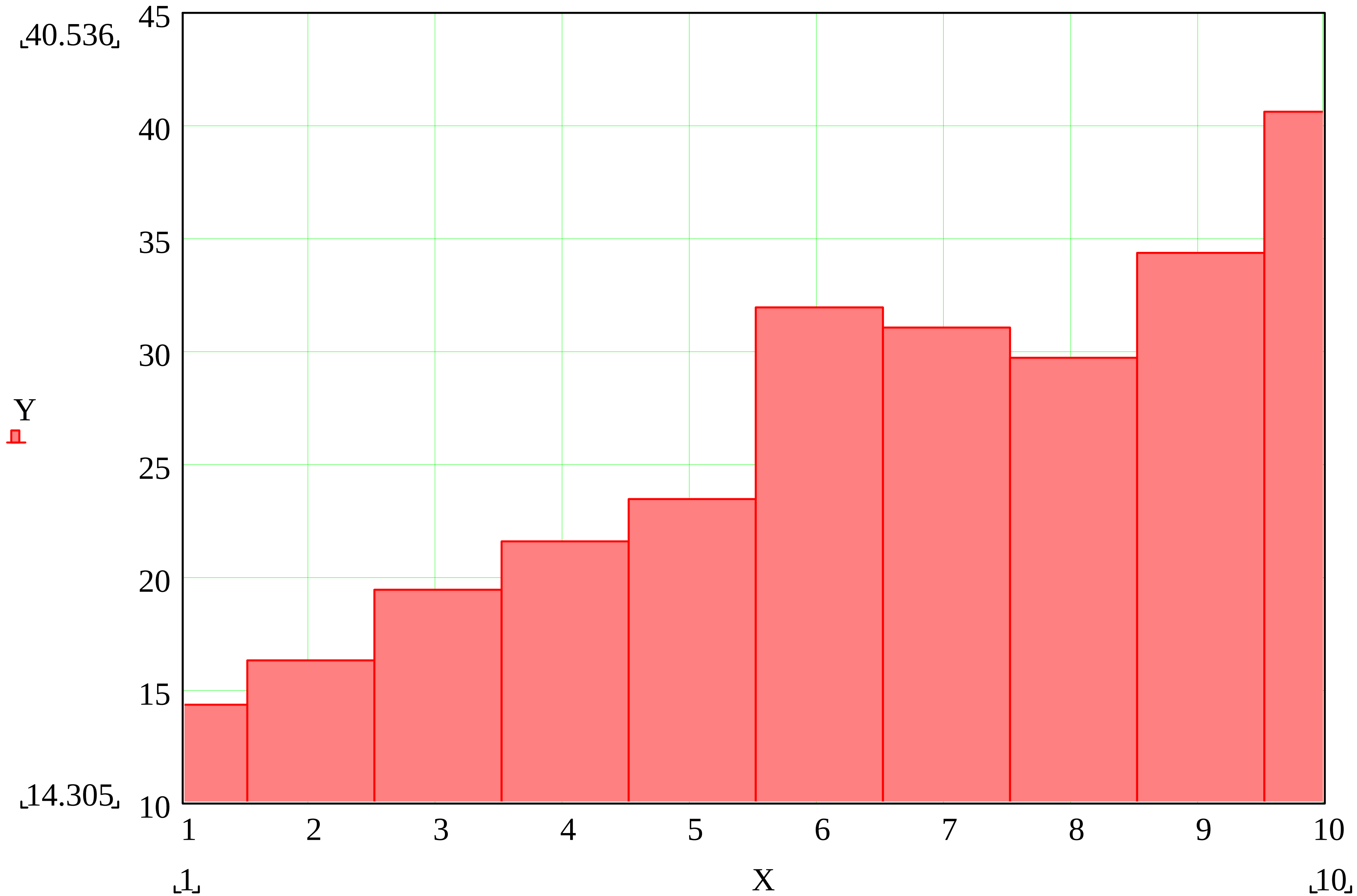


Plotting Experimental Data:

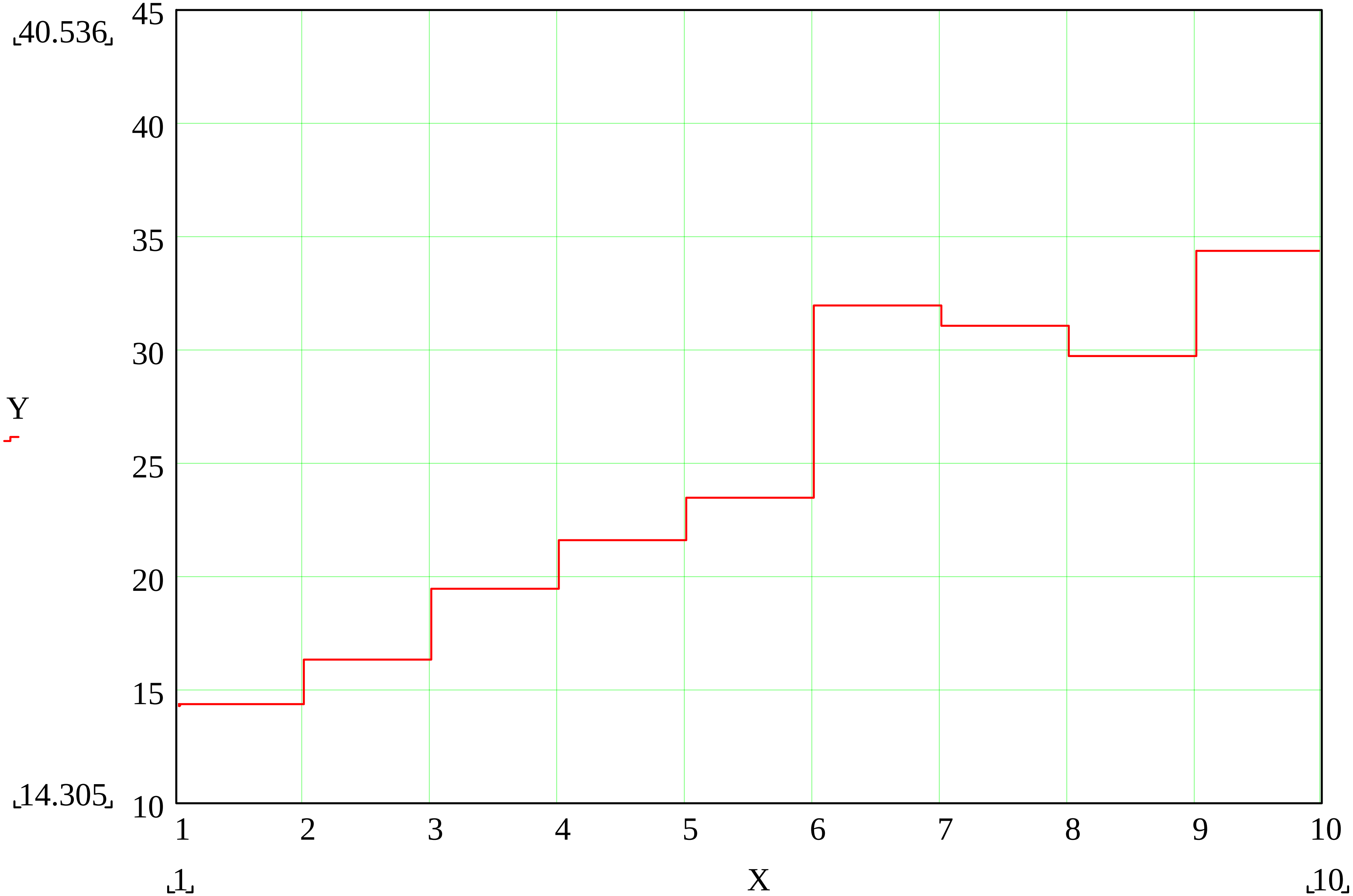
Graphing the data (data points connected by lines)



