in these equations are correct. We think it is necessary to examine Keller's theory in this light.

Keller bases his model on two equations: an "equation of motion," equation 2, and an "equation of energy or oxygen balance," equation 5. Equation 2 is Newton's second law of motion applied to the runner. It contains a force term, $f(t)$, defined as the "total propulsive force per unit mass exerted by the runner, part of which is used to overcome the internal and external resistive force, $v/\tau$," where $\tau$ is a damping coefficient and $v$ the velocity of the runner. This force is not the force exerted by the runner on the track (otherwise it would have to overcome external resistance only) but is an "internal" force conceived as the resolution (obtained in some way) of forces active at the muscle-fiber level. Clearly neither this force nor its associated damping coefficient can be measured. Equation 2 is therefore operationally ambiguous. However, $f(t)$ appears also in equation 5, from which perhaps its operational definition can be inferred.

Equation 5 follows from the author's energy principle, which he states as follows: "the rate, $fv$, of doing work per unit mass must equal the rate at which the body supplies energy." But this statement is wrong because it ignores heat transfer between the runner and the atmosphere, which is not negligible. In fact, Lehninger[1] estimates that this heat is about three times as great as the work done. However, perhaps Keller means *free* energy rather than energy. If so his statement is still wrong since it now ignores dissipation (maximum possible work rate less actual work rate), which is not negligible. In one step alone in the conversion process of free energy into work about 50% of the available free energy is dissipated. This step is the phosphorylation of ADP into ATP.

The only way for equation 5 to be correct (and thus provide a definition for $f$) is for $fv$ to be the *maximum* power obtainable from the metabolic process; that is, the power output from a *reversible* (hence fictitious) muscle machine. Let us temporarily assume that this is the definition intended for $f$ and pursue the consequences of this assumption. Keller assigns $f$ the maximum value $(F)$ of 12.2 newtons/kg. Thus at 8 meters/sec, $Fv$ for a 70-kg runner is about 7000 watts. The question now is whether or not work physiologists would accept this number. The answer is probably no. Schmidt-Nielsen,[2] and others, estimate the cost (in metabolic free energy) of running to be roughly 50 kcal/km for a 70-kg runner. At 8 meters/sec, this corresponds to a power of 1600 watts. Thus $fv$ cannot be interpreted as the maximum power obtainable from metabolic free energy, and we therefore see no way for equation 5 to be correct.

We are forced to conclude that the "success" of Keller's theory is not a result of good physiological modeling.

### References


1. A. Lehninger, *Bioenergetics*, Benjamin, New York (1965).
2. K. Schmidt-Nielsen, Science **177**, 222 (1972).



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As a track fan I read with interest the article about running records, by Joseph Keller. Discrepancies of 3% are reasonable in many fields, but comparing a 3:57 mile to a 26:54 10 000 meters will shock any follower of the sport. I like to point out that the world records for running, from 400 m to the marathon, display a rather simple mathematical relationship. If the speeds and distances are plotted on judiciously selected co-ordinates the form is seen to be

$$S = a - b \log D + cD^{-k}$$

where $S$ is the average speed in m/sec and $D$ the total distance in meters. By eyeballing the curves I have chosen the constants to be: $a = 9.63$, $b = 0.9$, $c = 1.5 \times 10^4$ and $k = 1.5$. These yield the following times for the Olympic distances (with the current world bests in parentheses): 400 m—43.7 (43.8), 800 m—1:44.2 (1:43.7), 1500 m—3:33.4 (3:33.1), 5000 m—13:08.3 (13:13.0), 10 000 m—27:34.3 (27:30.8), marathon—2:08:33.9 (2:08:33.6). The maximum discrepancy is 0.6%.

The $a - b \log D$ term is associated with the rate of oxygen replacement and suffices in calculating records for the longer distances, from 5000 m to the marathon. The $cD^{-k}$ term describes the depletion of the initial oxygen reserve. I have no opinion how the above formula may be derived from basic physiological quantities, but closeness of fit and simplicity of form argue that a workable theory will have to be consistent with it.


