sential to explain the scaling component of approximately 0.5 for the weakly compensated case? Although there may still be disagreement, some researchers believe the answer is no. Two different calculations, both featuring the two-component model, yield $\sigma \propto k_F$, the Fermi wavevector, and $k_F \propto (E_F - E_c)^{1/2}$ for noninteracting carriers. That explanation is consistent with a Boltzmann–Drude conductivity.[5] Since $k_F = 2\pi/\lambda_{dB}$, with $\lambda_{dB}$ the de Broglie wavelength, the calculations demonstrate a second scaling length besides the ubiquitous correlation length $\xi(n)$. Those explanations were ignored by Lagendijk and coauthors.

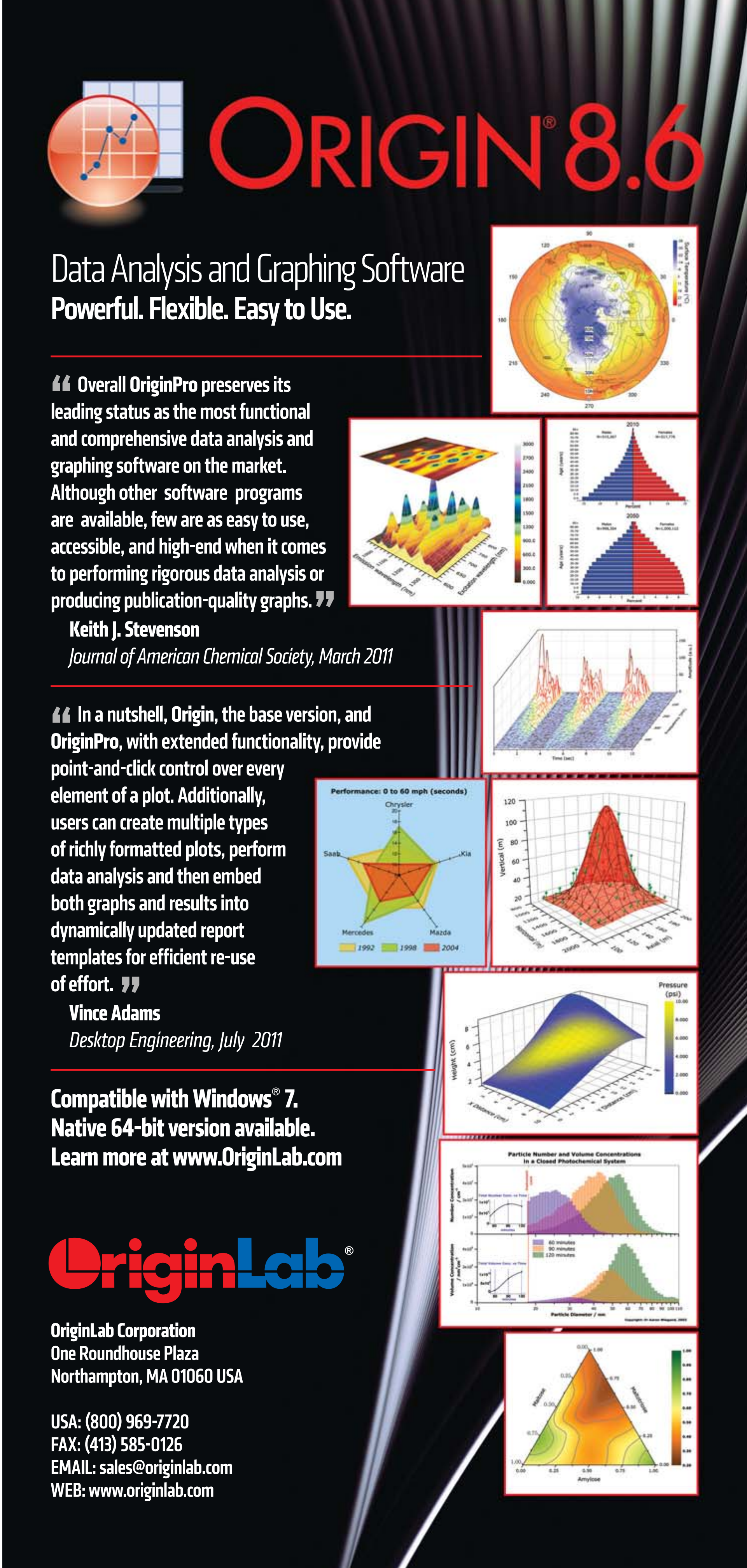
## References

1. M. A. Paalanen, T. F. Rosenbaum, G. A. Thomas, R. N. Bhatt, *Phys. Rev. Lett.* **48**, 1284 (1982).
2. H. Stupp, M. Hornung, M. Lakner, O. Madel, H. von Löhneysen, *Phys. Rev. Lett.* **71**, 2634 (1993); T. Castner, *Phys Rev. Lett.* **73**, 3600 (1994)
3. S. Bogdanovich, M. P. Sarachik, R. N. Bhatt, *Phys. Rev. Lett.* **82**, 137 (1999); S. Waffenschmidt, C. Pfleiderer, H. von Löhneysen, *Phys. Rev. Lett.* **83**, 3005 (1999).
4. T. G. Castner, *Phys. Rev. Lett.* **87**, 129701 (2001).
5. J. C. Phillips, *Phys Rev. B* **45**, 5863 (2001); T. G. Castner, *Phys. Rev. Lett.* **84**, 1539 (2000).

**Theodore Castner**
*(tgc@pas.rochester.edu)*
*Rochester, New York*

■ **Lagendijk, van Tiggelen, and Wiersma reply:** In his response to our story on the history of Anderson localization, Theodore Castner classifies our statements regarding both the scaling of the conductivity with temperature and the exponent puzzle as “misleading.” He also says we “ignored” important contributions, in particular his own proposition to explain a critical exponent 0.5 in weakly compensated semiconductors by the so-called ion-impurity scattering mechanism.[1] That mechanism would lead to a Drude electronic conductivity proportional to the Fermi wavenumber.

It is true that the controversy over critical exponents around the mobility edge and the ongoing debate about the Mott minimum conductivity at the mobility edge marked the history of Anderson localization. They should be mentioned—as we did—by any review on the subject. Given length constraints, it was impossible for us to go into more detail and to discuss recent speculations, including claims on the Mott minimum conductivity.[2] We



