OutPost on the Endless Frontier©

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By Paul M. Grant

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Journey Down the Path of Least Resistance

Imagine our surprise when Dr. Deborah Chung, Niagara-Mohawk Professor of Mechanical and Aerospace Engineering, State University of New York, Buffalo (SUNY-Buffalo), reported July 10^{th} last via a university press release and in a keynote paper delivered to a composite materials conference in Las Vegas, that she and her group had discovered an embodiment of “negative electrical resistance.”[1] Moreover, her samples when placed in series with a normal resistor of equal positive resistance yield a net zero resistance, or, as the SUNY-Buffalo press release put it, a system “superconducting at room temperature.” This announcement was later duly reported on the wire services and briefly on CNN.

A search engine webscan on “negative resistance” will turn up a large number of hits on a trendy exercise regimen akin to “dynamic tension” popular a number of years ago. This was not the kind of effect Dr. Chung was referring to. Recall the essential nature of electrical resistance…electrons move through a metal in an applied electric field producing a current which is limited by the electrons banging against the fixed atoms of the metal, causing them to shake and produce heat. This is all expressed by the well-known Ohm’s Law, $V = I R$, with V the voltage applied, or “dropped,” I the current flowing, and R the resistance. The power dissipated by the resistance to current flow is $P = I^2 R$, where P goes directly into heating up the metal conductor in question.

What would be the consequences of R a negative number? This would imply a direct conversion of heat (not a difference in heat) into electrical energy, a violation of the Second Law of Thermodynamics, which states, among other things, that a body at constant temperature cannot produce useful work. My, my, wouldn’t that be great…we’d be out of business in a heartbeat (Incidentally, the Second Law is one of the most robust principles of physics. It has survived all the revolutions of modern physics since it was first postulated in the 18^{th} and 19^{th} centuries, and, in fact, underpinned their development. The Second Law is truly awesome, man.)

Before continuing, we need to clarify one point. There are a number of valid manifestations of “negative resistance,” but always within the differential form of Ohm’s Law, $R(V) = dV/dI$, the sometimes negative slope of V vs. I, which, however, themselves are always both positive. This kind of negative resistance is OK and occurs often in nonlinear semiconducting devices such as the Esaki diode, and can be quite useful. Many ages ago your correspondent did his Senior Thesis on an amplifier based on the Esaki tunneling diode.

Is there any way Dr. Chung could have observed a static negative resistance not requiring us to give up our beloved Second Law? The answer is yes, but following the argument will require some patience by the reader. This is one of those instances where we regret our self-imposed editorial practice of not using diagrams or drawings in *OutPost*.

The common method of measuring the electrical resistance of an unknown material is as follows: Assume the unknown to be in the form of a long, narrow bar or rod. Let's say our sample is 4 cm long by 5 mm in diameter. We solder wires on each end and connect them to a battery to cause a current to flow through the sample, e.g, the positive terminal of the battery on the left and negative on the right. Next attach two more wires 1 cm from each end of the sample, at the 1 cm point and 3 cm points, respectively. Assume for the sake of later discussion, we put the 1 cm contact on top and the 3 cm on the bottom. Got the picture? Now connect these two wires to a voltmeter, with the positive terminal of the voltmeter toward the positive terminal of the battery supplying the current. The voltage measured between the 1 and 3 cm contacts divided by the applied current, both positive in numerical sign, is then the sample resistance. This is the traditional four-probe method of measuring an unknown resistance. Nothing could be simpler, right? Wrong!

Imagine taking a little saw and cutting underneath the 1 cm contact all the way toward the 3 cm contact, but not through the sample, just along it beneath the top surface. Do the same thing at the 3 cm contact toward the 1 cm contact, again being careful to not cut all the way through the sample. What we have just done is to effectively switch the polarity of the voltage measurement without having physically moved the wire contacts or the voltmeter terminals to which they are attached. Repeat the measurement and the voltmeter now reads a negative voltage. Voila, negative resistance!

