2.3. ★ Rewrite the following results in their clearest forms, with suitable numbers of significant figures:

(a) measured height $= 5.03 \pm 0.04329$ m

(b) measured time $= 1.5432 \pm 1$ s

(c) measured charge $= -3.21 \times 10^{-19} \pm 2.67 \times 10^{-20}$ C

(d) measured wavelength $= 0.000{,}000{,}563 \pm 0.000{,}000{,}07$ m

(e) measured momentum $= 3.267 \times 10^{3} \pm 42$ g·cm/s.

2.5. ★ Two students measure the length of the same rod and report the results 135 ± 3 mm and 137 ± 3 mm. Draw an illustration like that in Figure 2.1 to represent these two measurements. What is the discrepancy between the two measurements, and is it significant?

2.7. ★ **(a)** A student measures the density of a liquid five times and gets the results (all in gram/cm^3) 1.8, 2.0, 2.0, 1.9, and 1.8. What would you suggest as the best estimate and uncertainty based on these measurements? **(b)** The student is told that the accepted value is 1.85 gram/cm^3. What is the discrepancy between the student's best estimate and the accepted value? Do you think it is significant?

2.9. ★ In an experiment on the simple pendulum, a student uses a steel ball suspended from a light string, as shown in Figure 2.8. The effective length l of the

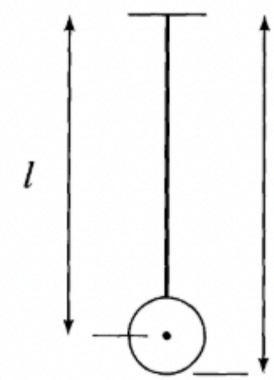

Figure 2.8. A simple pendulum; for Problem 2.9.

pendulum is the distance from the top of the string to the *center* of the ball, as shown. To find l, he first measures the distance x from the top of the string to the bottom of the ball and the radius r of the ball; he then subtracts to give $l = x - r$. If his two measurements are

$$x = 95.8 \pm 0.1 \text{ cm} \quad \text{and} \quad r = 2.30 \pm 0.02 \text{ cm},$$

what should be his answer for the length l and its uncertainty, as given by the provisional rule (2.18)?

2.13. ★★ An experimenter measures the separate masses M and m of a car and trailer. He gives his results in the standard form $M_{\text{best}} \pm \delta M$ and $m_{\text{best}} \pm \delta m$. What would be his best estimate for the total mass $M + m$? By considering the largest and smallest probable values of the total mass, show that his uncertainty in the total mass is just the sum of δM and δm. State your arguments clearly; don't just write down the answer. (This problem provides another example of error propagation: The uncertainties in the measured numbers, M and m, propagate to cause an uncertainty in the sum $M + m$.)

2.17. ★★ The power P delivered to a resistance R by a current I is supposed to be given by the relation $P = RI^2$. To check this relation, a student sends several different currents through an unknown resistance immersed in a cup of water and measures the power delivered (by measuring the water's rise in temperature). Use the results shown in Table 2.10 to make plots of P against I and P against I^2, including error bars. Use the second plot to decide if this experiment is consistent with the expected proportionality of P and I^2.

Table 2.10. Current I and power P; for Problem 2.17.

Current I (amps) (negligible uncertainty)	Power P (watts) (all ± 50)
1.5	270
2.0	380
2.5	620
3.0	830
3.5	1280
4.0	1600

2.19. ★★★ In an experiment with a simple pendulum, a student decides to check whether the period T is independent of the amplitude A (defined as the largest angle that the pendulum makes with the vertical during its oscillations). He obtains the

Table 2.12. Amplitude and period of a pendulum; for Problem 2.19.

Amplitude A (deg)	Period T (s)
5 ± 2	1.932 ± 0.005
17 ± 2	1.94 ± 0.01
25 ± 2	1.96 ± 0.01
40 ± 4	2.01 ± 0.01
53 ± 4	2.04 ± 0.01
67 ± 6	2.12 ± 0.02

results shown in Table 2.12. **(a)** Draw a graph of T against A. (Consider your choice of scales carefully. If you have any doubt about this choice, draw two graphs, one including the origin, $A = T = 0$, and one in which only values of T between 1.9 and 2.2 s are shown.) Should the student conclude that the period is independent of the amplitude? **(b)** Discuss how the conclusions of part (a) would be affected if all the measured values of T had been uncertain by ± 0.3 s.