

concerning the generation of lift by an airfoil. The fact that lift is described by “circulation” around a foil has been known for almost a century, since the introduction of the Kutta–Joukowski theorem. Reference 2 in my February article discusses circulation in mathematical detail.

The article as originally submitted contained a brief reference to circulation and lift. However, I decided that lift for a foil would need to be presented in detail elsewhere. I used the space available to discuss the application of lift to sails and keels and the concepts of resistance, induced drag, hull speed, and so forth, that determine how a sailboat performs. I did provide a quick review of “classical” lift theory while indicating that the basic physical understanding is hard to arrive at. I refer the reader to Ross Garrett’s attempt to do that in his book *The Symmetry of Sailing*.¹ In chapter 3 he outlines three ways for understanding lift. First is the “flow line method,” which describes classical lift theory and arrives at Bernoulli’s principle applied to a foil. Garrett’s second way, “momentum change,” emphasizes that macroscopically a foil must have the net effect of deflecting the fluid flow in order to derive lift. That is obvious, but must be appreciated. His third way to understand lift is the “mathematical approach,” which introduces circulation, using several fluid flow theorems leading to the Kutta–Joukowski theorem. That approach is what engineers use to calculate lift, but it does not provide a clear physical description of lift. Several websites discuss lift.²

I am aware that airflow around a foil is not isochronal. I was careful not to say that it is. The flow over the “top” is faster and arrives at the end of the foil sooner than the flow along the “bottom.” That difference in flow times leads to circulation. Because the flow is faster over the top, the pressure is reduced, as verified by measurement—which I did mention. Whether that is the cause of lift or the consequence of circulation becomes, I think, a matter of semantics.

References

1. R. Garrett, *The Symmetry of Sailing: The Physics of Sailing for Yachtsmen*, Sheridan House, Dobbs Ferry, NY (1996).
2. See, for example, A. Gentry, “The Origins of Lift,” http://www.arvelgentry.com/origins_of_lift.htm.

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Most pressurized elements aren’t simple cubic

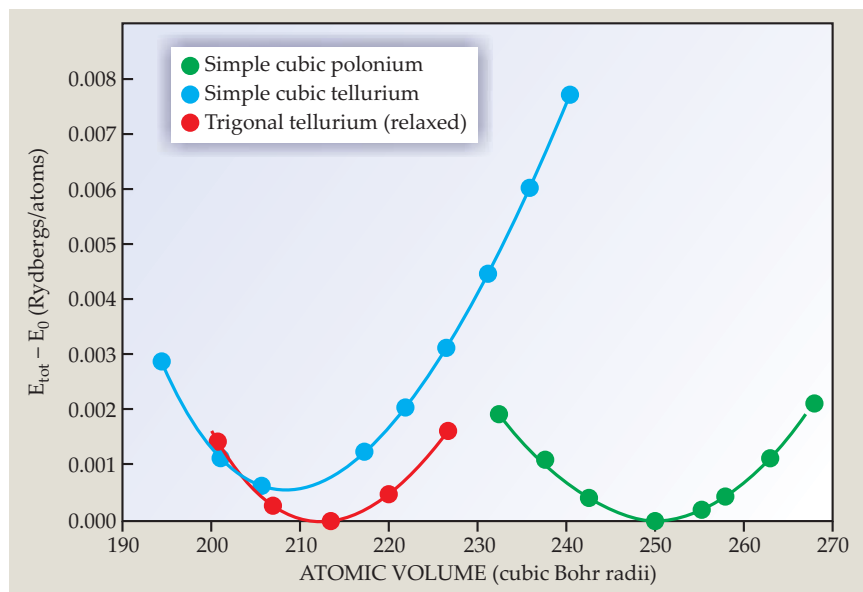
I have a comment regarding the three contributions under the heading “Some Elements Go Cubic Under Pressure” in the Letters section (PHYSICS TODAY, October 2007, page 17).

The *s* orbitals of all atoms are relativistically stabilized because, unlike for all other orbitals, their probability density at the nucleus is greater than zero. The relativistic contribution to the energy increases with nuclear charge, gradually, even if nonlinearly, across the periodic table. There are many il-

lustrations) enough to bring them into the polonium-type structure with bonds formed from unhybridized *p* orbitals. The relativistic effect is a factor shaping the periodic system, and it affects more than just the heaviest elements.

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Legut, Friák, and Šob reply: Relativistic effects are important in solid-state physics and chemistry. However, in our experience, they are usually not strong enough to promote a phase transition to the simple cubic structure under pressure. The figure below shows the energy–volume curves of tellurium



lustrations of that phenomenon in chemistry, such as the increasing redox stability of carbon-group cations from Ge^{2+} to Sn^{2+} to Pb^{2+} , the decreasing melting point from zinc to cadmium to mercury, and the increasing difficulty of hybridization of the *s* and *p* valence orbitals in elemental structures.

The last of those three phenomena is nicely manifested in the gradual decrease in bond angle of oxygen-group elements, from sulfur to selenium to tellurium to polonium. Elemental sulfur forms nearly tetrahedral bond angles, and Se and Te form similar structures with sharper angles. In polonium, the *s* and *p* orbitals will not mix anymore because the *s*-orbital energy is too low, so the bond angle is 90° . It is only natural that a high enough pressure would increase the relativistic stabilization of the *s* orbitals in Se and Te (or other *s*, *p* ele-

ments) enough to bring them into the polonium-type structure with bonds formed from unhybridized *p* orbitals. The relativistic effect is a factor shaping the periodic system, and it affects more than just the heaviest elements. If we compare it with figure 2 in our paper,¹ in which the relativistic effects were ignored, we see that the transition pressure needed to transform the trigonal spiral to the simple cubic structure, proportional to the slope of the common tangent of both energy–volume curves, is about twice as high in the nonrelativistic Te as in the relativistic case. Also, the energy difference between the two structures of Te is considerably higher in the nonrelativistic Te. Hence, the relativistic effects somewhat facilitate that phase transition in Te but are not the driving force. In Po, the relativistic effects are strong enough to reverse the order of the two structures.¹

Those considerations, however, are