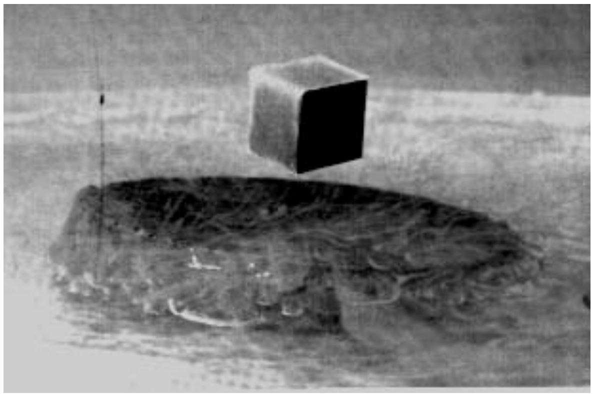
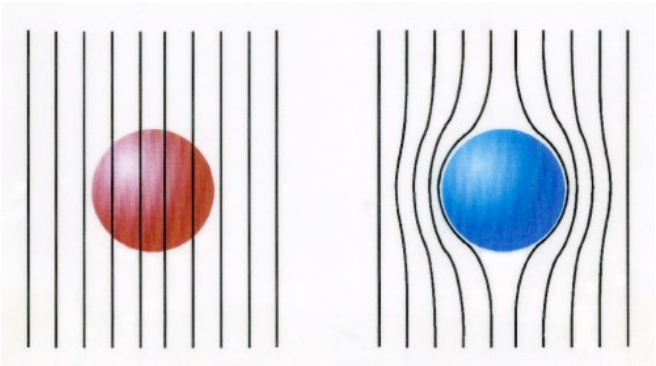
The Superconducting phenomena was first observed in 1911 when mercury was cooled to a few Kelvin with the recently discovered liquid helium.[1] Over the decades, other materials were found to be superconducting, but their critical temperatures were also prohibitively low. Then in the late eighties a 30K superconductor was discovered , then the liquid nitrogen barrier was broken, and now with the aid of 10^6 atms of pressure we get Tc at over 150K. In the search for ever higher Tc, cobalt oxide compounds have generated some interest of late, not because of its own high Tc, but because of its *similarity* to the record holding cuprate family. After a basic review on superconductivity, we'll discuss the importance of the cobaltites, and finally I'll discuss recent research on this material.



- **Fundamentals**

There are four kinds of magnetism which are easy to confuse. Ferromagnetism occurs when all the spins are aligned creating a bulk magnetic moment. This is the familiar iron variety which is relatively strong. The antiferromagnetism state occurs when the spins alternate creating a bulk magnetic moment of zero. Paramagnetism is an induced state where an external magnetic field aligns the dipoles in a material creating an induced magnetic moment. Finally diamagnetism anti-aligns the dipoles under an external field with the effect of canceling it.

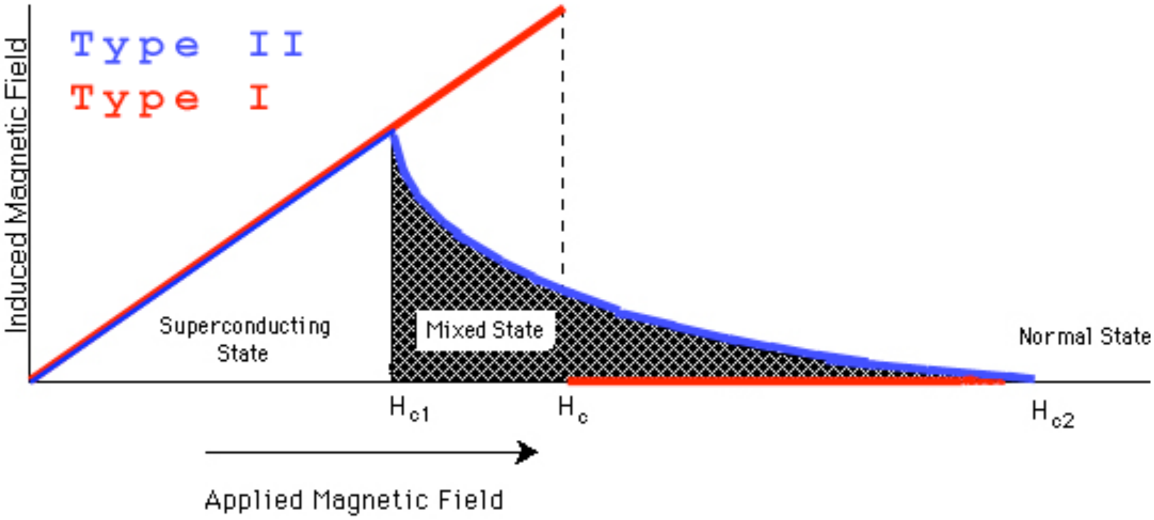
Superconductors exhibit zero resistivity below a certain temperature. This can be viewed in the Meisner effect which expels all of the magnetic field inside the



