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

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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?

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Dual-transform pairs

voltage, v	current, i
inductance, L	capacitance, C
resistance, R	conductance, G
charge, Q	flux linkage, λ
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

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.

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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