We can use Bar Graphs

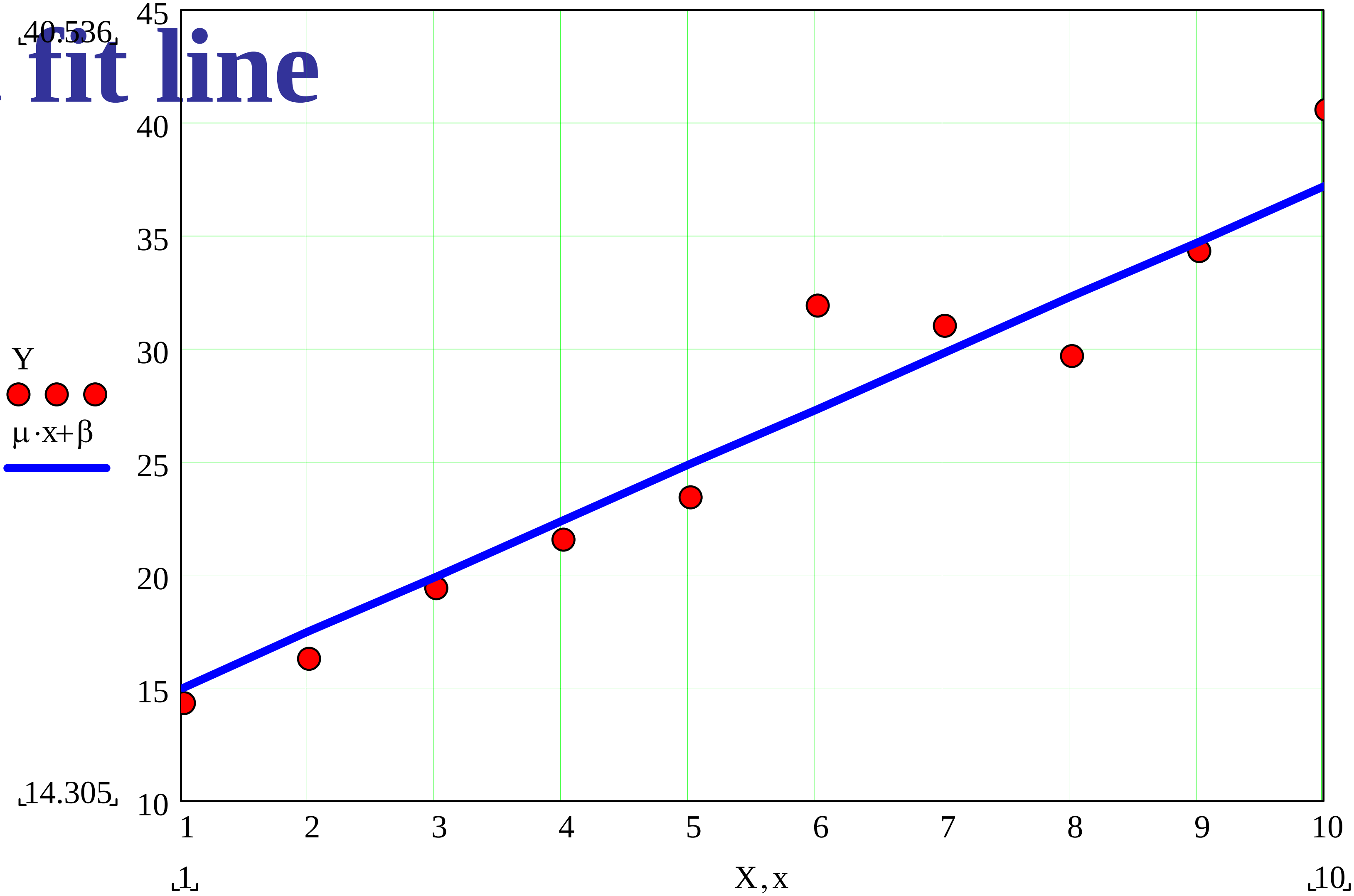


..Or steps



Linear Interpolation:

