2018

Solutions for Fermi Questions, May 2018: Question 1: Throwing Out Energy; Question 2: Blood Pressure

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► Question 1: Throwing out energy

How much energy do Americans waste each year by throwing out the unused ice in their drinks? (*Thanks to John Klinck of Old Dominion University for suggesting the question.*)

Answer: To estimate this, we need to estimate the energy content of ice and the amount of ice discarded. While the specific heat of water should be well known ($C = 1$ in units of either cal/°C-g or BTU/°F-lb), the latent heat of fusion is less so. We could duckduckgo it, but (a) it's more pedagogical [and more fun] to estimate it and (b) I'm stuck on an airplane as I write this. We can estimate the latent heat by observing that a glass of 25/75 ice/water takes about 10 times longer to warm up (by, say, 10 °C) than a glass of water at 0 °C (more than 1 and less than 100 times longer). This means that the latent heat of 1 unit of ice equals 10 times the energy needed to raise the temperature of 4 units of water by 10 °C. Therefore we estimate that

$$L = 4 \times 10^\circ\text{C} \times 1 \text{ cal/}^\circ\text{C-g} = 40 \text{ cal/g} = 160 \text{ J/g}$$

(which turns out to be a factor of two lower than reality).

The average person consumes a beverage with ice (ice water, soda from a soda fountain, scotch on the rocks, etc.) more than 10 and fewer than 10^3 times per year, giving a geometric mean of $N = 10^2$. The ice remaining in a typical drink will be more than 1 ounce (30 g) and less than 8 ounces (250 g), giving an estimate of $m = 10^2$ g of ice wasted per drink. We will ignore the small fraction of the population (more than 1% and less than 30%) who irritatingly and loudly chew all the remaining ice in their cup.

Now we can calculate the energy discarded per person per year:

$$\begin{aligned} E &= NmL \\ &= (10^2)(10^2 \text{ g})(1.6 \times 10^2 \text{ J/g}) \\ &= 2 \times 10^6 \text{ J.} \end{aligned}$$

Even if we multiply by a factor of five to account for all possible inefficiencies in producing the ice, this is still only 10^7 J or 3 kW-hr, or about 30 cents of electricity per year.

The total ice-energy discarded by all Americans in one year is, of course, a lot more.

$$E_{\text{total}} = (2 \times 10^6 \text{ J})(3 \times 10^8) = 6 \times 10^{14} \text{ J,}$$

which is a lot of energy and would cost about \$100 million per year. This is, of course, a very silly comparison. What

it really shows is just how small \$100 million is when distributed among 3×10^8 Americans.

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► Question 2: Blood pressure

Why is blood pressure measured on the upper arm? Does it really matter?

Answer: When our blood pressure is measured, the cuff is typically wrapped around the upper arm, at about the same height as the heart. A typical healthy blood pressure reading is 100 (systolic) over 60 (diastolic). Or maybe it's the other way around. I'm a physicist, not a doctor. A difference of 20 units is important. Of course, we also need to know the units. Pressure has a remarkably large number of different units in common use, including mm Hg (torr), inches of water, Pascals, psi, bar etc. In this case, the units are in mm Hg (where 760 mm Hg = 10^5 Pa).

The difference in pressure due to the height of a column of fluid is $\Delta P = \rho gh$, so we need to estimate the height difference and the density. Although blood is thicker than water, for our purposes they have the same density, $\rho = 1$, in units of tons/m³, kg/L, g/cm³, lb/pint, or oz [weight]/oz [volume]. The location of the cuff on the upper arm can vary by up to ± 5 cm (2 in), giving a pressure variation of

$$\begin{aligned} \Delta P &= (10^3 \text{ kg/m}^3)(10 \text{ N/kg})(5 \times 10^{-2} \text{ m}) \\ &= 5 \times 10^2 \text{ Pa} \approx 4 \text{ mm Hg,} \end{aligned}$$

which is not particularly significant.

However, placing the blood pressure cuff near the wrist with the arm hanging downward would change the height by 0.5 m, changing the pressure by 40 mm Hg, which is quite significant.

Placing the blood pressure cuff at the ankle on a standing patient would be more inconvenient and result in a three times larger height difference (1.5 m) and pressure difference (120 mm Hg).

Thus, our blood pressure varies from head to toe by over 100 mm Hg and it is quite important to measure it at a consistent location at the same height as the heart.

The special case of giraffes is left as an exercise for the reader.

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