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Reflections

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Using Assessment to Extend Instruction: Evaporating Water Molecules

Peter Gendel

The laboratory test "Evaporating Water Molecules" found in the *Introductory Physical Science Assessment Package* yields excellent student results that can be connected to other concepts and skills in physical science. In this article, sample data from the assessment is used to illustrate some of these connections. Opportunities for further student investigations are also suggested.

Overview of the Experiment

In the "Evaporating Water Molecules" assessment, students are asked to find the number of water molecules that evaporate from a known surface area of water in one second. The reasoning process is central to the exercise, in particular the relation between the mass of a sample, the number of molecules in the sample, and the mass of one molecule. The experiment can also be extended to determine the number of molecules that evaporate from a surface area of one cm^2 in one second, as described below.

The experiment can be performed in any laboratory in a single class period. A small container or jar cap is ideal for use on a standard electronic top-loader, and the total surface area can be calculated from the measured diameter of the cap. A balance sensitive to at least the nearest 0.01 g should be used. Sample data★ for a single trial is shown below:

Sample Data	
Inside diameter of cap	6.20 cm
Surface area of water	3.02×10^1 cm^2
Initial mass of cap and water	25.66 g
Final mass of cap and water	25.47 g
Mass of water evaporated	1.9×10^{-1} g
Evaporating time	1.8×10^3 s
Mass of one water molecule	2.99×10^{-23} g/molecule

The number of water molecules evaporated per square centimeter per second is then:

$$\frac{1.9\times10^{-1}\ \text{g}}{(2.99\times10^{-23}\,\text{g/molecule})\times(3.02\times10^{1}\ \text{cm}^2)\times(1.8\times10^{3}\ \text{s})} = 1.2\times10^{17}\ \frac{\text{molecules}}{\text{cm}^2\cdot\text{s}}$$

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This is a very large number of water molecules indeed! How large is it? Like the traditional, and effective, mapping of events through geologic time onto a calendar year or a 24 hour clock, teachers can use this opportunity to help students envision just how big 10^{17} is. Invite students to determine the number of seconds that have elapsed from the origin of the earth to the present day. Like the experiment itself, the question provides yet another opportunity to teach, or for students to practice the use of scientific notation, significant digits, and dimensional analysis. Selecting a value of 4.5 billion years for the age of the earth, we determine the total number of seconds elapsed:

$$\frac{4.5\times10^{9}\,\text{yr}}{} \times \frac{3.65\times10^{2}\,\text{days}}{\text{yr}} \times \frac{2.4\times10^{1}\,\text{hr}}{\text{day}} \times \frac{6.0\times10^{1}\,\text{min}}{\text{hr}} \times \frac{6.0\times10^{1}\,\text{sec}}{\text{min}} = 1.4\times10^{17}\,\text{seconds}$$

The number of water molecules that evaporated from the jar cap is roughly equivalent to the number of seconds in 4.5 billion years!

Evaporation and the Water Cycle

There may well be no more ubiquitous cycle studied in schools than the water cycle, which includes evapora-

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tion, condensation, and precipitation, among other processes. Our day-to-day experience largely involves the precipitation part, which is also transmitted to us by daily weather reports. Except for the presence of clouds, evaporation and condensation are abstract components. We are more apt to be impressed with a downpour than an account of water vapor condensing in the atmosphere. But does what comes down must also have gone up?

The global water-flow budget, or mass balance, describes the flow of water from one place to another within the water cycle. The focus here is on the oceans because the evaporative surface is easier to determine. A number of estimates for global water or oceanic water budgets have been published.★★ Trenberth et. al. (2007) estimate the average annual precipitation over the oceans to be 3.73×10^{20} g/yr. Yet another 4.0×10^{19} g/yr enters the ocean through surface runoff, for a total average annual contribution from both precipitation and runoff of 4.13×10^{20} g/yr.

This value can now be compared with an estimate of total oceanic evaporation, in g/yr, based on the sample data given above (A figure of 3.62×10^{18} cm^2 is used for the surface area of the world's oceans):

$$(1.2 \times 10^{17} \text{ molecules/cm}^2\cdot\text{s}) \times (2.99 \times 10^{-23} \text{ g/molecule}) \times (3.62 \times 10^{18} \text{ cm}^2) \times (3.2 \times 10^{7} \text{ s}) = 4.2 \times 10^{20} \text{ g/year}$$

Remarkably, the two estimates differ by less than two percent! A student-performed experiment involving the evaporation of invisible molecules seems to have a meaningful relationship to a global phenomenon.

Suggestions for Discussion and Further Investigations

Both the similarities and differences between student results for oceanic evaporation and estimates for annual precipitation and runoff into the oceans should not be ignored.★ Students can be invited to suggest explanations or encouraged to pursue ideas experimentally. Reasons for differences certainly include experimental uncertainty on one end and the uncertainty of estimates for global water-flow budgets on the other, even if those cannot be well known. Students may wish to look into the range of estimates for the global water-flow budget.★★

Why is it that the classroom experiment is consistently within the order of magnitude of the accepted values? The experiment certainly can be tested under different conditions. How do differences in airflow, temperature, or humidity affect the results obtained in the classroom? What results will be obtained if the experiment is performed outside, under direct sunlight, on a cloudy day, or at night, and so on? What if salt water is used?

Hopefully, you will think of many more possibilities. Turn your students loose!

Reference

Kevin E. Trenberth, Lesley Smith, Taotao Qian, Aiguo Dai, and John Fasullo, 2007. Estimates of the Global Water Budget and Its Annual Cycle Using Observational and Model Data. Journal of Hydrometeorology, 8, pp. 758-769.
http://journals.ametsoc.org/doi/full/10.1175/JHM600.1

Notes

★ The experiment was conducted at Isidore Newman School in New Orleans, LA. The sample data reported in the IPS *Assessment Package* yields a different result: 6.33×10^{16} molecules/cm^2/s. Different results can be expected, but should fall within an order of magnitude of oceanic water-flow budget estimates.

★★ A good starting point to begin research is an article by Vernon Wu, entitled "Volume of Earth's Annual Precipitation," which is posted on the website of Glenn Elert, a high school science teacher at Midwood High School at Brooklyn College, NY.

http://hypertextbook.com/facts/2008/VernonWu.shtml