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## God exists?

The proof of the existence of God offered by Michael Mendillo and Richard Hart (February, page 73) would appear to settle this matter. We have here a mathematical proof that a widely ob-

*continued on page 70*

## letters

*continued from page 15*

served phenomenon, exactly total eclipses, is a miracle, and hence that God exists. No doubt as soon as this news seeps down to all those people who do not read PHYSICS TODAY, skeptics will become an endangered species. Theologians who claim that God is dead are premature in their judgment.

I see only one slight blemish. Arguments based on conservation of angular momentum and the mechanical energy loss arising from tidal action have established that the Earth-Moon distance is increasing by about five inches per year. This means, by the Mendillo–Hart formula, that the eclipse ratio is decreasing. In fact, the time in years, $Y$, required to reduce the eclipse ratio $E_r$ to $E_r'$ is given by

$$Y = (D_m/\dot{o})[(E_r/E_r')^{1.2} - 1]$$

where $\dot{o}$ is the increase in distance each year. When $E_r'$ is equal to 1, we will have no more exactly total eclipses. When we put in the present maximum value of $E_r$, which is 1.09, and the other numerical data, the formula says that after $1.3 \times 10^8$ years there will be no exactly total eclipses.

Now to my question. Could skeptics possibly be mean enough to conclude that the existence of God will be terminated in a paltry 130 million years?

There is another consideration that I find bothersome. The lower limit on the eclipse ratio is 0.82. If one puts this number into the above formula, one finds that there were no exactly total eclipses until about two hundred and eighty million years ago. Is there a danger that someone might infer that God did not exist until 280 million BC?

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It is always interesting to read another "proof" of the existence of God. Unfortunately, the proof offered by Michael Mendillo and Richard Hart contains errors even more severe than the usual logic errors associated with such proofs. In this case the fundamental theorem advanced by the authors, that the phenomenon of an exactly total solar eclipse is unique in our solar system, is incorrect. Because of the peculiar circumstance that the orbit of Pluto passes within the orbit of Neptune, exactly total solar eclipses may be viewed from either planet while the other planet serves as the occluding body. Admittedly, these circumstances are extremely rare, but such eclipses will occur.

If this added piece of data is now incorporated into the logic structure of Mendillo and Hart's original proof, the necessary modifications lead to some rather surprising conclusions. Since it follows that there must be observers to witness an exactly total solar eclipse, extraterrestrial life will be found to exist on both Neptune and Pluto. In addition these beings will have extremely long life spans in order to observe even one such eclipse. Quite remarkable. Maybe someone should tell NASA.

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### Pauli's proof

It may be useful to clarify a point in my recent review of P. Dennery's *An Introduction to Statistical Mechanics* (February, page 48). Due to exigencies of space, a paragraph was cut out of the review when printed. This paragraph made clear that the whole master-equation discussion was based on Pauli's original "proof," which simply *asserted* the justifiability of using the random phase approximation. That approximation has good physics behind it, but needs to be considered in detail. It is the lack of any such discussion that I find unsatisfactory in Dennery's text, not the general approach of starting from the master equation.

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### Problem-solving courses

I could not agree more with Paul Tannenbaum's letter (March, page 13). The fundamental difference between the physicist and the engineer or applied physicist can be described by saying that the physicist studies semiconductors because they interest him, the engineer because they are used to make transistors. Initially, their research may be very similar, but ultimately they will diverge because of their differing motivations.

This Fall, I shall be initiating the physics curriculum at Verrazzano College in Saratoga Springs, New York. We intend to have a strong science program. Guided by considerations like those Tannenbaum discusses, we have decided that the curriculum will be, basically, applied physics (with options to specialize somewhat in optics or lasers and astrophysics).

For the second year, I plan a course tentatively called "Methods of Applied Physics." The course will follow roughly the lines of a similar venture (required of all engineering students) with which I was associated for three years at Rensselaer Polytechnic Institute.