Best fit line



Eide,
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Fig. 4.21

Multiple Data Sets

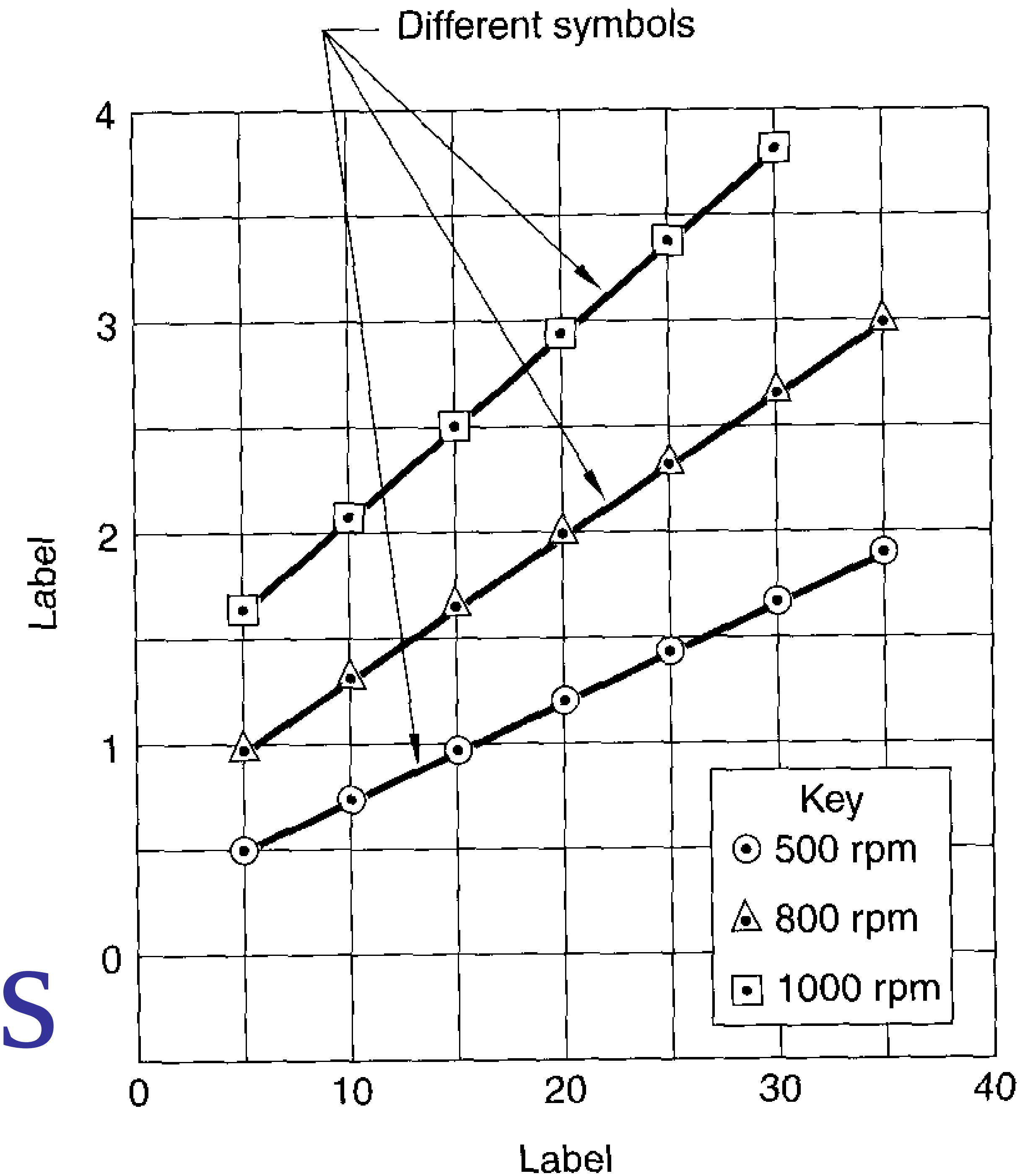

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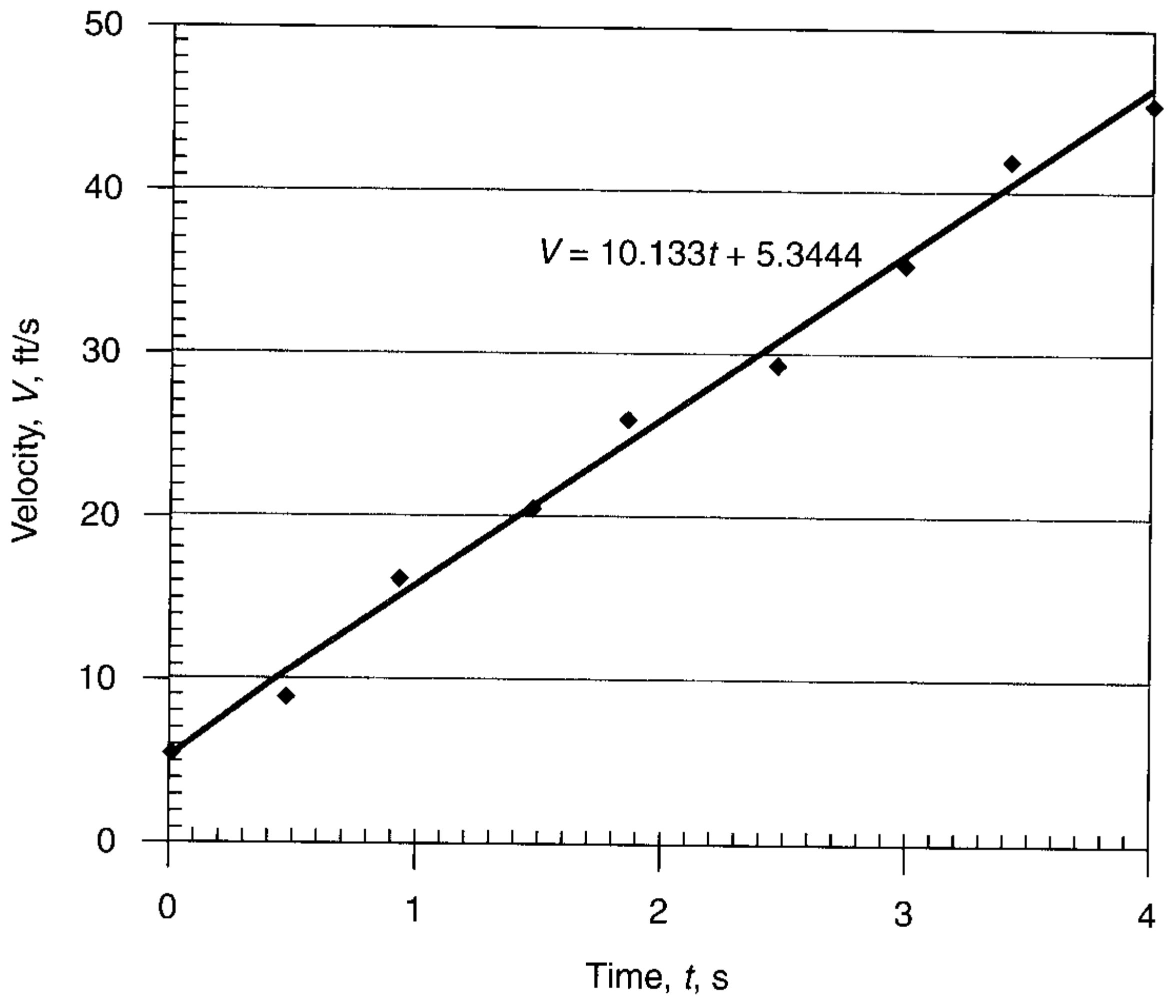
Fig. 4.23

Spreadsheet Rules



EXCEL spreadsheet hard copy of data displayed in Fig. 4.22.

Necessary steps to follow when using a computer-assisted alternative:

1. Record via keyboard or import data into spreadsheet.
2. Select independent (*x* -axis) and dependent variable(s).
3. Select appropriate graph (style or type) from menu.
4. Produce trial plot with default parameters.
5. Examine (modify as necessary) origin, range, graduation, and calibrations: Note, use the 1, 2, 5 rule.
6. Label each axis completely.
7. Select appropriate plotting-point symbols and legend.
8. Create complete title.
9. Examine plot and store the data.
10. Plot or print the data.

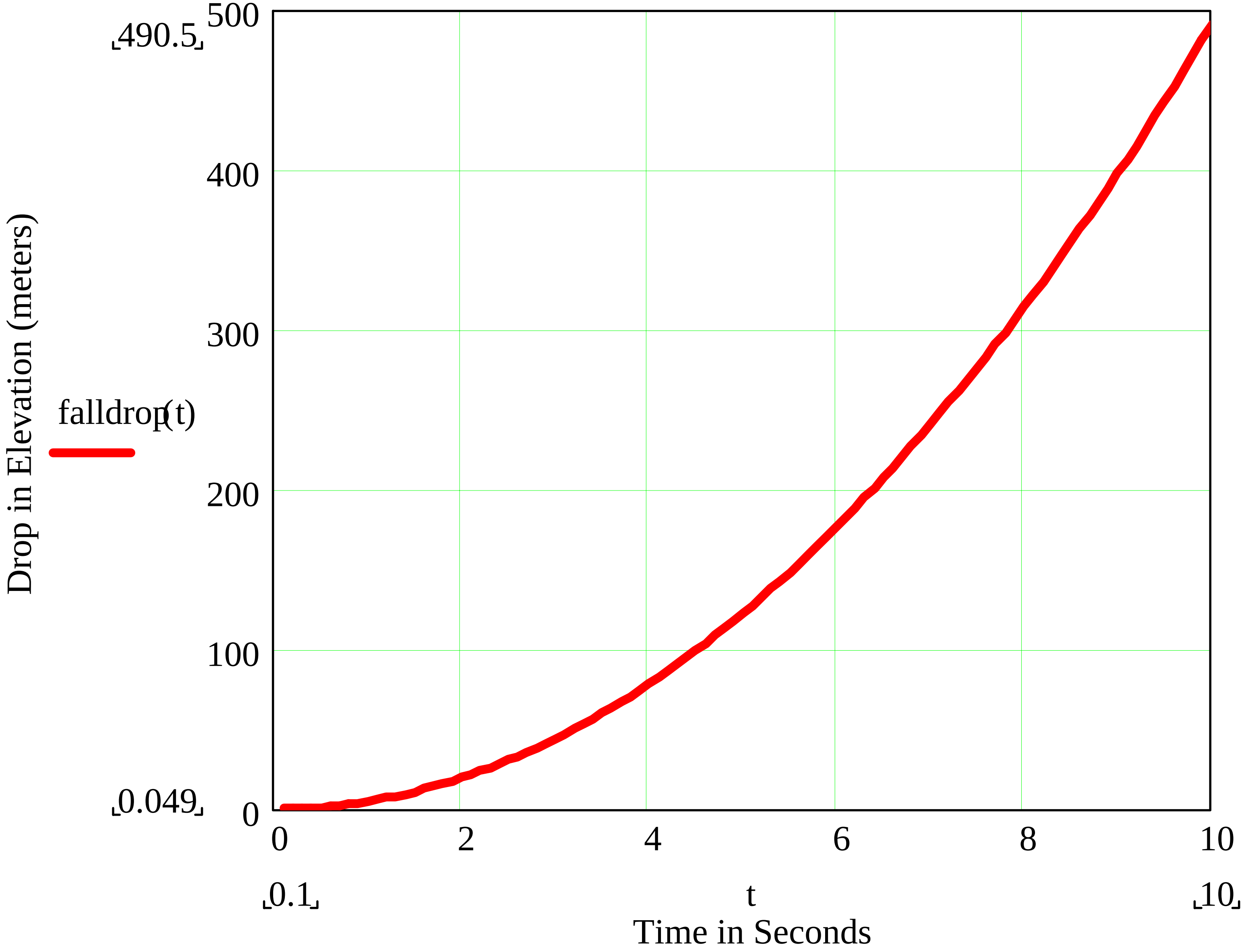
Plotting Experimental Data:
A Quadratic Function (free fall)