found it important to state that an exponent around 0.5 observed in uncompensated semiconductors would violate the lower limit of ⅔ set by the scaling theory and would thus require a scenario other than the one proposed by Philip Anderson and coworkers. Another view on compensated semiconductors is that charge carriers tunnel between impurity states, much like what is proposed in the Anderson model with diagonal disorder. That approach would lead to an exponent of 1.5.

We are very much aware that the extrapolation to zero temperature of the conductivity was a struggle in the early work at Karlsruhe University and at Bell Labs (Castner's references 1–3). In 1996 Issai Shlimak and coworkers claimed that with a better justified extrapolation toward zero temperatures, even uncompensated germanium:arsenic, germanium:antimony, and silicon:phosphorus would exhibit a critical exponent of order one.[3]

For a more extended historical overview with due credit, see our website http://www.andersonlocalization.com, which has been in operation since 2008.

## References

1. T. G. Castner, *Phys. Rev. Lett.* **84**, 1539 (2000).
2. A. Möbius et al., *Phys. Rev. B* **60**, 14209 (1999).
3. I. Shlimak et al., *Phys. Rev. Lett.* **77**, 1103 (1996).

**Ad Lagendijk**
*FOM Institute for Atomic and Molecular Physics*
*Amsterdam*
**Bart van Tiggelen**
*CNRS*
*Grenoble, France*
**Diederik Wiersma**
*European Laboratory for Nonlinear Spectroscopy/INO-CNR*
*Florence, Italy*

# A better option for US fusion program

Permit me to share a few thoughts about US participation in the German stellarator program Wendelstein 7-X (W7-X) and about the best overall strategy for the fusion program (Physics Today, September 2011, page 30). While one hopes W7-X will work well, skepticism is also appropriate. A great deal is already known about stellarators, and in many respects that information is not encouraging. For example, the Japanese have built a large tokamak, JT-60, and a stellarator of comparable size, the Large Helical Device. One important figure of merit for any magnetic fusion device is the product of number density $n$, the temperature $T$, and the confinement time $\tau$, $nT\tau$. It is roughly proportional to the fusion power divided by the input power. The Large Helical Device has achieved an $nT\tau$ of $4 \times 10^{19}$ m$^{-3}$ keV s; JT-60 has achieved $1.6 \times 10^{21}$, 40 times greater.[1]

