Sample solutions for Experiment 1: Static response of a magnetically active fluid

General Note: these solutions look brief for many parts. Students do, however, have to manipulate the equipment and try to take good data, which will require taking some time. The solutions try to indicate some of the tricks.

A1: Measurement taken on sample bottle: $\Delta z = 0.061 \pm 0.004$ m, when well balanced. (0.5 for good z, 0.3 for reasonable uncertainty) *Expect to see multiple attempts for full credit*

A2: Density difference gives the nett buoyant force, so balancing gravitational and magnetic forces: $\Delta\rho g = 3\,\chi B_r^2 a^4 l^2 / 8\mu_0 z^7$ (0.3)

Need to divide by g to rho, then substituting in the values for the large magnet yields

$\Delta\rho = 15$ kg m^{-3} (0.3)

Uncertainty sources: primarily z - hard to measure but can be controlled, and χ - not actually constant for a superparamagnet.
Any reasonable uncertainty method is fine. Using the data above, an estimate of 6 kg m^{-3} (0.2) could be made. Students should have some indication of where their labels come from.

Fresh bottles will be measured.

B1: $z_{crit} = 22 \pm 1$ mm (from uncertainty in when spikes appear) (0.2 + 0.1)

$\lambda = 6 \pm 1$ mm (from angle through the glass causing uncertainty about measurements of the incipient wavelength) (0.2 + 0.1)

Expect multiple attempts for full credit

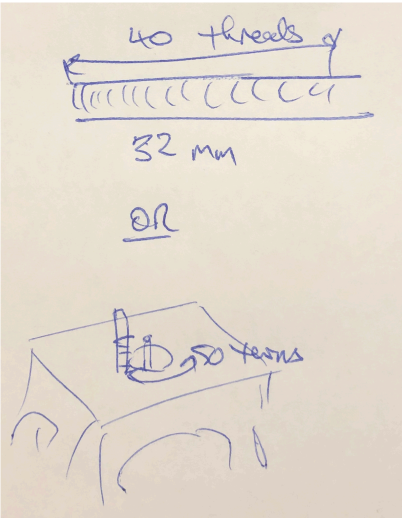
Points will be given to good values. Doing this part is easiest if the bottle is on its side, although it can be done with the bottle upright.

B2: It may look as though there are a lot of points for nothing much here, but the credit is for the experimental skill that goes into taking high quality data. It is possible to be quite precise if one is careful and this will be rewarded here as well as the calculation details..

Surface tension may be calculated using the relationship above. It also requires the density difference from the earlier part, meaning that a large uncertainty in both parts will compound to the point where the uncertainty in this part is unreasonable.

For the values in these sample solutions $\sigma = 1.3 \times 10^{-2}$, N m^{-1} (0.3 if correct within an order of magnitude). Uncertainty estimate: in these data, $\Delta\sigma = 6 \times 10^{-3}$ N m^{-1} . (0.2 if correctly calculated from a reasonable method, 0.1 additional if less than 50%).

C1: There are many solution approaches.. All need to count threads and measure distance. For a diagram of a useful setup, **0.2**. For example:



0.2 for measurements and calculations.

Students should find that
$\Delta z = 0.80 \pm 0.02$ mm (**0.2**)

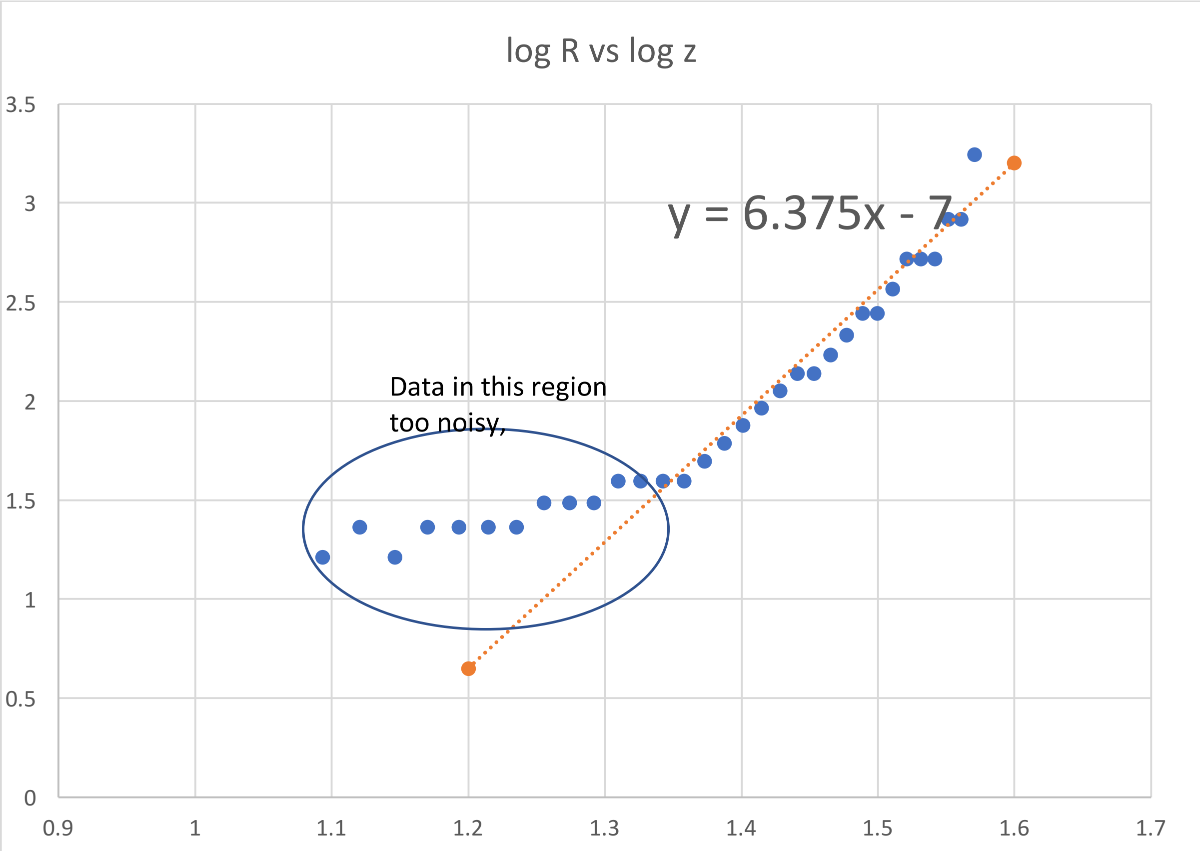
If a visual counting technique is used, at least three measurements are expected. If a turn-by-turn method, then distance measurements should be taken for at least three numbers of turns.