The falling distance is proportional to time²

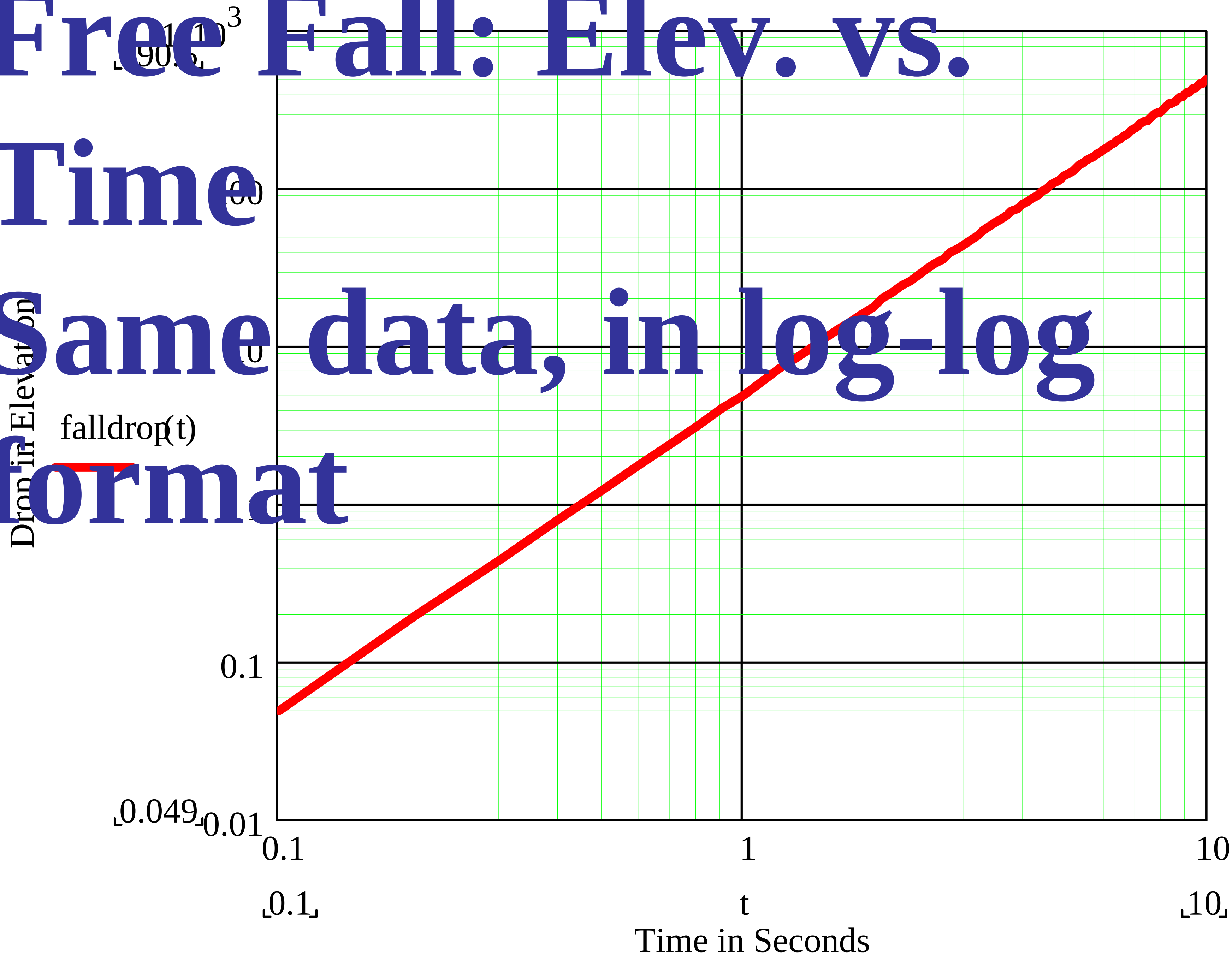
$$t := 1, 2 .. 10$$

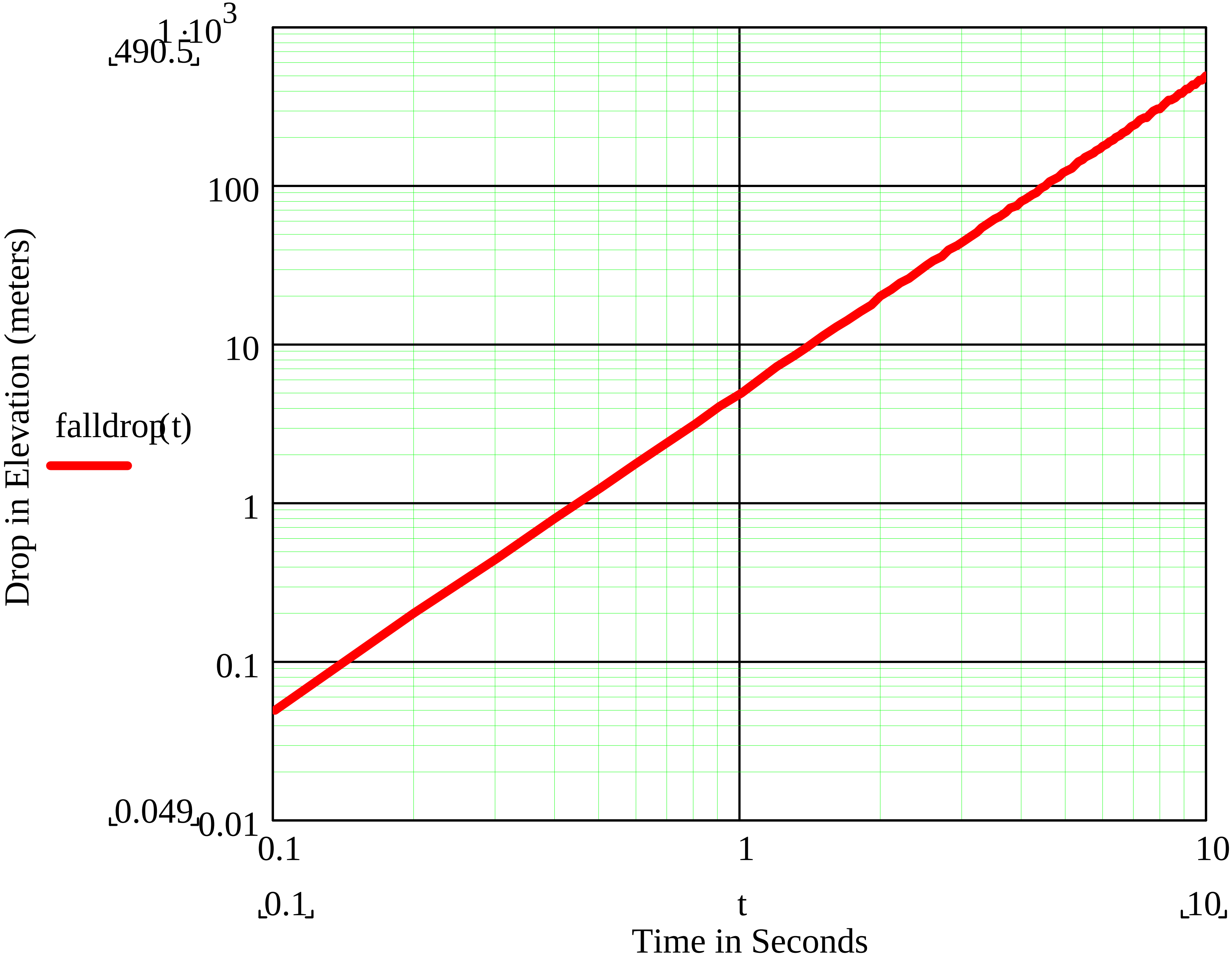
$$\text{falldrop}(t) := \frac{1}{2} \cdot g \cdot t^2$$

Free Fall: Elev. vs. Time



Free Fall: Elev. vs. Time
Same data, in log-log format

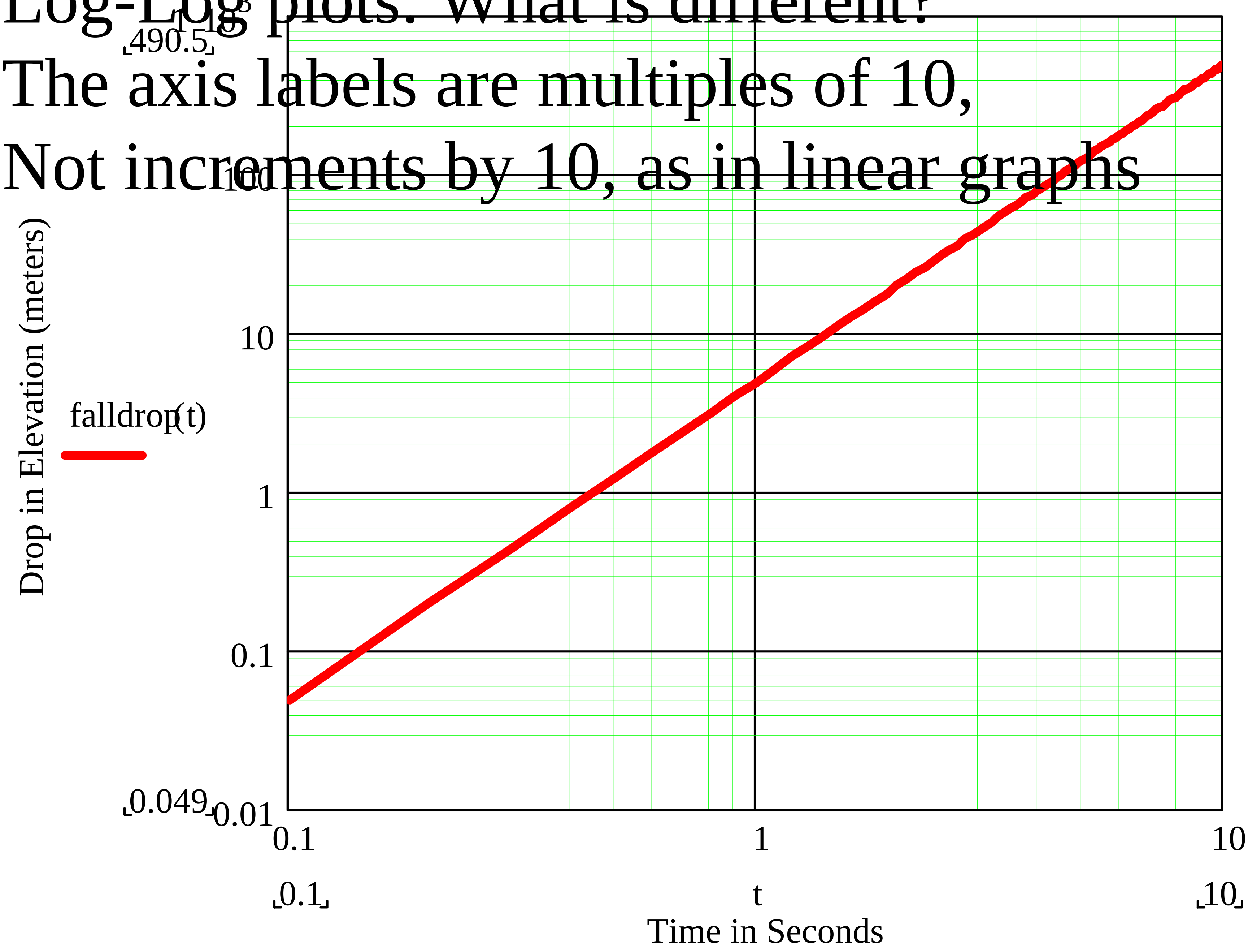



1·10^3
490.5
100
10
1
0.1
0.049
0.01
Drop in Elevation (meters)
falldrop(t)
0.1
1
10
0.1
t
10
Time in Seconds

Log-Log plots: What is different?

