(2) A paper cup on the table is empty, except for the air it contains. The surrounding air is perfectly still. What is the best guess for the time it will take diffusion to replace half the air molecules in the cup with new molecules: a second, a minute, an hour, or a day?

Suppose the cup is 10 cm tall. A molecule starting near the center of the cup must random-walk its way 5 cm upward to escape. Of course, it may then wander back in, but for a crude estimate I'll ignore that. Recall that the mean free path $\bar{l}$ of an "air" molecule in air is 10^{-5} cm and its mean speed $\bar{v}$ is 5×10^4 cm/s. [We used those round numbers in February's problem (3).] The mean-square free path is $2\bar{l}^2$, with a mean-square z component $2\bar{l}^2/3$. (I've tacitly assumed isotropic scattering at each collision.) There are $\bar{v}/\bar{l}$ steps per second in the random walk, so a mean-square displacement of 25 cm^2 accumulates in a time t such that $(\bar{v}t/\bar{l})(2\bar{l}^2/3) = 25$ which gives $t \approx 75$ s. This probably underestimates the time. For one thing, our molecule was as likely to wander down as up. But an accurate answer, pretty clearly, will be closer to a minute than an hour. Diffusion on this scale seems surprisingly slow. There is a common but generally mistaken notion that odors spread by diffusion. An interesting problem can be posed as follows: 10 mg of ether is released in still air, 2 m from a nose (an artificial nose that doesn't have to breathe). About how much time will elapse before the *first molecule* of ether enters the nose? (The diffusion constant for ether in air is 0.1 cm^2/s.) Answer: one hour. Odors are *wafted*.