C2: Table of measurements:

turns	length of ligh	z (has offset)	M	R	z (corrected)	log z	log R
32.50	20.00	26.00	1.00	#DIV/0!	38.00	1.58	#DIV/0!
31.50	19.00	25.20	0.95	1748.00	37.20	1.57	3.24
30.50	18.00	24.40	0.90	828.00	36.40	1.56	2.92
29.50	18.00	23.60	0.90	828.00	35.60	1.55	2.92
28.50	17.00	22.80	0.85	521.33	34.80	1.54	2.72
27.50	17.00	22.00	0.85	521.33	34.00	1.53	2.72
26.50	17.00	21.20	0.85	521.33	33.20	1.52	2.72
25.50	16.00	20.40	0.80	368.00	32.40	1.51	2.57
24.50	15.00	19.60	0.75	276.00	31.60	1.50	2.44
23.50	15.00	18.80	0.75	276.00	30.80	1.49	2.44
22.50	14.00	18.00	0.70	214.67	30.00	1.48	2.33
21.50	13.00	17.20	0.65	170.86	29.20	1.47	2.23
20.50	12.00	16.40	0.60	138.00	28.40	1.45	2.14
19.50	12.00	15.60	0.60	138.00	27.60	1.44	2.14
18.50	11.00	14.80	0.55	112.44	26.80	1.43	2.05
17.50	10.00	14.00	0.50	92.00	26.00	1.41	1.96
16.50	9.00	13.20	0.45	75.27	25.20	1.40	1.88
15.50	8.00	12.40	0.40	61.33	24.40	1.39	1.79
14.50	7.00	11.60	0.35	49.54	23.60	1.37	1.69
13.50	6.00	10.80	0.30	39.43	22.80	1.36	1.60
12.50	6.00	10.00	0.30	39.43	22.00	1.34	1.60
11.50	6.00	9.20	0.30	39.43	21.20	1.33	1.60
10.50	6.00	8.40	0.30	39.43	20.40	1.31	1.60
9.50	5.00	7.60	0.25	30.67	19.60	1.29	1.49
8.50	5.00	6.80	0.25	30.67	18.80	1.27	1.49
7.50	5.00	6.00	0.25	30.67	18.00	1.26	1.49
6.50	4.00	5.20	0.20	23.00	17.20	1.24	1.36
5.50	4.00	4.40	0.20	23.00	16.40	1.21	1.36
4.50	4.00	3.60	0.20	23.00	15.60	1.19	1.36
3.50	4.00	2.80	0.20	23.00	14.80	1.17	1.36
2.50	3.00	2.00	0.15	16.24	14.00	1.15	1.21
1.50	4.00	1.20	0.20	23.00	13.20	1.12	1.36
0.50	3.00	0.40	0.15	16.24	12.40	1.09	1.21

1.0 points for the raw measurements of number of turns and M.
0.5 points for correct conversion to R.

Graph:.. **1.0** points for a graph allowing the calculation of the exponent.



0.5 for fit to correct region
0.5 for answer n within range 6 to 7 with reasonably estimated uncertainty.

Note: if students do not account for the distance between the surface of the stand and the surface of the fluid, the log-log graph will not have a proper linear region as it does not follow a reasonable power law. In this case there will be no credit for the conversion, the fit or the answer.

