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Question 1: Kale; Question 2: Hurricane Angular Momentum

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Weinstein, Larry, "Question 1: Kale; Question 2: Hurricane Angular Momentum" (2018). *Physics Faculty Publications*. 307.
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Original Publication Citation

Weinstein, L. (2018). Question 1: Kale; question 2: Hurricane angular momentum. *Physics Teacher, 56*(8), 534-534. doi:10.1119/1.5064564

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Larry Weinstein

Citation: The Physics Teacher **56**, 534 (2018); doi: 10.1119/1.5064564
View online: https://doi.org/10.1119/1.5064564
View Table of Contents: http://aapt.scitation.org/toc/pte/56/8
Published by the American Association of Physics Teachers

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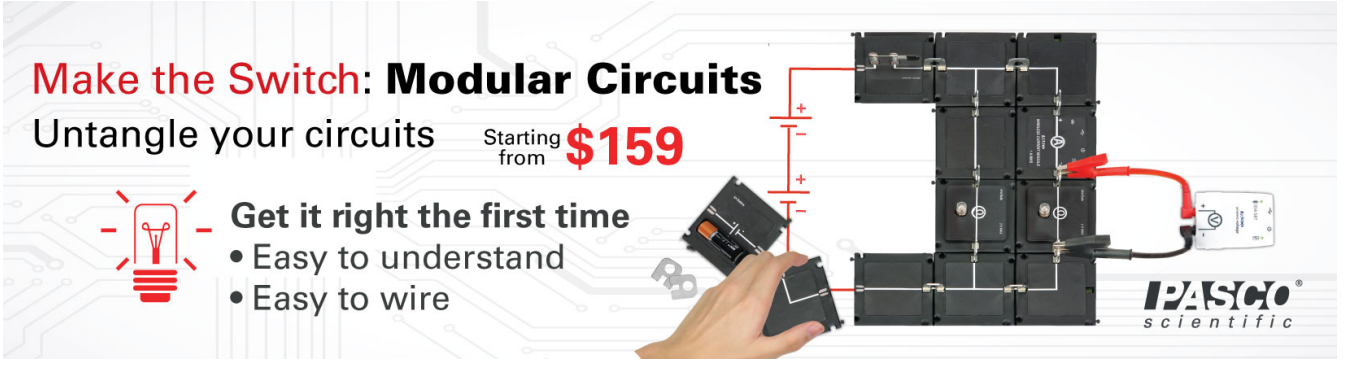

11. In the research lab, in the kitchen, and elsewhere, on measuring devices where the range and sensitivity are fixed, there is usually (albeit not always) at least one built-in guard digit. More uncertainty comes from drift, hysteresis, nonlinearity, etc. than from roundoff or readability. Manufacturers could redesign the devices to provide a coarser display—but you wouldn't want them to. That would increase the overall uncertainty, making the devices less useful. Furthermore, the thing being measured is often less than perfectly reproducible. If you repeatedly measure "the" thickness of a shag carpet or potato using a micrometer caliper, you will get many different answers. Do not discard uncertain digits just because they are uncertain! They are your guard digits.
12. When using a calculator, you shouldn't key in π as a decimal, but instead rely on the calculator's built-in notion of π, for which the roundoff error is probably 10^{-15} or less.
13. Clifford E. Swartz, "Editorial: Insignificant figures," *Phys. Teach.* **6**, 125 (March 1968).
14. "Tolerance, Sensitivity Analysis, and Uncertainty" [submitted to *TPT*].
15. Wikipedia[7] suggests overlining, but that conflicts with the notation for repeating decimals.
16. Anything between 0.15 and 1.5 is considered "comparable" to a half. However, it's not worth being super precise about it, because the sig figs representation is a very coarse approximation. It rounds the uncertainty to the nearest order of magnitude, or worse, which is not good enough for many real-world applications.[22] (The $A \pm B$ representation is better.) If/when roundoff is dominant, the worst-case error is exactly half a count, and the RMS error, averaged over all possible roundoff errors, is approximately 0.289 counts.
17. We bow to convention and write $T = 294$ K, even though it would be more logical to write $T \in 294$ K, using the set-membership symbol, since T is a single point whereas 294 K is a set of points, i.e., a probability distribution.[9]
18. In the figure, we focus attention on the position of the points along the n-axis. The height above the axis has no immediate physical significance.
19. In multi-step calculations, including iterative calculations, you need to worry about accumulated roundoff error, which can be much larger than the roundoff error at any one step. This increases the number of guard digits required for intermediate steps. Also, correlations and cancellations can greatly increase the need for guard digits. Intermediate results are often correlated even when the raw data are not.
20. If the data are to be subjected to signal averaging, curve fitting, or more advanced data analysis, multiple guard digits may be needed.
21. Pick a calculation where the roundoff errors accumulate, as in the PV/RT example, not one where they fortuitously cancel.
22. We care about precise values for the uncertainty whenever one data point is to be weighed against others. This is important for curve fitting, decision theory, etc. The details are beyond the scope of this article.

John Denker *was a Caltech undergrad and Cornell grad student. He was cofounder and proprietor of a small technology company, then worked at Bell Labs for many years, as a researcher and manager. Activities and interests include large-scale pranks, the world's first handheld electronic games, the physics of energy-efficient nearly reversible computation, ultra-low-noise quantum measurement, spin waves in gaseous monatomic hydrogen at millikelvin temperatures, biological computation, machine learning, cryptography, network services and security, and aviation security.*
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Fermi Questions

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Question 1: Kale

How much kale would be needed to provide enough calories for a person for an entire year? (*Thanks to Michael Briggs and Beverly Sher of William & Mary for suggesting the question.*)

Question 2: Hurricane angular momentum

How much angular momentum did Hurricane Florence have when it hit land?

Look for the answers online at *tpt.aapt.org*

Question suggestions are always welcome!

For more Fermi questions and answers, see *Guesstimation 2.0: Solving Today's Problems on the Back of a Napkin,* by Lawrence Weinstein (Princeton University Press, 2012).

DOI: 10.1119/1.5064564