herent models for the origin and evolution of the Moon and other terrestrial planets.

The lunar programs have conclusively proven the value of continuing scientific research after the cessation of a major flight program such as Apollo. Most of our understanding of the Moon has been achieved since the last Apollo flight. I will be glad to supply further information to readers interested in participating in any of these programs.

EDWARD A. FLINN
*Deputy Director, Lunar and Planetary Programs*
*National Aeronautics and Space Administration*
*Washington, D.C.*

## Engineering physicists

I would like to add to the discussion of the relevance of physics to training for the engineering profession. (See the letters of T. G. Stinchcomb and C. E. Riedel, January, pages 95 and 96).

At the University of Oklahoma we have trained engineers with a major in physics for over 50 years. The degree is called "Engineering Physics" and granted by the College of Engineering. The major department faculty is Physics and Astronomy which, incidentally, is a part of the Arts and Sciences College. Physics course requirements are comparable to those of the non-engineering physics major.

Employment is in a wide range of industries, which include the chemical, petroleum production, refining, electronic, nuclear, computer, electric machinery, automotive, aerospace, energy services, optical, steel manufacturing and processing industries.

The fundamental motivation of engineering physicists is problem solving. As engineers they work more directly with physics as a basic tool than any other kind of engineer and because of this are

- pioneers—they often work in areas not widely developed,
- versatile—they work on a variety of problems that span all engineering fields,
- communicators—they speak the language of other engineers and scientists and assist engineering group efforts.

The engineering physicist with a broad training in the fundamentals of physics can choose a specialized area of work after a broad exposure to several problem areas. He or she can change the area as the needs of society change.

ROBERT M. ST JOHN
*University of Oklahoma*
*Norman, Oklahoma*

THE AUTHOR REPLIES: Robert St John refers to the letter of Charles Riedel and myself as discussing "the relevance of physics to the training of persons entering the *engineering* profession." Riedel's letter talks about physicists obtaining jobs by describing themselves as engineers rather than physicists. To me it seems that he almost proposed their disguising themselves as engineers. St John's letter discusses the employment of *engineers* who have as their speciality "Engineering Physics" rather than one of the other specialities. His main point appears to be that these graduates are "*bona fide*" engineers and need no disguises. My letter, on the other hand, discussed the employment of baccalaureate physicists from physics departments in colleges of arts and sciences. Most of these departments are not related to colleges of engineering. My main point was that if the physics community in the United States is interested in the survival of these physics departments, it should increase by orders of magnitude its concern and its efforts to match the training of these baccalaureate physicists with jobs available in the *physics* profession. The physics community needs to identify and develop a large group of baccalaureate positions that are fully recognized, not only by the physics community, but also by society at large, as an essential part of the physics profession. It may well be that engineering physics should be a significant member of this group, but many other equally significant members are needed also.

St John states further in his letter, "Physics course requirements are comparable to those of the non-engineering physics major." This implies an equivalency between the two curricula, which I would like to question in two ways: Do graduates of both curricula who seek employment at the baccalaureate-degree level have the same degree of success as measured by the number of job offers, starting salary, and so on? (St John may be able to provide us with such statistics from the placement service of the University of Oklahoma.)

Do graduates of both curricula who seek to enter graduate study in physics, both at the University of Oklahoma and elsewhere, have the same degree of success as measured by the absence of make-up courses, by the percentage obtaining teaching and research assistantships and the percentage obtaining fellowships, and so on? If the answer to both questions is a definitive affirmative, then the equivalency must be more than an implication. It must be a fact, which could benefit all baccalaureate physics graduates to the extent that their major is similar to that at the University of Oklahoma. The physics community should then make sufficient effort and publicity to convince engineering personnel managers that it is very much to their company's advantage to consider

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## letters

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physics baccalaureates from colleges of arts and sciences unrelated to engineering schools.

T. G. STINCHCOMB
*De Paul University*
*Chicago, Illinois*

## Help wanted

The purpose of this letter is to request information regarding the relationship between a concept frequently called *duality* in lumped-constant physics and the continuum formulations of physical laws. The underlying motive to the query is to determine whether there is a more symmetrical formulation of Maxwell's equations than the traditional ones. More specifically: Can Maxwell's equations be formulated in such a way that there are no blanks that tempt one to insert magnetic charge and current? This question was recently addressed to the Forum section of the IEEE *Spectrum*. A handful of responses was received, none of which were satisfying. With a world-wide readership, this is surprising.

