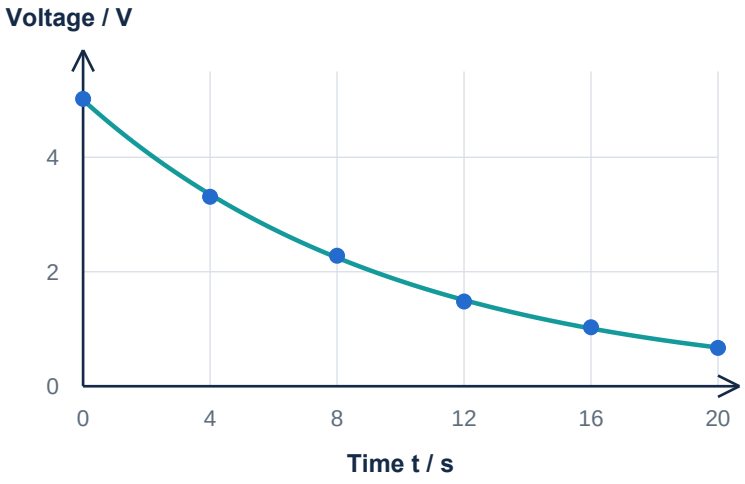
LESSON 6.2.3

Spreadsheet Modelling and Graphical Analysis

A spreadsheet connects measured data to a physical model. Its job is to make calculations traceable, reveal patterns and test how well a proposed relationship describes the evidence.

ONE EXAMPLE THROUGHOUT: CAPACITOR DISCHARGE



Blue points: illustrative voltage readings, not a real experimental record.

Teal curve: trial model with initial voltage 5.00 V and time constant 10.0 s.

$$V = V_0 e^{-t/\tau} \qquad \tau = RC$$

Assume constant resistance and capacitance, negligible meter loading and a corrected voltage zero. A larger time constant gives a slower discharge.

1. ORGANISE	Keep raw readings separate from formulas. Label quantities, units and the basis of any uncertainties.
2. CALCULATE	Use cell references to calculate predictions and transformed variables; retain full precision internally.
3. TEST	Plot the data, extract physical parameters and check residuals before drawing a conclusion.

Physics reference: OpenStax University Physics 2, §10.5 RC Circuits.

1 Build an auditable worksheet

Enter numbers only in the data cells; put units in the headings. Here column B contains numerical voltages in volts, so LN(B2) represents ln(V / 1 V).

A. DATA AND CALCULATED COLUMNS

Row	A: t / s	B: V / V	C: ln(V / 1 V)	D: model / V	E: residual / V
2	0	5.02	1.6134	5.000	+0.020
3	4	3.31	1.1969	3.352	-0.042
4	8	2.28	0.8242	2.247	+0.033
5	12	1.48	0.3920	1.506	-0.026
6	16	1.03	0.0296	1.009	+0.021
7	20	0.67	-0.4005	0.677	-0.007

A and B are the illustrative raw data. C, D and E are formula results, rounded here for display only. Use the unrounded cell values for later calculations.

PARAMETERS: LABEL COLUMN G; NUMERIC VALUE COLUMN H

H2 = 5.00 (initial voltage / V) H3 = 10.0 (time constant / s)

H4 = 10000 (resistance / Ω)

B. ENTER IN ROW 2, THEN FILL DOWN TO ROW 7

C2 `=LN(B2)`

Natural log; all input voltages must be positive.

D2 `=$H$2*EXP(-A2/$H$3)`

Trial voltage from the exponential model.

E2 `=B2-D2`

Residual = measured voltage - predicted voltage.

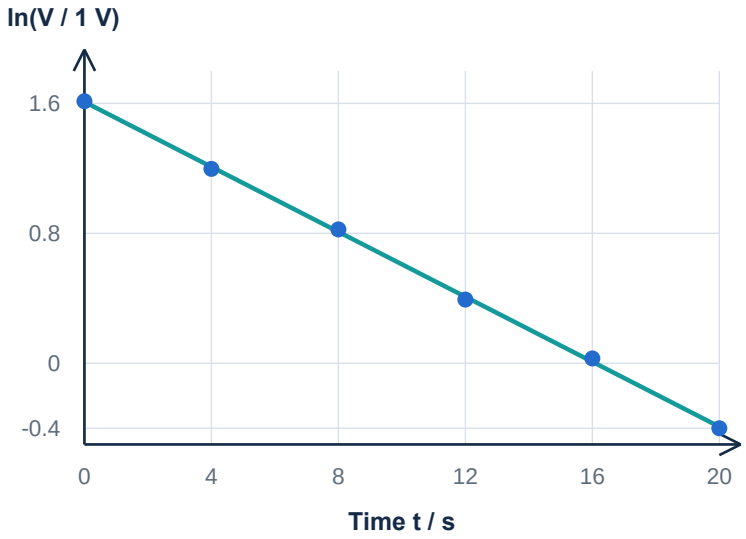
A2 and B2 are relative references: they become A3 and B3 in the next row. $H$2 and $H$3 stay fixed. Check one copied row by hand: at 4 s, model = 3.352 V and residual = -0.042 V.

