Fermi Questions

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His concern is apparently with the use (or name?) of the slug of the gravitational system, a unit seldom used outside of these courses. His remedy: to use freely the pound-mass unit and, when necessary in dynamic equations, to use it with a proper conversion factor, the combination having the units of lb-sec²/ft. The student is not to be told that this is the slug!

This is, in my mind, hardly a cure. It would merely compound the confusion and make it difficult to teach units in a consistent way. The situation has its counterpart in the mks system when in the beginning laboratory, for instance, we use "weights" calibrated in grams and give the resulting forces the units of grams (or gram-forces). However, this is usually a temporary laboratory expedient so that later the gram-force is ordinarily converted to the dyne for the sake of consistency and/or correctness. Here the dyne is called by its proper name and not by its definition, the gram-cm/sec².

Why treat the slug differently? I see no objection to using the pound-mass when it is convenient to do so much as we use the gram-force for convenience. But why not also use the slug in all other situations? The use of this unit, as in the case of the dyne, helps the student unravel the mystery that seems to accompany the double meaning of the pound (and the gram). We should at least be consistent.

For those of us who insist on doing something about the problem of the archaic English units, the solution is too obvious. Of course, some of our engineering friends may not appreciate our ignoring the units they are forced to live with. Perhaps we can get around this by taking the budding engineers aside and teaching them in private all the facts of English life.

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[1] F. T. Worrell, Am. J. Phys. 31, 305 (1963).

The Slug? PTUI!

PROFESSOR Worrell's letter[1] on the elimination of the abominable slug is certainly welcome, but I would argue that he does not go far enough in killing the beast. He says that the slug was invented for a good reason ". . . to complete a coherent system of units." Later he notes that "ideally" we would like to use either the slug and the pound mass or the poundal and the pound force in Newton's Second Law. There is nothing good, coherent, or ideal about the slug and even this slight temporizing only prolongs its life and comforts its supporters. Newton's Second Law should be written;

$$F=m(g/g_c), \qquad (1)$$

where F is in pounds force (lb_f), m is in pounds mass (lb_m), g is the acceleration due to local gravity and g_c is a conversion constant of size 32.2 (lb_m ft/sec², lb_f), fixed in value everywhere in the universe. Is this so confusing to a student? Not if the instructor points out that g_c is exactly the same as J(ft-lb_f/BTU), 12 (in./ft) and all the other conversions that he has been using since fourth grade. Why don't the slug-enthusiasts invent a new unit of heat in the English system to replace the BTU, and call it the Pound Thermal Unit Improved (PTUI) to achieve that all important consistency? Thus, one ft-lb_f equals one PTUI.

But there is much more to Eq. (1) than just dropping the slug. When Newton's second law is written in this form, the student is never again bothered by such questions as these:

(A) When local gravity is 32.0 ft/sec², what does a spring scale read with 1 lb_m in the pan?

(B) The specific weight of an insulating material is 13 lb_f/ft³, and it has a specific heat of 0.5 BTU/lb_m °F. On a planet having $\frac{1}{6}$ the gravitational attraction of earth how much energy is required to raise 1 ft³ 10°? (The student's instant question should be, of course: Where was the specific weight figure taken?)

(C) A viscosimeter reading in units (lb_f sec/ft²) is used with an oil specimen on the moon and then on the earth. Will the readings be different and, if so, which is larger?

In our junior engineering thermodynamics course we must break the slug habit. Students with the usual $F=mg$ under their belts find such short quiz questions as these rather longer than the time allotted. They seldom locate a rational approach because they cannot quickly see how to introduce the all-important local g. Thus, far from being coherent, the slug-lb_f method only obscures the essential truth. Of course, the sluggers say that all would be well if only tables and texts and the whole engineering complex would just change to slugs. True enough, but our young men must design and build in the real world of lb_f and lb_m. The (g/g_c) notation is clear and powerful and by the end of the semester our juniors have entered the space-age universe of variable g problems without qualms. And this is certainly fortunate because in the second semester we must undertake fluid mechanics and its essential handmaiden, dimensional analysis. To do this topic with the primary dimensions lb_f, slugs, and seconds is something I for one would not care to even think about.

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[1] F. T. Worrell, Am. J. Phys. 31, 305 (1963).

Fermi Questions

THE thoughtful recommendations of the Second Ann Arbor Conference are bound to have a strong effect on the training of physics majors for years to come.[1] For this reason, I think it important to bring out that the authors of the report themselves remind us that there are pitfalls in the way of designing a curriculum solely from any list of texts and topics, valuable as that list can be. The key paragraph occurs in Sec. II of the Recommendations, immediately before the subheading "Curriculum R." I should like to echo, indeed, to amplify, their paragraph. For that purpose, I append a paragraph or two of my own which I hope may aid in realizing the intent of this part of their helpful Recommendations.