First, the meaning of the term "duality," in the present context, must be explained. In lumped-constant circuit theory there is a transformation that may be performed on circuits, equations and statements, which we will refer to as the *dual transform*. This transform is its own inverse. A partial listing of dual-transform pairs is given in the table. The transform has the property that, if a statement is valid for a given circuit, then the dual of that statement is true for the dual circuit. Another property is that the five laws of circuit theory (Kirchhoff's current and voltage laws plus the $V$–$i$ terminal relations for inductance, resistance and capacitance) transform into themselves, but in a different order.

The same principle obtains in lumped-constant mechanics. Here, Kirchhoff's laws are replaced by "Newton's force and velocity" laws. The former says that the sum of forces (including inertial forces) into a mechanical node is zero. The latter says that the sum of relative velocities between "terminals" of mechanical components around any closed path is zero. The terminal relations for $L$, $R$ and $C$ are replaced by those for mass, dashpot and spring. These five relations also transform into themselves, but in a different order.

The following two equations are Kirchhoff's laws in point form.

$$\nabla \times \mathbf{E} + \frac{\partial \mathbf{B}}{\partial t} = 0 \qquad \text{(KVL)}$$

$$\nabla \cdot \mathbf{J} + \frac{\partial \rho}{\partial t} = 0 \qquad \text{(KCL)}$$

They strongly suggest that they are dual-transform pairs. But the remaining two equations are not obvious.

The basic question is: Is there a way to formulate the laws of continuum electrodynamics and/or mechanics in such a way that the dual transform changes them into themselves? If so, what are the continuum transform pairs? More generally, can dual symmetry replace the traditional asymmetry?

**Dual-transform pairs**

| | |
|---|---|
| voltage, $v$ | current, $i$ |
| inductance, $L$ | capacitance, $C$ |
| resistance, $R$ | conductance, $G$ |
| charge, $Q$ | flux linkage, $\lambda$ |
| Kirchhoff's voltage law, *KVL* | Kirchhoff's current law, *KCL* |
| mesh | node |
| series connection | parallel connection |
| short circuit | open circuit |
| reference node | outer mesh |
| cut set | tie set |
| tree branch | link |
| mass, $M$ | spring compliance, $K$ |
| damping constant, $D$ | (damping constant)$^{-1}$, $D^{-1}$ |
| force, $f$ | velocity, $u$ |
| Newton's force law, *NFL* | Newton's velocity law, *NVL* |

JOHN A. BALDWIN, JR
*University of California*
*Santa Barbara*

## Practical vs. real physics

In the recent past, due to the fine studies of Lee Grodzins and others, our profession has finally acknowledged that career opportunities in academia and "pure" research may indeed be finite. There is much talk about the necessity of revising curricula, both undergraduate and graduate, to prepare our students for a future in applied research and development. Prestigious committees on education and manpower have called for new courses and facilities for better preparation of a new generation of students to man the applied societal needs of the future.

Yet all these founder at their inception because of the zero-population growth status of physics faculties: There simply is no new money available to hire the new faculty to staff new programs. We seem to be hell-bent on ensuring our own demise. There *is* another way, but one which I have never seen articulated, and one which would cost essentially nothing. We should, in plain and simple words, "put our money where our mouth is"! We should *legitimize* "practical" physics by bringing the living, on-campus, examples of it *inside* the physics departments. Why, for example, are solid-state physicists largely outside the physics faculties at Harvard, Yale, Princeton, Stanford and Caltech? How can their resident physics students even meet the "applied" physicists as instructors in required physics courses or as TA supervisors in elementary courses? How can we expect some of the best of these students to aspire to careers in "practical" physics when most of the actual practitioners who could serve as role models are invisible, housed in limbo in some other department down the street?

Some departments, happily, have not opted for such segregation. As examples, Cornell and my own department have co-mingled solid-staters and other "practical" types with "real" physicists for so long that even the faculty cannot tell the difference. No one in Urbana is ashamed to have John Bardeen as a colleague! I believe other departments could do likewise, returning their distinguished, on-campus, "practical" physicists to the fold simply by a bookkeeping feat: eliminating the extraneous "departments," "programs," and "operations" which have placed such individuals in limbo and letting them take their place as living, breathing *physicists*, with no special adjectives, as an integral part of the physics-department faculties. Such a change would involve no new funds or staff positions. We might even save a few dollars by eliminating the need for different kinds of letterhead stationery! Most important, we would thereby acknowledge that practical physics *is* physics, and is worth the serious study and effort of our best students.

DAVID LAZARUS
*University of Illinois at Urbana-Champaign*
*Urbana, Illinois*

## Large Space Telescope

We read with interest your editorial in the April issue (page 96) supporting an increase in funding for nuclear energy research and the development of a Large Space Telescope by NASA.

NASA recommended to the Office of