The axis labels are multiples of 10,

Not increments by 10, as in linear graphs



use the general form of the equation

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Page 168

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

$A(0.2, 1.09)$

$B(0.6, 1.89)$

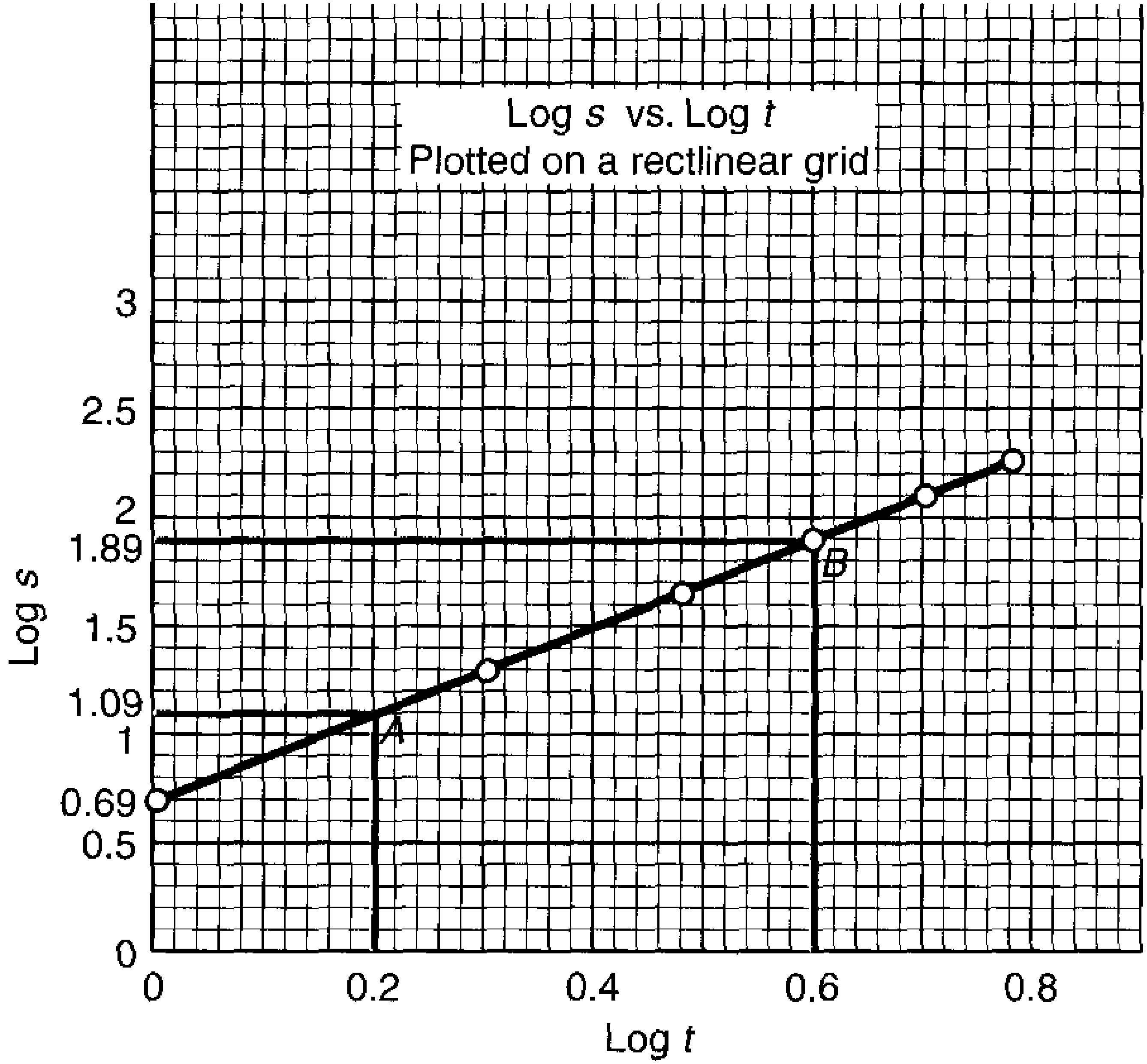
Points A and B can now be substituted into th
$\log s = m \log t + \log b$ and solved simultaneously.

$$1.89 = m(0.6) + \log b$$

$$1.09 = m(0.2) + \log b$$

$$m = 2.0$$

Eide,
Page 169

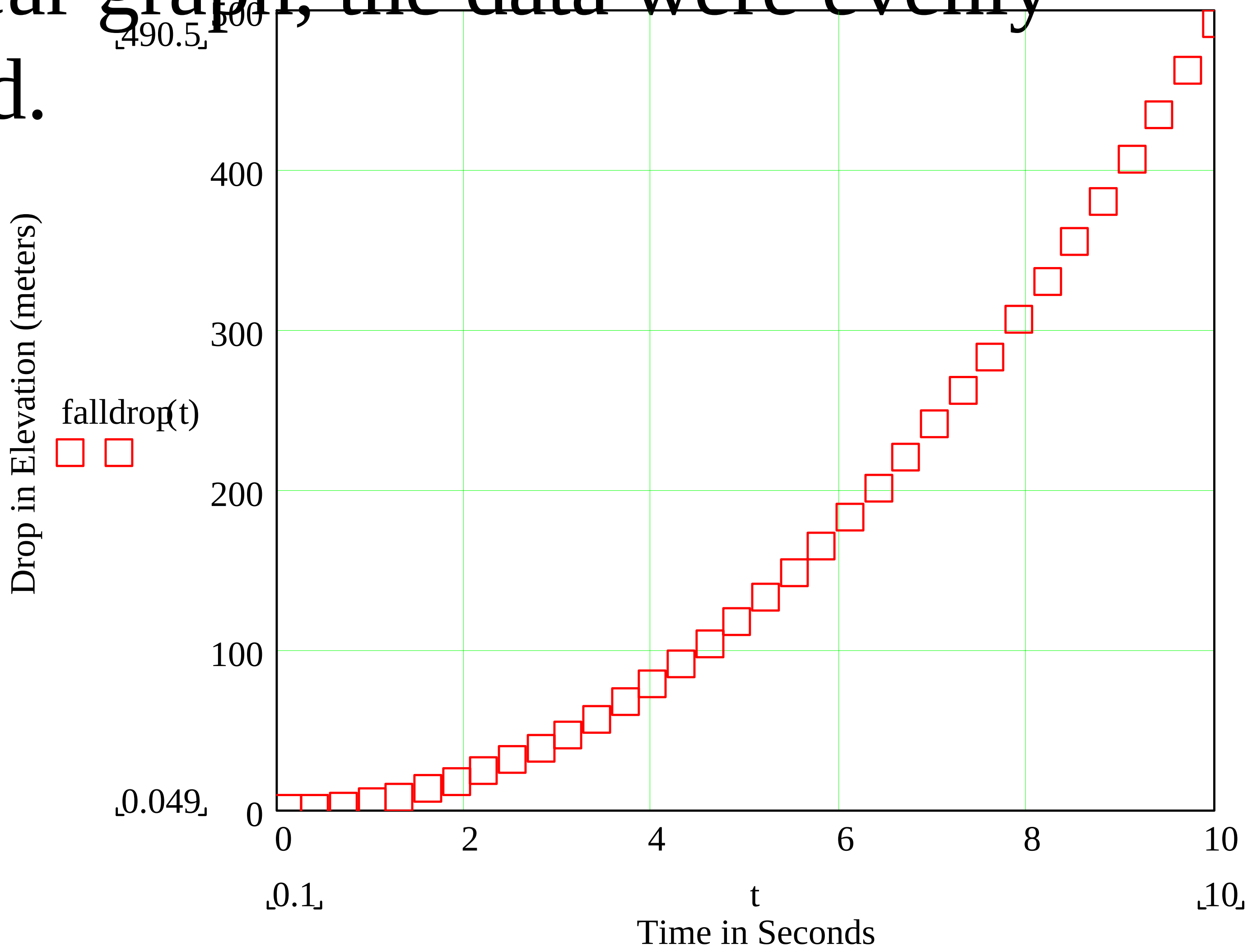


Plotting log of variables on rectilinear grid paper.

