ing the following method. First I point out the following facts:

1. An increase in intensity of one dB is about a 25% gain in intensity.

$$\left(I \approx \frac{5}{4} I \right)$$

2. A 3-dB increase doubles the intensity or a 3-dB decrease halves the intensity.

$$\left(\frac{5}{4} \times \frac{5}{4} \times \frac{5}{4} \approx 2 \right)$$

3. A 10-dB increase raises the intensity exactly by a factor of 10.

$$\left(2 \times 2 \times 2 \times \frac{5}{4} = 10 \right)$$

4. The ear can detect about a 1-dB change in intensity regardless of the sound level. Since the ear's response covers 120 dB this means the ear is capable of detecting about 120 changes in intensity. This nonlinear response explains why when you walk away from a speaker the sound appears to decrease slowly although the intensity may be hundreds of times less.

The first three facts can be used to approximate any dB change in intensity changes and vice versa as shown below.

Example 1:

A gain of 26 dB leads to a gain of 10 dB + 10 dB + 3 dB + 3 dB. The intensity gain is then 10 x 10 x 2 x 2 = 400 gain in intensity.

Example 2:

A gain in intensity of 350 times can be broken down to the factors 10 x 10 x 2 x 1.25 x 1.4 which is approximately 10 dB + 10 dB + 3 dB + 1 dB + a little more than 1 dB or a total of about 25 dB.

Then in order for the students to appreciate the ear's response I ask them to consider a small speaker for which we turn the volume up until sound is barely heard. This gives 0 dB. We now add another speaker and increase the volume to the same level as the first speaker. The intensity has now doubled. We are at 3 dB and three levels of sound increase could be detected.

When we add the third identical speaker we increase the intensity 50%. I tell them this increases the intensity by 1.7 dB and only one sound level increase is heard.

When the fourth speaker is added we get a 33% or 1-dB increase and an increase in sound level is barely detected.

When the fifth speaker is added no increase in sound level is detected.

I then jump to what would happen if we had 100 speakers. In order to then detect an increase in sound level 25 more speakers must be added. At 1000 speakers 250 more would be needed in order to detect a sound increase, and so on. Finally, at the threshold of pain we have 10^{12} speakers and in order to hear an increase in sound we must add an additional 2.5×10^{11} speakers. I then ask them to approximate how long that would take to accomplish.

References

1. Alan H. Cromer, *Physics for the Life Sciences* (McGraw-Hill, New York, 1977) pp. 286-290.
2. Jonathan and Amos Turk, *Physical Science* (W. B. Saunders Co., Philadelphia, 1977) pp. 265-282.

Newton's law of cooling or is ten minutes enough time for a coffee break?

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A recent article[1] used a cup of coffee to gain some insights in cooling processes. The article gave some much needed attention to Newton's law of cooling. This interesting and, as we shall see, easily observed phenomenon is a much neglected topic in first year heat studies.

Newton found that, as long as the temperatures were not too extreme, the rate of cooling of an object is directly proportional to the differences between its temperature and the temperature of the surrounding region. In equation form, if

$T(t)$ represents the temperature of an object at any time t,

T_s represents the temperature of the surroundings,

T_o represents the initial temperature of the object, and

κ represents the temperature change constant (measured in reciprocal seconds);

then

$$T(t) = T_s + (T_o - T_s)e^{-\kappa t} \qquad (1)$$

Newtonian cooling represents the combined effects of conduction, convection and radiation.

Unfortunately, the cooling law has a very low profile in college physics courses. Typically, it is either completely omitted[2] or appears in the problem section of physics texts.[3-6] Discussions on applications of ordinary differential equations[7-11] introduced me to the topic and these texts are still the best place to find a relatively complete discussion.

The rather simple experiment I am about to describe has at least two appealing aspects for first-year students (and their instructors): it works and the equipment is easy to manipulate. Each two-person group requires a stopwatch, two thermometers, a hot cup of coffee (the machine vendors around here love my physics sections) and a lid for the cup.

One thermometer is required to record the ambient temperature; the other monitors the coffee's slow slide to thermal equilibrium. When the thermometer is placed in the coffee (through a hole in the lid), start the stopwatch and (*important*) record the maximum temperature registered by the thermometer. Consider this temperature to be the coffee's initial temperature [T_0 in Eq. (1)].