Try H3 = 12.0: the model decays more slowly. Restore 10.0 before using the residual graph on page 4. Record parameter changes; never overwrite raw readings to improve a fit.

Spreadsheet reference: Microsoft Support, relative and absolute cell references.

2 Turn a graph into physical parameters

Use an XY scatter graph with time as the numeric x values. A category line chart can conceal unequal time intervals. Label axes and plot measurements as separate points.



Plot A2:A7 on x and C2:C7 on y; add a linear fit.

Do not force the intercept to zero: it contains information about the initial voltage.

$$\ln(V / 1\ V) = \ln(V_0 / 1\ V) - \frac{t}{\tau}$$

FIT CELLS: y RANGE FIRST, THEN x RANGE

H6	`=SLOPE(C2:C7,A2:A7)`	gradient m = -0.100027 per second
H7	`=INTERCEPT(C2:C7,A2:A7)`	intercept b = 1.609554
H8	`=-1/H6`	time constant = 9.997 s
H9	`=EXP(H7)`	initial voltage = 5.001 V
H10	`=H8/H4`	capacitance = 0.0009997 F

$$m = -\frac{1}{\tau} \qquad \tau \approx 10.0\ s \qquad C = \frac{\tau}{R} \approx 1.00\ mF$$

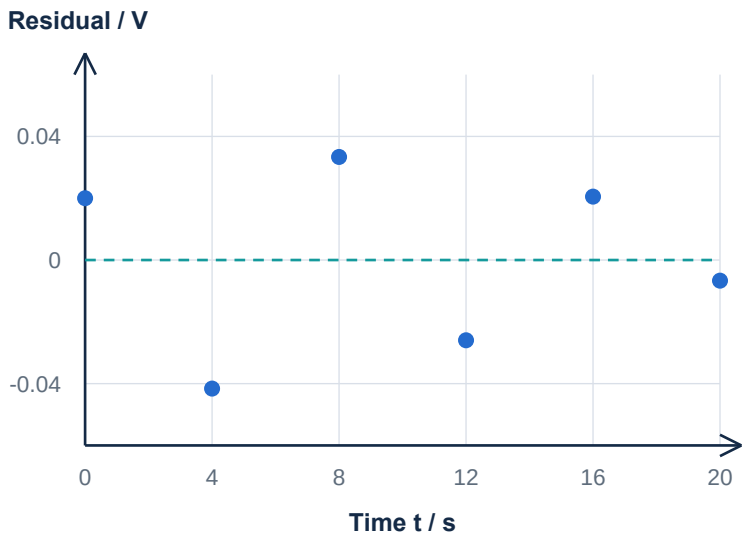
Use fitted cells, not a heavily rounded equation label. The extra digits above make the calculation reproducible; they do not establish the measurement precision or uncertainty.

This is an unweighted fit in log space. Taking logs changes the error structure; it is not generally identical to fitting voltage directly.

Function reference: Microsoft Support, SLOPE (linear regression).

3 Test the model, not just the picture

A smooth curve and a high R^2 are not proof of the physical model. Inspect the differences between measurements and predictions, and consider the experimental uncertainties.



Plot A2:A7 against E2:E7. These residuals use the trial parameters H2 = 5.00 and H3 = 10.0.

Points lie on both sides of zero. With only six illustrative points, keep the conclusion cautious.

To test the fitted parameters instead, use =$H$9*EXP(-A2/$H$8) in D2 and fill down. E updates automatically. Label which model your residual plot uses.

A. LOOK FOR STRUCTURE

RANDOM SCATTER	Scatter around zero is compatible with the model. Compare its size with expected uncertainty; absence of a visible pattern is not proof.
CURVATURE / OFFSET	A curved pattern suggests a missing effect or unsuitable model. Residuals mostly on one side suggest a biased prediction or offset.
CHANGING SPREAD	A widening spread suggests non-constant scatter. For a small voltage uncertainty, the log uncertainty is approximately $\delta V/V$, so low voltages may be less precise in log space.

B. BEFORE REPORTING

Check units, copied ranges and one manual calculation. Add justified error bars where available; investigate anomalies rather than deleting them. Report fit assumptions, uncertainty and the measured range. Avoid unsupported extrapolation.

Model checking: NIST/SEMATECH e-Handbook, residual diagnostics.

Next: 6.3.1 Evaluating experimental limitations.