Log-Log plots: What is different?

The axis labels are multiples of 10,

In the linear graph, the data were evenly distributed.

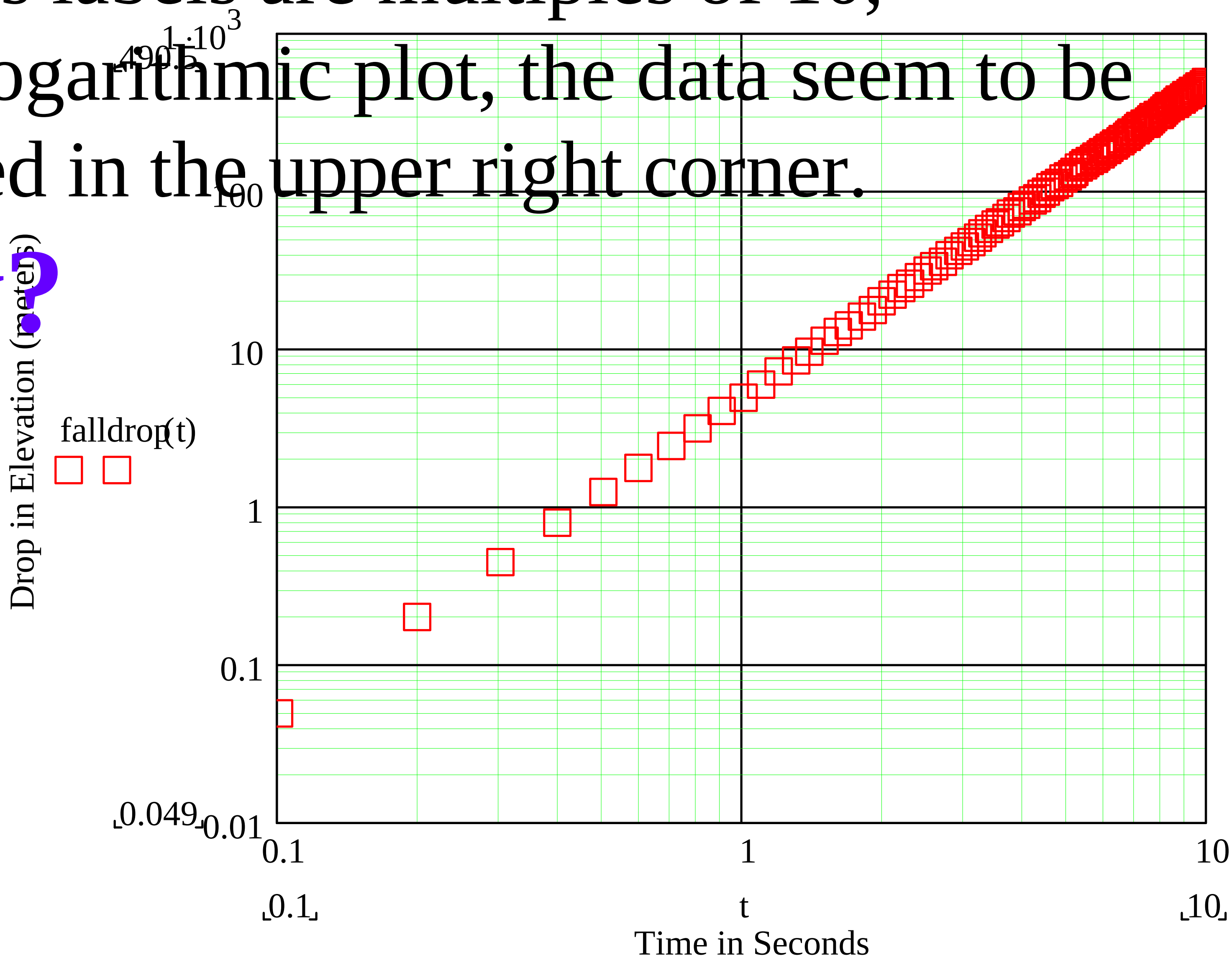


Log-Log plots: What is different?

The axis labels are multiples of 10,

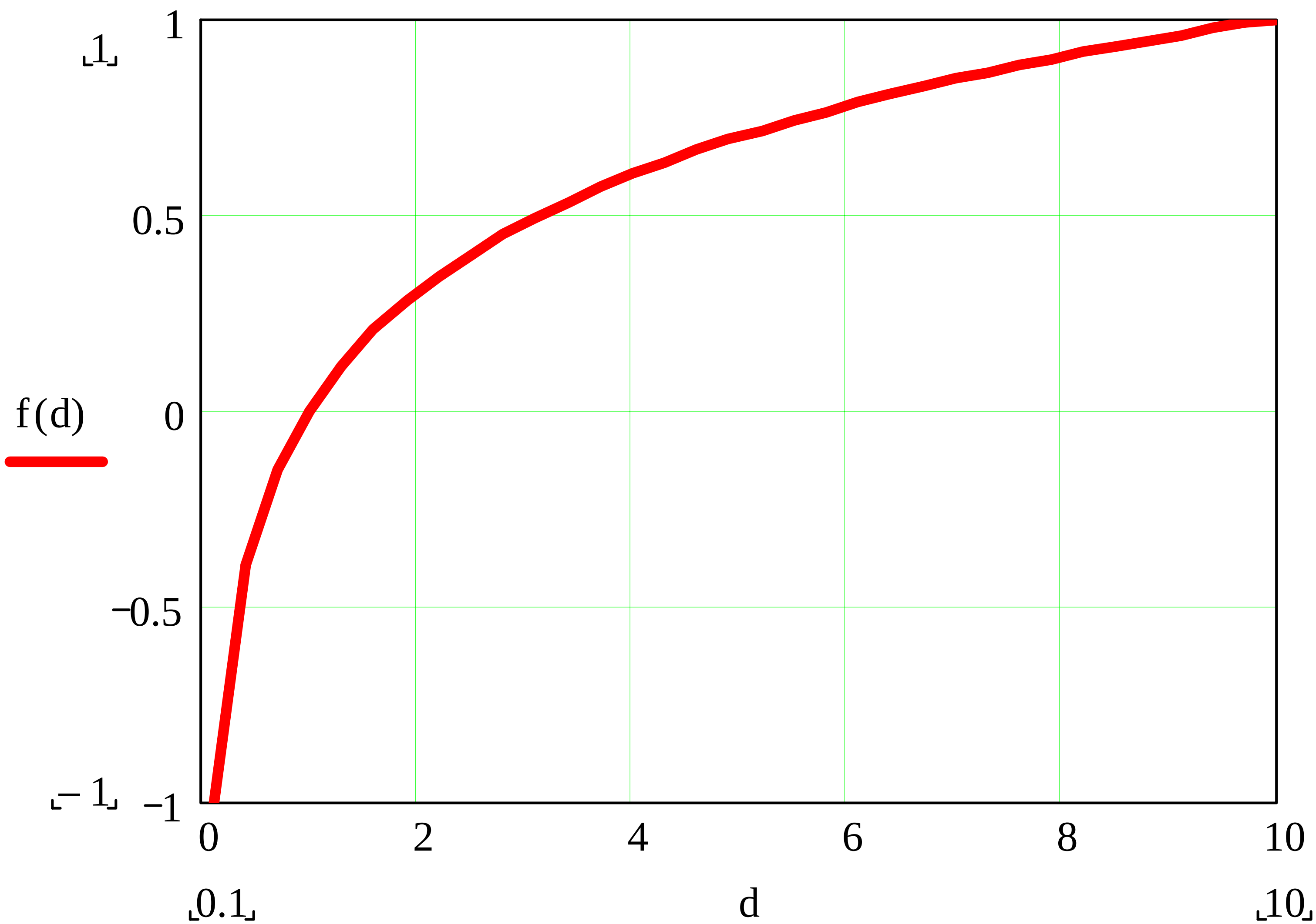
In the logarithmic plot, the data seem to be clustered in the upper right corner.

