## letters

reference in his field of view during the sighting.

Taylor's objection to my estimate of the "angular resolution of the eye as one second of arc" is correct. The statement should have read "one minute of arc" and a quick calculation proves my intent. It was simply a typing mistake. I chose a value of one minute because it is easy to extrapolate to larger angles. I am aware that four minutes, for example, would have been a more realistic choice. I might point out that the value "one minute" appears in many elementary physics texts.

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### Novelty vs. profundity

As a physician who has actively worked in theoretical biophysics for approximately 15 years, I would like to respond to Carlton Frederick's letter (May, page 15). I believe today's physicist is *brighter* than he has ever been. Both the subject of physics and the total culture, particularly our own, have had an immense increase in complexity since the 1930's, and simply meeting this greater demand has pushed (or pulled) intellectual development further. One has merely to read the influential texts of this earlier period and note their simpler, more pedestrian outlook to see this. What has happened, I agree, is that this complexity has fostered the over-specialization of career and placed the super specialist in a position of excessive influence by rewarding novelty on an equal footing with profundity. Since it is much easier to achieve a result with some novelty than one that is both novel *and* profound, the novelists proliferate at a far greater rate than the profounders.

In the past the physicist of note was almost invariably a man who had mastery of the entire subject, and either a profound innovator or one who had every possibility of being such. These men set the tone and character of physics forty and more years ago and continue to inspire the student of today. The contemporary physicist of this stature, however, may very well be a "profounder profounder," that is to say *profounder squared*.

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### Materials science courses

The fine summary of the Conference on "Tradition and Change in Physics Graduate Education" held on our campus last summer, failed to make one point which is of importance to the academic physics community: The mismatch in the thesis topics with employment fields was clearly identified. However, not enough attention was paid to the fact that physics faculties must face the issue of defining the optimum *course work* for undergraduate as well as graduate students. As it turns out now, a typical student in electrical engineering or materials science has a good grasp of the fundamentals of quantum mechanics and solid-state physics, while their colleagues in physics have *typically* not had a single course in materials science or electrical engineering. Since the materials field (broadly defined) is likely to employ perhaps half the physicists produced in the near future, I believe that the report of the National Academy of Sciences Committee on Materials Science and Technology[1] bears serious consideration by every physics department, when it says:

"We believe that materials science will play an increasingly significant part in the education and work of physical and life scientists, as well as of engineers and technologists."

A 3–6 credit requirement in materials science (or biophysics or geophysics) may be the test of the physics community's commitment to change and the translation into real life of its concern for "applied physics."

#### References

1. Materials and Man's Needs. Summary Report of the Committee on the Survey of Materials Science and Engineering. N.A.S. Washington, D.C. 1971.

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### Predicting earthquakes

Your April issue (page 74) carries a review by Bruce Bolt of *The Jupiter Effect* by Stephen Plagemann and myself in which, following a sound precis of our arguments, he notes that "California records . . . indicate that 1803 or thereabouts was not specially active" in seismic terms, although that was the last occasion of the planetary alignment discussed in our book. This is incorrect; since the book appeared, I have visited the region of the San Andreas just south of San Francisco, and this visit included the mission of San Juan Bautista, which suffered greatly during the 1906 earthquake. The mission records describe a series of major tremors in that area in the early 1800's, and although this proves nothing it is clearly of interest to our hypothesis. Plagemann and I have included a discussion of these records in the paperback edition of the book, which should now be available, and the discussion will also appear in future hardback editions.

Perhaps I could also take this oppor-

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tunity of redirecting the emphasis that reviewers of *The Jupiter Effect* have placed on the planetary-alignment hypothesis. The essence of our study is that more seismic activity is likely *at times of maximum solar activity;* the planetary-influence model is the only one we know of that makes firm predictions about when the next solar maximum will be, and we therefore included one chapter about this for completeness. Even should that model prove incorrect, however, there remains good evidence that the years around the next solar maximum will produce enhanced seismic activity. Since just adding 11 years to the previous maximum suggests that the next peak is due in 1979, the planetary hypothesis might be seen as unduly optimistic, suggesting as it does a further three years of grace. Finally, I fully endorse Bolt's warning that "buildings should be constructed to resist great earthquakes on the assumption that they will occur tomorrow." The presentation of our ideas in the form of *The Jupiter Effect* was exactly to encourage such an attitude among those who have been less aware of the need for caution; I hope that your readers, who clearly do not need to be warned in such dramatic terms, will make appropriate allowance for that presentation and may be interested in the original exposition of these ideas,[1] which drew remarkably little response.

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## Flywheel energy storage

Due to the increased interest in storing energy with flywheels, the reader is reminded of the virial theorem, which predicts the maximum energy that can be stored in the structural mass of a flywheel. This is a "measuring stick" that can be applied to any flywheel design; in general, the theorem predicts the best use one can make of a given material.

Originally derived by Clausius in 1870,[1] the virial theorem applies to gases, plasmas and all mechanical devices including flywheels. A similar theorem applies to electromagnetic systems including superconductive energy storage magnets.[2,3,4,5]

The virial theorem relates the time-average kinetic energy of a system of particles to the time-average forces acting on those particles, and a little manipulation from the standard form of the theorem yields, for rotating bodies, the result

$$M_s \geq 2\rho_s T/\sigma \qquad \text{(uniaxial stress)}$$

$$M_s \geq \rho_s T/\sigma \qquad \text{(biaxial stress)}$$

where $M_s$ is the structural mass and the volume of the load-carrying material is $M_s/\rho_s$. The equalities in the equation can be approached in certain specialized cases. A thin spinning cylinder has minimum mass for uniaxially stressed structures, while a disc that is thick near its center[6] can approach the biaxial limit.

Anyone considering the economic feasibility of flywheel energy storage should measure their design against this theorem. Depending on the structural materials used, it places an absolute minimum on the cost per unit of stored energy.[5] In MKS units, that is

$$\text{cost/joule} \geq (\text{cost/kg})\, 2\rho_s/\sigma \qquad \text{(uniaxial stress)}$$

$$\text{cost/joule} \geq (\text{cost/kg})\rho_s/\sigma \qquad \text{(biaxial stress)}$$

These relationships have long been known[6,7,8] but seemingly have not been used to pinpoint correctly a major obstacle preventing the use of flywheels. This is, of course, the basic materials cost of flywheels. For example, steel at $6.9 \times 10^8 \text{N/m}^2$ (100 000 psi) should cost less than 31¢/kg fabricated to be used in a storage unit with a ten-hour discharge time for the electric utility industry. Lighter weight epoxy materials at 100 000 psi should cost less than 63¢/kg fabricated for ten-hour use. In addition, there are the costs of the bearings, clutches, motor-generators and containment housings. The basic materials costs above are independent of flywheel design details. Regardless of other costs, the one derived from the virial theorem may make flywheels prohibitively expensive for applications such as diurnal energy storage with ten hours of energy discharge. Flywheels could become more competitive with the development of new strong inexpensive materials.

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8. R. F. Post, S. F. Post, Scientific American, December 1973, page 17.

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