superconductor by induced surface currents Think of it as applied diamagnetic behavior which emerges when the thermal noise is eliminated. Another way of viewing it is where surface currents are generated to cancel the applied magnetic field. Other materials do this well, but superconductor can do it *perfectly*.

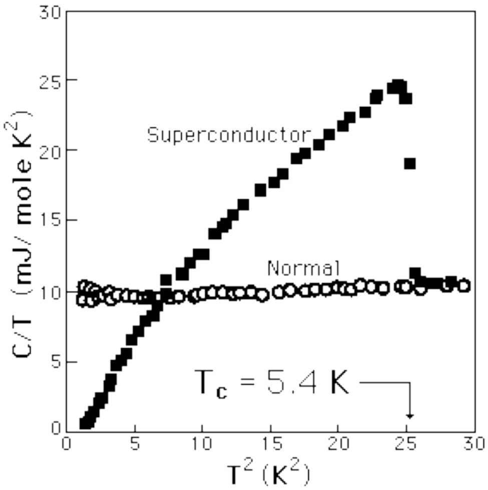
A superconducting state can be broken several ways. By running too much current through it. Each material has a critical current density—a figure very important to the superconducting industry. Simply put, an overload superconducting state and it will be destroyed.

Another way to break the superconducting state is by applying an external magnetic field. All superconductors will increase their internal magnetization proportional to the applied field up to a point. At this point there emerge two classes of material creatively called type I and type II.



Type I superconductors have a jump discontinuity in their magnetization vs applied magnetic field. Where the magnetization of the type II superconductors tapers off gradually which dramatically extends the region of superconductivity—hence high Tc.

The graph shows the amount of magnetic field necessary to break the superconducting state at a given temperature. With this tool we can analyze the effect superconductivity has on a material such as the specific heat of aluminum. $C_{super} = A\ T^3$ in the low temperature limit for superconducting vanadium, but in the same temperature range $C_{normal} = B\ T$ is linear for the magnetically backed up superconducting material.



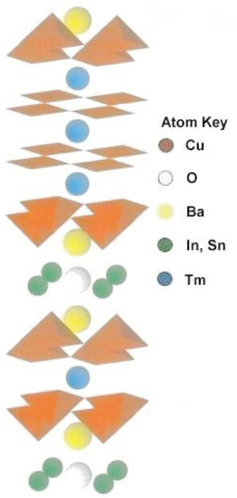
In most materials electrical and thermal conductivity go hand in hand; superconductors however have poor thermal conductivity--in fact, many of them are insulators.

- **Fun Facts about Superconductivity** [1]

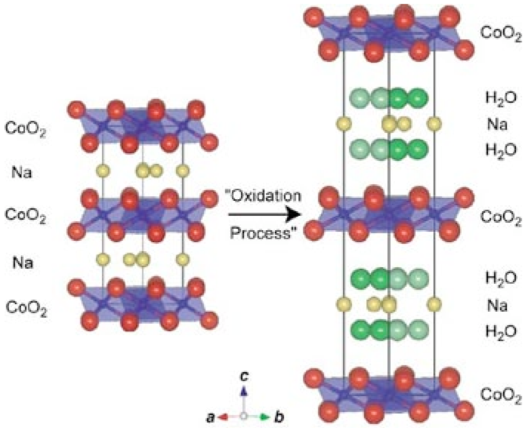
"Once thought a rare anomaly, it now appears that superconducting states can be formed in most materials, including thousands of inorganic compounds, most of the natural elements, alloys, oxides, and even organic materials and, significantly, the double-stranded molecules of DNA" Superconducting DNA! Knowing that it takes hundreds of thousands of atmospheres of pressure makes this fact less surprising.