After exactly five minutes, the temperature of the coffee is recorded and Eq. (1) is then solved for κ, the temperature change constant.

Once κ is determined – and it usually takes about two minutes – the students are required to predict the coffee's temperature at the ten minute mark. The very accurate prediction appears on their calculator displays with about thirty seconds to spare. The quantitative sciences always win a convert or two after this experiment!!

The presence of a lid for the coffee cup appears to make the cooling conditions somewhat less than true-to-life. It is important for one to realize, however, that lidless heat loss is achieved through the action of two processes: Newtonian cooling (predominantly convection from the surface) and evaporation.[12] The rate of convective cooling is proportional to $(T - T_s)^n$, where T and T_s are as previously defined and n is *not generally* equal to 1. For natural convection (i.e., the situation in lidless cooling) n ranges from 1.3 to 1.6[13]; since our mathematical modeling assumes that the cooling is directly proportional to the temperature difference, that is $n = 1$ [see Eq. (2) below], it cannot accurately describe the temperature decrease. The lid insures that the coffee will *not* cool by convection or evaporation, and so Eq. (1) becomes an effective temperature predictor. [It should be pointed out that Eq. (1) can also describe the temperature slide of a lidless cup under *forced* convection, since in that case $n = 1$].

I have described an obscure yet potentially very flexible experience in first-year physics. This experiment can be beneficial to several different types of students. As described above, it allows students in an algebra-based course the opportunity to observe a decay similar to that of a radioactive substance and to "tone up their natural log muscles." The experiment could also serve as an introduction to differential equations for more advanced students. Expressing Newton's cooling relation quantitatively we have

$$\frac{dT}{dt} = -\kappa(T - T_s) \qquad (2)$$

With this equation as a starting point, one could demonstrate the basic techniques for the solution of this typical first order differential equation. Solution of this equation results in the appearance of Eq. (1). Rush the students to the coffee machines and then into the lab where Eq. (1) can be examined empirically. The result of this attack gives your students a glimpse of the relationship of physics to reality. Finally, students with computer science backgrounds could probably devise some graphic and intriguing offshoots.

I should point out a possible "negative" aspect of this experiment. Students who eventually go from this lab experience into the American labor force, may very well form the tough core of a militant work-schedule revision movement. After all, they will be well aware that management has been short-changing labor for years: ten minutes is definitely not enough time for a coffee break!!!

References

1. R. Edge, Phys. Teach. **17**, 466 (1979).
2. A review of 12 standard first-year texts, which included the familiar books by Franklin Miller, Sears and Zemansky, and Harvey White, revealed that 8 texts did not mention the cooling law.
3. F. Bueche, *Principles of Physics*, 3rd edition (McGraw-Hill, New York, 1977) p. 267.
4. L. Greenberg, *Physics with Modern Applications* (Saunders, Philadelphia, 1978) p. 154.
5. D. Halliday and R. Resnick, *Physics*, 3rd edition (Wiley, New York, 1978) p. 471.
6. G. Shortley and D. Williams, *Elements of Physics*, 5th edition (Prentice-Hall, Englewood Cliffs, New Jersey, 1977) p. 328.
7. R. Agnew, *Differential Equations*, 2nd edition (McGraw-Hill, New York, 1960) pp. 77-79.
8. M. Boas, *Mathematical Methods in the Physical Sciences* (Wiley, New York, 1966) p. 357.
9. W. Boyce and R. DiPrima, *Elementary Differential Equations and Boundary Value Problems*, 2nd edition (Wiley, New York, 1969) pp. 59, 479.
10. E. Rainville, *Elementary Differential Equations*, 3rd edition (Macmillan, New York, 1964) pp. 47-49.
11. P. Ritger and N. Rose, *Differential Equations with Applications* (McGraw-Hill, New York, 1968) pp. 77-79.
12. G. Kell, Am. J. Phys. **37**, 564 (1969).
13. T. Brown, ed., *The Taylor Manual of Advanced Undergraduate Experiments in Physics* (Addison-Wesley, Reading, Mass., 1959) p. 115.