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Response to Penn's "Comment on Pictet's experiment"

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[12]E. Lindelöf, *Le Calcul des Résidus et ses Applications à la Théorie des Fonctions.* (reprinted by Chelsea, New York, 1947), pp. 78 and 79.
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COMMENT ON PICTET'S EXPERIMENT

The very interesting paper, "Pictet's experiment: The apparent radiation and reflection of cold,"[1] concludes with a modern explanation of the effect illustrated in its Fig. 1. It is not evident how this explanation accounts for the experimental observation that "if, instead of being placed directly in the focus, the thermometer was displaced a short distance to the side, the cold body ceased to exert its former cooling power." In the extreme, how would the authors' explanation change if the cold object *C* or the left-hand mirror *A* were entirely removed? I do not get it.

S. Penn
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235 East 42 Street
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2 August 1985

[1]J. Evans and B. Popp, Am. J. Phys. **53**, 737 (1985).

RESPONSE TO PENN'S "COMMENT ON PICTET'S EXPERIMENT"

I believe that the paradoxical nature of the apparent radiation and reflection of cold stems from our habitual neglect of exchanges of radiant heat with the environment. Let us take up the question of the placement of the thermometer.

If a hot object were at focus *C*, one would expect its influence to be most plainly demonstrated when the thermometer was placed exactly in the conjugate focus *D*. If the thermometer were displaced from *D*, it would cease to receive the reflected radiation from the hot object. This is a change that we never overlook. There is, however, a second change that occurs simultaneously and that usually goes unremarked: When the thermometer is displaced from *D*, it begins to receive *more* radiation from the other objects in the room. (When the thermometer was at focus *D*, it was shielded from these objects by the mirrors.) The loss of the high-temperature radiation from *C* more than offsets the gain in lower-temperature radiation from the environment, so the level of the thermometric fluid indeed falls. The role of the ambient radiation is usually neglected in explanations of the focusing of radiant heat, with—so it appears—no harm to the explanation. In the case of the apparent focusing of cold, however, the ambient radiation cannot be neglected.

Let a cold object be at *C*. The thermometer, at focus *D*, has descended to a certain level, where it remains stationary. Let the thermometer now be displaced from *D*. The thermometer begins to receive less radiant heat from *C*, but more radiation from other objects in the room (because of the diminished shielding effect). The gain in high-temperature ambient radiation more than offsets the loss of the low-temperature radiation from *C*, so the level of the thermometric fluid rises. The effect of the removal of the cold object, or of mirror *A*, may be explained in a similar way.

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LIMITLESS NUMBERS OF MULTIPLE-CHOICE PROBLEMS

In our elementary physics courses, we structure the students' study time by requiring them to do large numbers of homework problems. After we heard of the favorable results obtained by Hudson,[1] we developed ways to use multiple-choice problems for homework, in addition to using them in quizzes and tests. Typically, during each semester we assign 40 homework sets of ten problems each. The students report their homework answers on cards that are read by machine and graded by computer. Thus we need about 400 multiple-choice questions for homework alone, plus about 150 more for quizzes and tests. To avoid tempting the students to copy or memorize the answers from earlier semesters, we need to generate about 550 multiple-choice physics problems each semester.

This letter concerns the production of homework problems. We expect to report our progress on techniques for developing quiz and test problems at a later time.

We take a homework problem having a numerical answer from some textbook and turn it into a multiple-choice problem by asking the students to find the *second significant* figure in the answer. The machine-readable answer cards require the student to mark A, B, C, D, or E as the answer. If the second significant figure is 0 or 1, the student marks A, if 2 or 3, the student marks B, and so on. We use the second significant digit because it requires more care to find it than the first digit, and because there are ten possible second significant digits but only nine possible first significant digits.

From one such problem we generate another problem requiring the same skills to solve by instructing the students to change the value of one parameter from the text's value to that set by the professor. The second significant digit in the answer usually changes as a result, so the students cannot accurately guess the correct response. The process may be repeated each semester by further changes in the same (or a different) parameter.

There are advantages to assigning such problems for which answers are in the text or are otherwise known to the students. Students who are confident in their skills work only the revised problems to get credit. Students who are unsure of their methods work the problems twice, first as stated in the text to see whether they get the text's answer, then with the revised parameters to obtain homework credit.

To provide an incentive sufficient to persuade the students to do such a large number of homework problems, we normalize each student's homework score to be equivalent to one examination (or which there are usually four during the semester), and replace each student's lowest examination score by the normalized homework score if the latter is higher. We also give weekly optional multiple-choice quizzes whose scores are added to the homework scores. Thus each student knows that with steady effort, he will have at least one perfect "examination" score. (Superachievers have this score truncated at 100%.) The motivation appears to be effective. In an initial class of 350 students, 300 of them still hand in ten homework problems three times per week by the tenth week of the semester, and of all the students receiving final grades, 90%–