Does this rather artificial situation ever occur in practice? As they used to say in the old Red Ryder comics, "you betchum, Li'l Beaver." Your correspondent spent a good portion of his pre-EPRI days studying the physical properties of organic and polymeric conductors and superconductors. These materials were highly anisotropic in both their mechanical and electrical behavior. Crystals of such compounds would have a tendency to "exfoliate" under handling and temperature variations. Imagine a old, frayed deck of cards where the edges would open up and you sort of have the idea. Such bending of the "cards," crystal platelets in our actual samples, and you approach a close approximation of our little "saw-cuts" above. "Negative resistance" would be observed on occasion. Similar behavior would also be seen from time to time on our polymer samples, which would frequently fray and separate like bundles of straw in a whisk broom. Such spurious results could usually be mitigated by wrapping the voltage wires all the way around the sample, rather than just making point contacts, but not always. On high temperature superconducting ceramics, the samples would often develop micro-cracks under temperature excursion producing occasional "negative resistance" and sometimes an "unidentified superconducting object (see last issue of *OutPost*). The general difficulties involved in obtaining true values of sample resistance by four probe measurements in highly anisotropic and structurally weak materials have been reviewed by several workers.[2]

Was this the “phenomenon” Dr. Chung was observing? One can’t be certain, but *OutPost* believes this to be highly likely based on conversations we have had recently with her. As explained to us by Dr. Chung, she and her students have been investigating the physical properties of carbon fiber composites for some time. Carbon is a weak conductor of electricity and is frequently used as a “filler” in polymers and other dielectric materials to make them electrically conducting. Carbon, in fibrous form, will also greatly increase mechanical strength. Popular (non-electric!) applications of carbon fiber composites are in skis and tennis racquets. The Buffalo group was studying how “different curing pressures and matrix materials affected the junction between carbon-fiber layers”. The sample geometry was as follows. Consider the carbon fiber composite as a rod of bundles of straws or hay glued together, the straws or hay being the carbon fibers. Then take two such bundles and put one on top of the other in a “X” or “skull and crossbones” configuration. Connect current input leads on each end of one rod, and voltage contacts on the end of the other in a variation of the four-probe configuration just discussed. The purpose was then to observe the junction properties between the two bundles at the center point where contact was made. It is hard to imagine a more opportune geometry to yield occasional “current sneak path” effects such as we described in our simple example which would lead to “negative resistance.” Incidentally, for a given sample, the observation can be highly reproducible. Fortunately, Dr. Chung is willing to share her samples with other groups for independent analysis, so a clearer picture of the actual current paths involved should be forthcoming. She has, in addition, submitted her work for publication in a peer-reviewed journal. Finally, Dr. Chung takes issue, quite rightly, with the claim of her institution’s initial press release of room temperature superconductivity (“perfect conductivity” would have been a better term…a perfect conductor does not necessarily have to be a superconductor, although the only experimentally known perfect conductors are also superconductors. The attributes of a perfect conductor that does not superconduct are rather subtle…perhaps a subject for a future SS&T InSight article).

WARNING! Editorial comment about to begin.

The reader might wonder why today claims of extraordinary scientific advances occur before substantiation or authentication of their credibility. Traditionally, press releases, if thought warranted by scientific researchers or their institutions, occurred on the day of publication of the subject findings in a widely read, high respected, peer reviewed journal. The famous sheep-cloning report published last year in Nature is a particularly good example, and, in fact, most scientists still follow in this tradition. However, there has arisen in the last decade or so, an increase in pressure on researchers by their institutions, particularly universities, to release preliminary results prematurely without the benefit of the discipline that peer review, either by colleagues or journal referees, provides. Time-honored university tradition in support of academic freedom bestows on each individual faculty member an otherwise unusual independence from contrary views promulgated by their peers. The intense competition for government research grants and private industry investment has consequently made the temptation to hurry out presumably spectacular results difficult to resist. On the other hand, it is the practice in almost all outstanding industrial research centers, that an internal review is conducted before either submission of the work for publication or release to the general public.

In the meantime, we must wait for the final judgement of the scientific community on Dr. Chung's findings which is sure to come rapidly. Until then, *OutPost* is content that the local utility meter-reader for the SUNY-buffalo campus will continue to find it running in the usual direction. We're not out of business yet.

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[1] www.buffalo.edu/news; K. C. Cole, LA Times, July 10, 1998.
[2] L. R. Bickford and K. K. Kanazawa, J. Phys. Chem. Solids 37, 839 (1976), and references therein.