# Physics 496
# Introduction to Research

Lecture 1.0: Estimates in Research

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## Making good estimates is part of being "numerate"

And scientists need to be a little better at it than your average Josephine.

Why?

To be able to tell if a result makes sense.

To provide a rough check of more exact calculations.

To provide a rough check of research results or hypotheses.

To obtain estimates of quantities when other resources aren't available.

To obtain estimates of quantities that are difficult to measure precisely.

To obtain estimates of quantities for which no firm theoretical prediction exists.

To provide bounds for possible design alternatives.

## With some experience, you can become good at it

How do you estimate the answer to a question that appears impossible to determine at all, at least without access to an encyclopedia or the internet?

e.g., how many grains of sand are there on Earth's beaches?

Problems like this are sometimes referred to as Fermi problems, after the physicist Enrico Fermi, who was famous for (among other things) posing and solving such problems.

How do you 'solve' such a problem?

1. Don't panic.
2. Write down what you *do* know that's related.
3. Outline a procedure for arriving at an answer.
4. List what you need to know to execute Step 3.
5. Keep dimensional analysis in mind.
6. Keep track of your assumptions.

## Keep it simple

1. Round numbers
   $\pi = 3$ ; $8.4 = 10$
2. Choose convenient geometries when modeling
   e.g. Cows are spherical ; grains of sand are cubical.
3. Make educated guesses about things you don't know.
   Keep track of your guesses so you can evaluate the accuracy of your estimate.
4. Use ratios when possible – by comparing the value of one quantity (e.g., force, energy, etc.) in comparison to a related quantity – in order to eliminate unknown parameters and get a dimensionless parameter.
5. If possible, exploit plausible scaling behavior of some quantity, i.e., estimate an unknown quantity by assuming it scales linearly - from known values – with some parameter.

## Check

Checking your estimates:

1. Make sure that your estimates and calculations are dimensionally correct! ⇒ This is a very powerful tool!

2. Check the plausibility of your estimate, if possible
   e.g., if your answer exceeds the speed of light or the size of the universe, you've got a problem!

3. Check the plausibility of your estimate using an alternate calculation method
   do the two methods agree to within an order of magnitude?

4. Perform a "reality check" on your estimate based on the number and size of the approximations you made.

5. More quantitatively - place "bounds" on your estimate:
   To obtain an "upper bound" – in equations, put largest estimated values of quantities in the numerator and the smallest estimated values in the denominator.

   To obtain a "lower bound" – in equations, put smallest estimated values of quantities in the numerator and the largest estimated values in the denominator

## Back to the beaches

How many grains of sand are on the Earth's beaches?

1. What do we need to know:
   \# of grains = Total volume of Earth's beaches □ volume of one grain of sand.

2. The easy part first: estimate the volume of a grain of sand.
   Approximate a grain of sand as a cube 1mm on a side:
   $$V_{sand} = (10^{-3}\text{m})^3 = 10^{-9}\text{m}^3$$

3. How do we estimate the total volume of the beaches?
   $$V_{beaches} = L \times W \times D$$
   A typical beach? $W$= 50 m , $D$=5 m (these are educated guesses).

4. $L$ = total length of beaches on Earth.
   Assume the entire coastline is beach. How long are all the coastlines?
   Order of magnitude estimate: A few (~5) times the circumference of the Earth.
   $$V_{beaches} = 5 \times (40 \times 10^6\text{m}) \times 50\text{m} \times 5\text{m} = 5 \times 10^{10}\text{m}^3$$

5. So…
   $$N_{grains} = V_{beaches}/V_{sand} = 5 \times 10^{10}\text{m}^3/10^{-9}\text{m}^3 = 5 \times 10^{19}$$

## How would you set bounds on the estimate of $N_{grains}$ ?

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## Resources for making estimates

*A View From the Back of the Envelope*
http://www.vendian.org/envelope/

*University of Maryland Fermi Problems Site*
http://www.physics.umd.edu/perg/fermi/fermi.htm

*Old Dominion University Fermi Problems Site*
http://www.physics.odu.edu/~weinstei/wag.html

*Order of Magnitude Astrophysics*
http://www.astronomy.ohio-state.edu/~dhw/Oom/questions.html

*Back-of-the-Envelope Physics*, Clifford Swartz (Baltimore, Johns Hopkins University Press, 2003).

*The Back of the Envelope,* E.M. Purcell, monthly column in the *American Journal of Physics,* July 1984 – Jan. 1993.

*Consider a Spherical Cow : A Course in Environmental Problem Solving*, John Harte (Berkeley, University Science Books, 1988).

*Powers of Ten : About the Relative Size of Things in the Universe, and the Effect of Adding Another Zero*, Philip Morrison and Phylis Morrison (Scientific American Library, 1982, 1994).

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