It is by no means possible to specify the training and readiness of a prospective graduate student by a mere list of topics. There is a kind of power over the theoretical and experimental studies in which he has engaged which is difficult to define, but whose presence is perhaps more important than much knowledge which is more formal and complete. There is one test for such power which is at the same time a remarkably apt method for its development. That is the estimation of rough but quantitative answers to unexpected questions about many aspects of the natural world. The method was the common and frequently amusing practice of Enrico Fermi, perhaps the most widely creative physicist of our times. Fermi delighted to think up and at once to discuss and to answer questions which drew upon deep understanding of the world, upon everyday experience, and upon the ability to make rough approximations, inspired guesses, and statistical estimates from very little data. A few samples are indispensable:

How much does a *watch* gain or lose when carried up a mountain?

How many piano tuners are there in the city of Chicago? (These are authentic Fermi questions from the source.)

A few more of Fermi type:

What is the photon flux at the eye from a faint visible star?

How far can a crow fly?

How many atoms could be reasonably claimed to belong to the jurisdiction of the United States?

What is the output power of a firefly, a French horn, an earthquake?

Such questions can of course be found for nearly any level of education. It should go without saying that no such question fulfills its purpose unless it is being heard for the first time. The accumulation of confidence and skill which such answers bring is a very good apprenticeship to research. Indeed, the conception of experiments and the formation of theoretical hypotheses are activities which are well simulated by asking and answering good Fermi questions.

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[1] Am. J. Phys. 31, 328 (1963).

Physical Geometry—Reply to Criticism

RECENTLY,[1] Professor G. Schlesinger has criticized my article "On Physical Geometry."[2] I wish to show that his criticism is not on secure ground because both of his objections are based on misinterpretations.

In his first objection, Professor Schlesinger quotes my question "Why do universal forces, which according to their definition affect all materials in the same way, not affect the plane E?" and continues: "What he intends to imply by this question is, that obviously we cannot admit that indeed the plane itself too is affected, for then we would be back where we were before the introduction of universal forces." Now, I certainly did not mean to imply what Professor Schlesinger suggests. On the contrary, I have stated clearly in my article (see p. 593) that "we must allow the universal forces to affect the plane E also because it is a material object." When this is drawn into consideration, Professor Schlesinger's first objection becomes meaningless.

In his second objection, Professor Schlesinger deals with a physical situation which is quite different from the one which I have discussed in my article. When I say "Let us imagine that a geometrical figure, for example the circumference of a circle and one of its diameters, is laid out on the plane E," then this plane E is meant to be Reichenbach's plane E, i.e., a real two-dimensional plane in a three-dimensional space. Of course, the two-dimensional inhabitants of this plane do not know whether their space is a plane or not, but a three-dimensional observer does. When Professor Schlesinger says that "we may deduce that originally E was a curved surface of constant positive curvature," he shifts to a different physical situation. The experiment which he now discusses begins with a curved surface in three-dimensional space whereas my experiment begins with a plane in three-dimensional space.

Professor Schlesinger, in his second objection, tries to ignore the fact that a three-dimensional observer can always determine the shape of a two-dimensional object in his three-dimensional space by means of physical measurements. We ought to realize, however, that all our discussions about the influences of universal forces on the geometry of a physical space—including Reichenbach's discussion—are meaningless when the physical space in question is not embedded in a higher-dimensional physical space and when it consequently cannot be observed by a higher-dimensional observer. Professor Schlesinger himself gives an instructive example in his second objection. One finds there the following two statements: (1) "it is true that people confined to a given surface are oblivious to any changes in the universal forces," (2) "there is a definite difference between the case where a variable universal force is acting along a given surface and where no such force is acting—given the selfsame surface." These two statements contradict each other when both are made by a two-dimensional physicist. The contradiction disappears only when a higher dimension is drawn into consideration, i.e., when at least the second statement is made by a three-dimensional physicist. Since Professor Schlesinger makes use of the three-dimensional observer, at least implicitly, he must allow me to do the same when I distinguish a physical experiment which begins with a plane from an experiment which begins with a curved surface. Professor Schlesinger thus has no right to say that my "error consists in the assumption that the plane E along which a variable universal force is now acting was also a plane before this force was switched on."

The reader may finally compare the following two extracts from Professor Schlesinger's second objection: (1) "if originally we were given a plane and subsequently switch-on a variable universal force the plane will buckle and become a curved surface but the two-dimensional people confined to it will still get the results of plane geometry because of the corresponding changes which occur in their transported measuring rods. In other words it is true that people confined to a given surface are oblivious to any changes in the universal forces which affect them since the effects of these forces upon their measurements are always compensated by the accompanying changes in the geometrical character of the surface." (2) "if we are confined to a plane which is free from the effects of any