D1: Surface tension $\sigma \cong 2.3 \times 10^{-2}$N m^{-1}. **0.5** if within 10%, 0.3 within 20%, else 0.

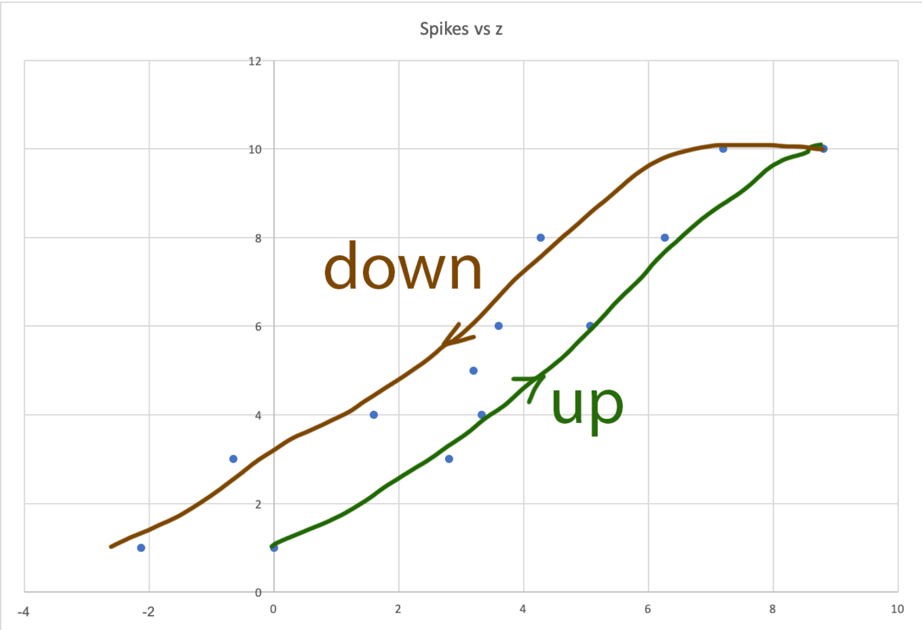
D2: Table:

Spikes	Turns	z
1	0	0
3	3.5	2.8
4	4.16	3.328
6	6.33	5.064
8	7.82	6.256
10	11	8.8
10	2	7.2
8	5.66	4.272
6	6.5	3.6
5	7	3.2
4	9	1.6
3	11.82	-0.656
1	13.66	-2.128

1.0 for at least 6 measurements each way with conversion to z and a reasonable uncertainty estimate..

Note: this requires time and care to get the points of appearance and disappearance correctly.

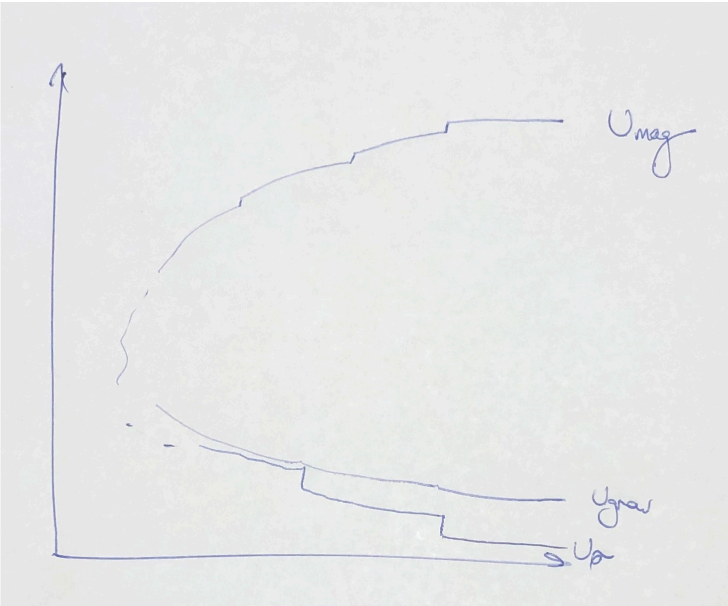
D3:



0.3 for a correctly plotted graph. 0.2 for each smooth curve fitting points. 0.3 if clear hysteresis shown: at least 1.5 mm separation in z between the up and down measurements.

Although the data are quantised they should still follow a reasonable curve.

D4:



Key features:
Magnetic energy should decrease at a rapid rate as the magnet moves closer, following a power law – as long as it looks reasonable credit will be given without trying to determine the power. There should be small steps at the spike formations as there is a slight release of magnetic potential energy from the drawing of fluid along a new unstable surface.

Surface energy should jump significantly at spike formation points and change much more slowly although still steadily throughout the rest of the time.

It is important that the overall energy decrease. Students should be able to tell this as the ferrofluid chamber will attract a magnet from underneath – most of the magnetic potential energy goes into lifting the magnet rather than being bound in the internal structure of the ferrofluid.

0.2 for each graph and 0.2 for correct behaviour of total energy.