The possible existence of some interesting hybrid materials nominally forbidden by basic physics

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These speculations begin with the observation by various scientists, probing new phenomena through the use of first principles studies, that the simultaneous occurrence of certain properties is unlikely. A prototype example is the simultaneous occurrence in a single material of ferromagnetism and ferroelectricity. These studies typically do not consider the possibility of a first order phase transformation (hence the word "nominally" in the title), but there is a lot of indirect evidence that, if the lattice parameters are allowed to change significantly, then one might have co-existence of such properties. This seems to extend to diverse sets of nominally incompatible properties. Thus, one could try the following: seek a reversible first order phase transformation, necessarily also involving a distortion, from, say, ferroelectric to ferromagnetic phases. If it were highly reversible, there would be the extremely interesting additional possibility of controlling the volume fraction of phases with fields or stress. The key point is reversibility.

Even big first order phase changes can be highly reversible (liquid water to ice, shape memory materials), and we argue that in solid materials it is the nature of the shape change that is critical. We suggest, based on a close examination of measured hysteresis loops in martensitic systems, that an idea based on "good fitting of the phases" governs reversibility. The mathematical status of this idea is not completely clear, as I explain, but its possible connection with quasiconvexity raises mathematical questions of fundamental interest.