But more important than the debate over tokamaks versus stellarators for magnetic fusion, or lasers versus heavy-ion beams for inertial fusion, is the question of the best strategy for fusion. Up to now, the choice has been pure fusion—using the 14-MeV fusion neutron's kinetic energy to boil water. But an alternate strategy is fission-suppressed hybrid fusion (Physics Today, July 2009, page 24). Also called fusion breeding, it uses the energy of the excess neutrons to breed fissile fuel for use in conventional nuclear reactors—for instance, light water reactors (LWRs).

The concept of fusion breeding was proposed by Andrei Sakharov[2] around 1950; Hans Bethe advocated it in 1979 (Physics Today, May 1979, page 44). However, the fusion community has always rejected fusion breeding, most likely because it involved partnering with the nuclear industry, something fusion scientists saw as having many environmental, proliferation, fuel supply, and safety problems. Pure fusion seemed nearly perfect by comparison.

As a plasma physicist participating in and observing the fusion program, I have become convinced that Sakharov and Bethe were right and the conventional strategy is wrong. Over the past 15 years, I have documented this view and the science backing it up.[3]

Fusion breeding is similar to fission breeding from a reactor such as the integral fast reactor[4] (IFR), but with two enormous advantages. First, the fusion breeder is much more prolific. One fusion breeder can fuel about five LWRs of equal power; it takes two IFRs at maximum breeding rate to fuel a single LWR of equal power. Second, an IFR needs a great deal of fissile material to start up, but a fusion breeder needs none. One advantage of an IFR, however, is that once started, it can burn any actinide. Run at a low conversion ratio, one IFR can burn the actinide wastes from as many as five LWRs of equal power.[3,4]

Fusion breeding is the optimum choice because I think the world will need an additional 10–30 TW of carbon-free power by midcentury.[5] The options for achieving that are few. The most optimistic proponents of pure fusion admit that it has no hope of making any major contribution in that time frame. Fusion breeding just might. The requirements on the fusion reactor are considerably relaxed, and that may be of great importance, particularly for the tokamak approach. Limits on density, pressure, and current, which have constrained tokamak operation for half a century, make it difficult to see how it can ever be viable as a pure fusion reactor.[3] But it can operate within those limits as a fusion breeder. For any fusion device, breeding is much easier than pure fusion.

Pure fusion has already been delayed more than 30 years. It seems to recede further and further into the future, and sponsors may well lose patience. Fusion breeding is hardly a cakewalk; it will take decades to fully develop. But there are about 400 LWRs in the world today, and about 70 more are in various stages of construction or planning. Proponents claim to have decades worth of fuel. But then what? It is far better for fusion scientists to attempt something that is achievable in the relevant time and that will fit within the likely midcentury infrastructure. Let's not lose the fusion program because perfect is the enemy of good enough.

## References

1. Japan Atomic Energy Agency, Naka Fusion Institute, Fusion Plasma Research, http://www-jt60.naka.jaea.go.jp/english/index-e.html; Large Helical Device Information, http://www.lhd.nifs.ac.jp/en.
2. A. Sakharov, *Memoirs*, R. Lourie, trans., Vintage Books, New York (1992), p. 143.
3. W. Manheimer, *Phys. Soc.* **40**(2), 10 (2011), and references therein, http://www.aps.org/units/fps/newsletters/201104/manheimer.cfm.
4. Y. I. Chang, *Phys. Soc.* **31**(2), 3 (2002), http://www.aps.org/units/fps/newsletters/2002/april/a1ap02.html; W. H. Hannum, G. E. Marsh, G. S. Stanford, *Phys. Soc.* **33**(3), 8 (2004), http://www.aps.org/ units/fps/newsletters/2004/july/hannum.html.
5. M. Hoffert, *Science* **298**, 981 (2002).

**Wallace Manheimer**
*(wallymanheimer@yahoo.com)*
*Chevy Chase, Maryland*

# Correction

**February 2012, page 35**—The exponents on the vertical-axis labels in figure 5b are positive. The minus signs were mistakenly added during the editing process. ■