Why?



$$d := .1, .2 .. 10 \qquad f(d) := \log(d)$$

$d =$	$f(d) =$
0.1	-1
0.4	-0.398
0.7	-0.155
1	0
1.3	0.114
1.6	0.204
1.9	0.279
2.2	0.342
2.5	0.398
2.8	0.447
3.1	0.491
3.4	0.531
3.7	0.568



The (decadic) logarithm of **0.1 = -1.**

Log**(1)= 0**;   Log**(10) =1** ……

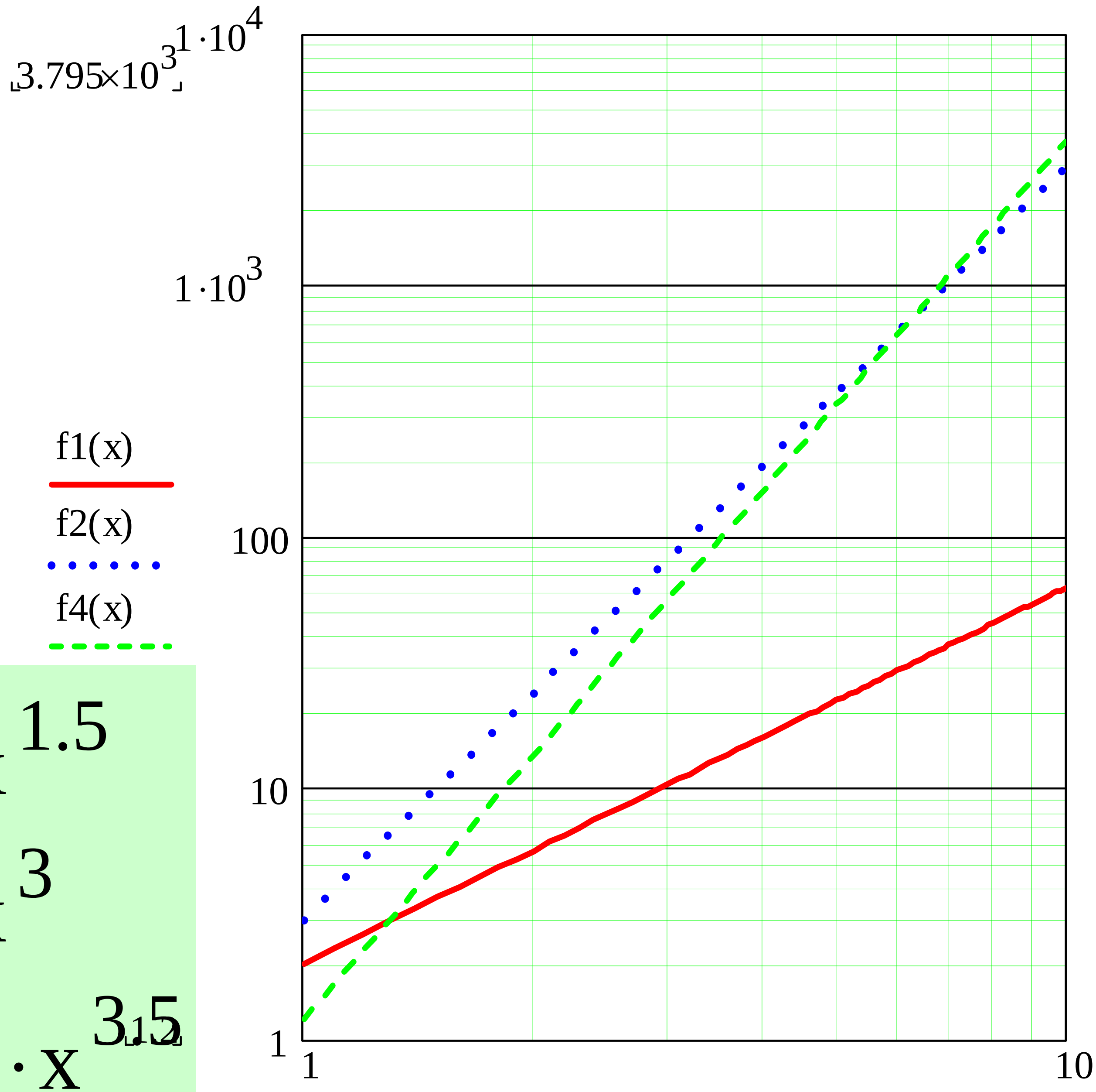
We can use logarithmic plots to test a data set for polynomial relationships. Look at these three polynomials:

$$f1(x) := 2 \cdot x^{1.5}$$

$$f2(x) := 3 \cdot x^{3}$$

$$f4(x) := 1.2 \cdot x^{3.5}$$

Now graph the three polynomials in log-log format:



$$f1(x) := 2 \cdot x^{1.5}$$

$$f2(x) := 3 \cdot x^{3}$$

$$f4(x) := 1.2 \cdot x^{3.5}$$

We can use log-log graphing to identify patterns.

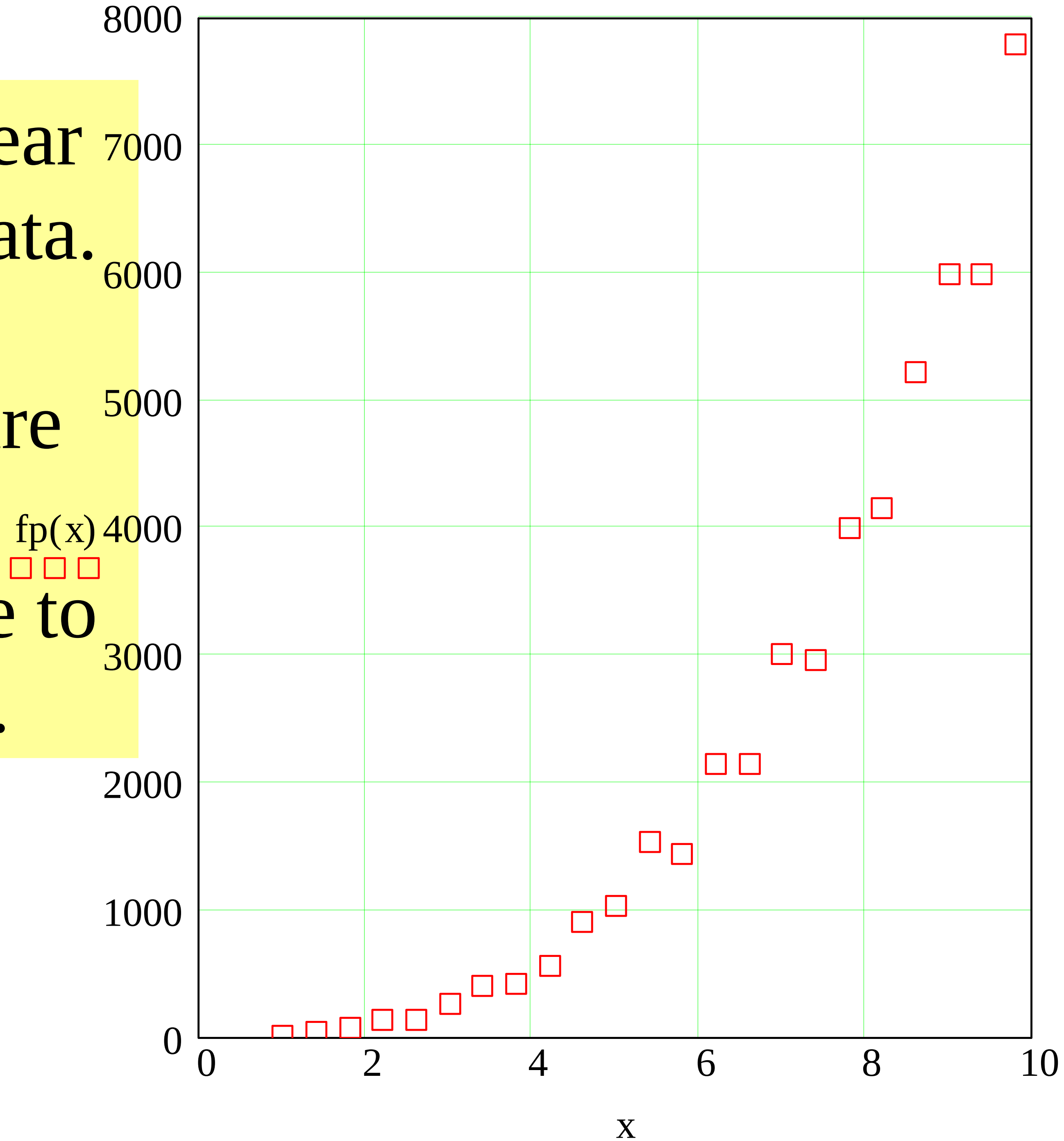
Example:

Testing the data Set at right for Polynomial Properties.

