Measurements on $CeIn_3$ in Non-Destructive 100 Tesla Magnet Fields

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Scientists have long since been able to subject materials to the extremes of magnetic field beyond 100 tesla, utilizing explosive flux compression or singleturn coil techniques. The destruction of the sample by the explosively driven systems is not an option for many "one-of-a-kind" or otherwise "valuable" samples. For conductors, however, the rapid rates of change of magnetic flux brought on by their microsecond duration proves to be an additional experimental hurdle to conquer. If not addressed the Joule heating caused by the induced eddy currents will raise the temperature of the sample significantly. To counteract these problems, high magnetic field scientists around the world have for the past two decades been attempting to generate magnetic fields approaching 100 tesla in a controlled fashion, non-destructively, with millisecond duration. The demands on material strength and electrical energy have proven to be much more of a challenge than previously anticipated. Only recently have controlled magnetic fields anywhere near 100 tesla become close to being realized. A team of scientists and engineers at the Los Alamos branch of the NHMFL have commissioning a 100 tesla multishot magnet with the intention of providing slightly reduced magnetic fields of ~90 T for experimental use in an interim period before the frontiers are finally pushed back to their ultimate goal. These World Record millisecond pulsed fields reach approximately 30 tesla beyond what was previously available for experiments in pulsed magnetic field laboratories— opening the door for countless new opportunities.

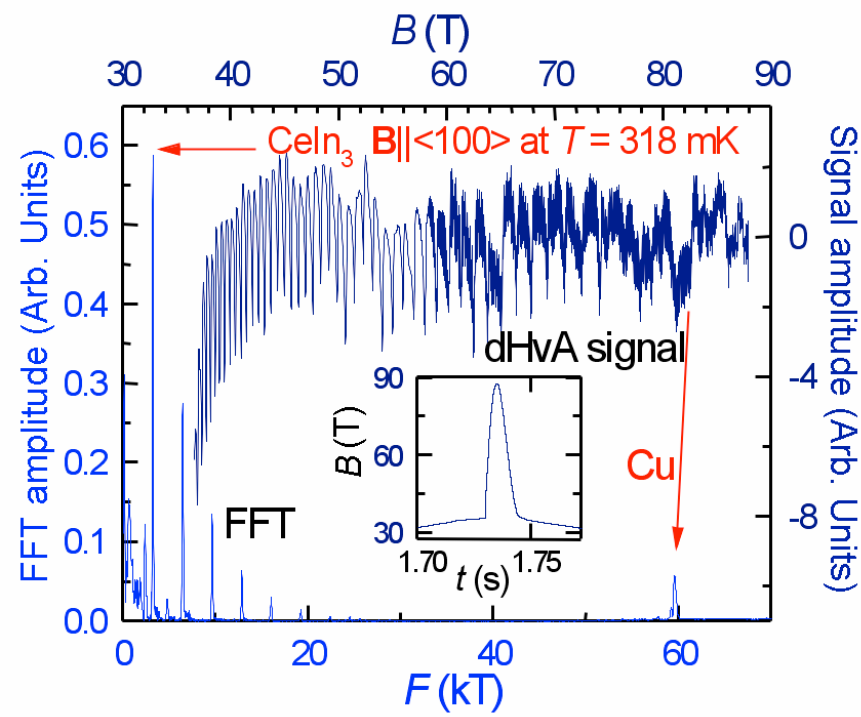

Figure 1. The raw dHvA signal in CeIn3 and the spectral analysis. (Inset) The Magnetic Field pulse near peak field showing the ~35 tesla platform field.

$CeIn_3$ provides the first example of a system, in which temperatures of ~318 mK (3/10 of a degree above absolute zero) enable observation of the quantum oscillations in the magnetization, better known as the de Haas van Alphen (dHvA) effect. Fig. 1 shows an example of raw data of such oscillations measured in a pulse extending to 88 tesla. The Fourier transform of the oscillations in Fig. 2 (done in reciprocal magnetic field) provides a reliable in-situ calibration of the magnetic field; the fundamental dHvA frequency F ~ 59.5 kT of Cu originates from the windings of the detection coil while that of F ~ 3.22 kT corresponds to a sample of CeIn3 aligned with the field is parallel to its <100> axis.

$CeIn_3$ is of interest because it belongs to a small family of Ce-based antiferromagnets that become superconducting under the application of hydrostatic pressure, just at the point where antiferromagnetic order is suppressed [1]. Knowledge on the degree to which the f-electrons contribute to the electrical properties throughout is an essential prerequisite for understanding the origin of unconventional superconductivity. Strong magnetic fields assist in our pursuit of this understanding by changing the extent to which the f-electrons contribute to electrical conduction by polarizing their spin degrees of freedom. This polarization depletes the system of available spin degrees of freedom for ordering, causing the antiferromagnetic order to be suppressed (as under pressure). This then manifests itself by way of subtle changes in the electronic structure that can be observed as field-induced changes in the dHvA Fourier spectrum. This work was jointly supported by the NSF, DOE, Florida State.

[1] Harrison, N., *et al*., Physical Review Letters 99, 056401 (2007).