These techniques for superconducting coercion sound a bit like molecular torture. Our first tool is to apply pressure. Using a diamond anvil, current methods deliver up to 260 GPa Through pressure techniques interesting, non-superconducting states were found for example metallic xenon or semiconducting nitrogen. This extra pressure often induces a change in crystal structure, for instance non-superconducting, low-pressure iron is in the bcc lattice, but after 20 GPa is applied it switches to a hcp structure and becomes superconducting at 2K. Niobium has the record for highest atmospheric with Tc = 9.25K. Lithium is most improved element with Tc jumping from 0K to 20K after only 60GPa. Other methods of Tc manipulation include: radiation, growth as a thin film, thin film on a superconducting substrate, and charge doping.

- **The players**



The reason scientists are excited about the family of cobaltites is that our efforts to produce higher Tc have plateaued. Here are series of increasingly complex introductions to the field of superconducting cobaltites [2-4]. The reigning king of high Tc, $(Hg_{0.8}Tl_{0.2})Ba_2Ca_2Cu_3O_{8.33}$ [5], comes from the cuprate family and clocks in at Tc=138K. $Na_{0.35}CoO_2 \; 1.3H_2O$, currently the most popular cobaltite, can only boast a meager 5K. [6] Despite the low Tc people are excited about this material because it is the *only* other superconductor to share the planar structure of the cuperates. The only way to get better theory is to search for ways to compare the structure of superconductors. While both materials share the low spin metal oxide layers, the electron structure of the cobaltites



yields a triangular lattice while the. The metal oxide layers of both materials need interplanar doping to enter magnetically neutral antiferromagnetic state. The magnetism of high spin metal ions hinders Cooper Pairs propagation. One final similarity is the anisotropic resistivity of both materials, this shouldn’t be too surprising since they both contain metal oxide planes.

Takada [6] was the first to discover that water is necessary for superconductivity in cobalt oxide. The sodium and water lie between the planar layers of. The more water present the larger the distance between the layers. Incidentally this makes (y=1.3) $Na_{0.35}$ CoO_2 yH_2O superconducting. Notice there is no superconductivity until y reaches a critical value. This is strong evidence for the dimensional dependence of superconductivity.

Water concentration	Tc
y=0	--
y=0.6	--
y=1.3	5K

- **Rabbits to chase**

Many of the early articles did not contribute much meaningful information. One such example is another one published by Takada et. al. [7] a year and half later. Four pages of dense writing yields to the last sentence, “Therefore, the difference in their stacking sequence has little effect on their superconducting properties, and compositional and structural features.

A slightly more enlightening article by Tatsuya et. al. [8] which used nuclear quadrupolar resonance to probe the spin relaxation rate suggested that $Na_{0.35}$ CoO_2 $1.3H_2O$ exhibits non-s-wave superconductivity.

It is not surprising that non-superconducting Na_x CoO_2 has anisotropic resistivity. The direction perpendicular to the planar CoO_2 layers has a resistivity about 10^3 times greater than that of the plane.[9]

The richness and diversity of Na_x CoO_2 $1.3H_2O$ is explored in many papers such as Phelan et. al. [10] who is analyzing the spin density waves and their critical temperature as a function of doping concentration x. I find it rather surprising that spin density waves arise with a wavelength is an irrational fraction of the lattice dimensions; these are incommensurate spin density waves. Might these spin density waves mitigate superconductivity?

"Studies on related superconducting phases should be very helpful in obtaining a deeper understanding of superconductivity."[6] Sugiyama et. al. [11] are following Takada's lead by investigating the "dome shaped" behavior of phase space of transition curve of temperature vs doping concentration. Both superconductivity and spin density waves exhibit similar phase space diagrams; when discovered, the underlying similarity between the two might prove illuminating.

Theoreticians are also involved. Aryanpour et. al. are using Hubbard model simulations along with Monte Carlo calculations to examine the structure and propagation of spin waves and their s-wave dependence. They recently found that the inhomogeneity of spin waves is not important [12].

I didn't have time to delve into the intricacies of a spin glass system, but a research group at the Chinese Academy of Sciences [13] is also studying the phase separation between manganites and cobaltites. I also didn't examine the hope that cobalt oxide compounds might be the resonating valence bond superconductor predicted by Anderson[14-15]

In summary, cobaltites are found to be superconducting if intercalated with the right amount of water. The similarity they share with cuperates—namely the planar metal oxide layer—makes them a boon to the budding field of superconductivity. This is an active field of research.

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