$x =$	$fp(x) =$
1	20.085
1.4	30.624
1.8	73.481
2.2	94.966
2.6	222.621
3	269.297
3.4	298.011
3.8	514.174
4.2	612.635
4.6	833.211
5	$1.231 \cdot 10^3$
5.4	$1.532 \cdot 10^3$
5.8	$1.625 \cdot 10^3$
6.2	$2.186 \cdot 10^3$
6.6	$2.226 \cdot 10^3$
7	$2.821 \cdot 10^3$

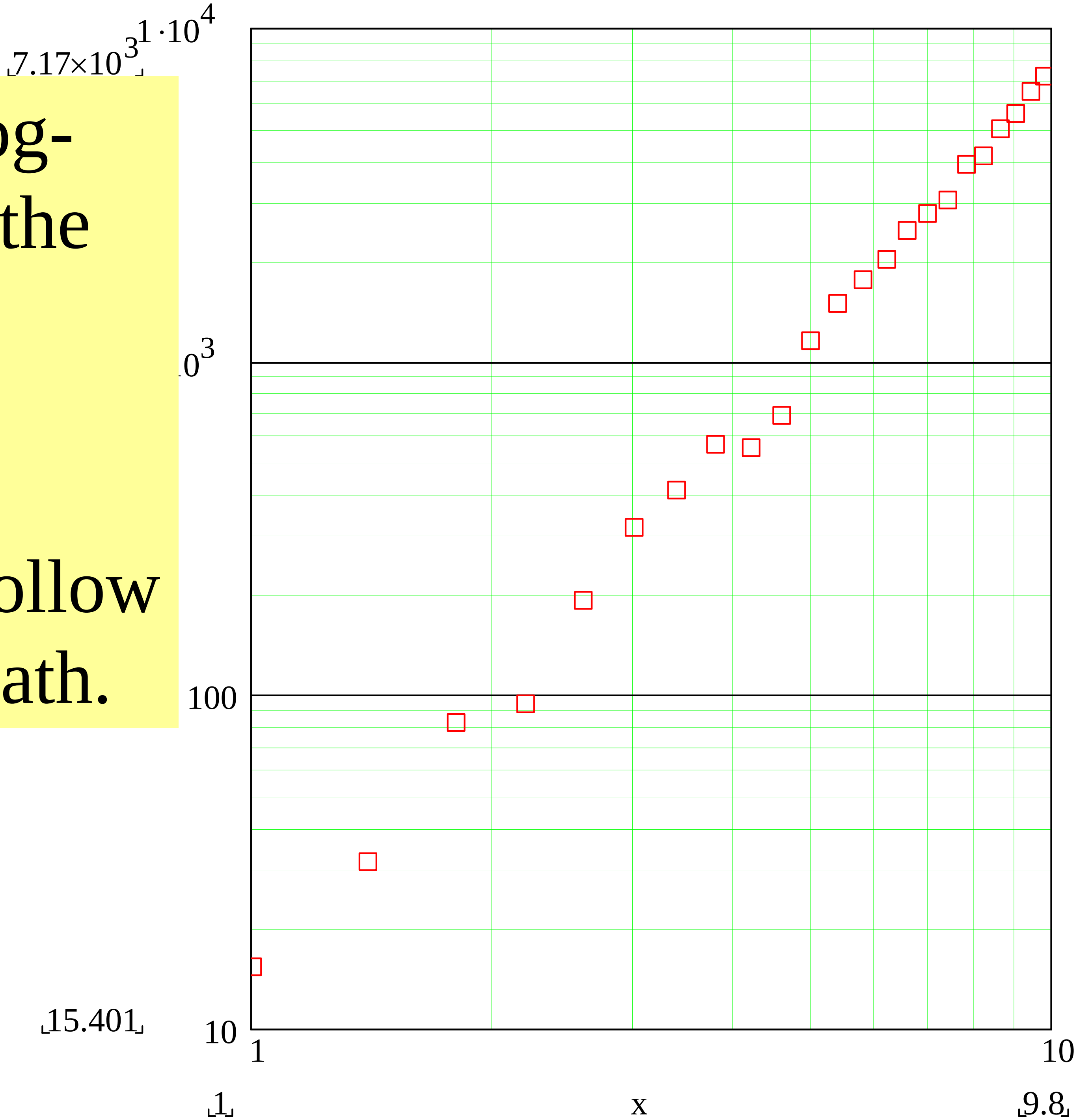
Here is a linear plot of the data.

The values are somewhat scattered due to sensor noise.

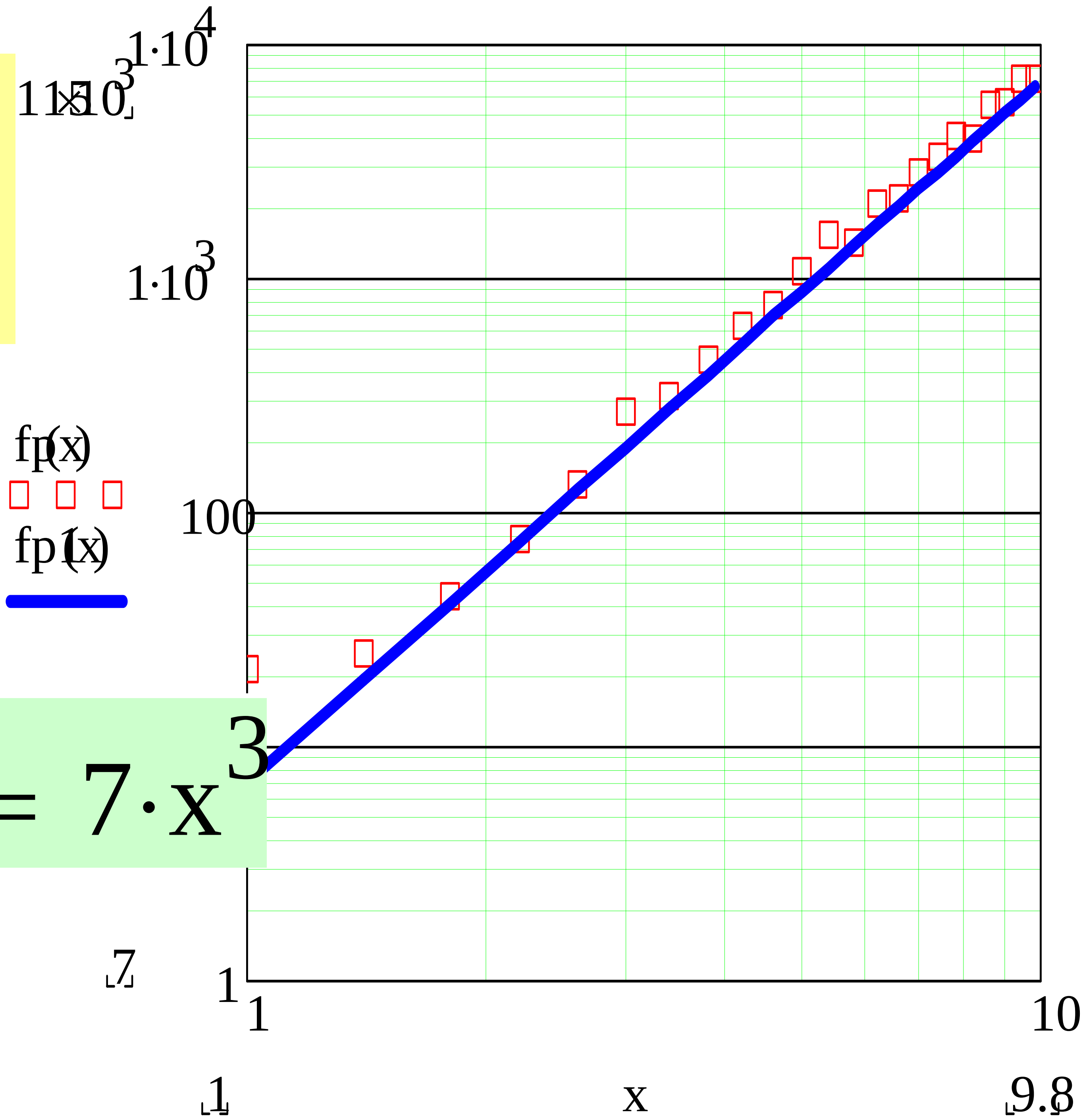


Here is a log-log plot of the same data.

The values appear to follow a straight path.



A best fit line is found as:



$$fp1(x) := 7 \cdot x^{3}$$