	Experiment title: Magnetic properties of isolated atoms and small clusters of vanadium on Cu(100)	**Experiment number:** HE-1104
Beamline: ID08	**Date of experiment:** from: 26/09/01 to: 02/10/01	**Date of report:** 01/03/02
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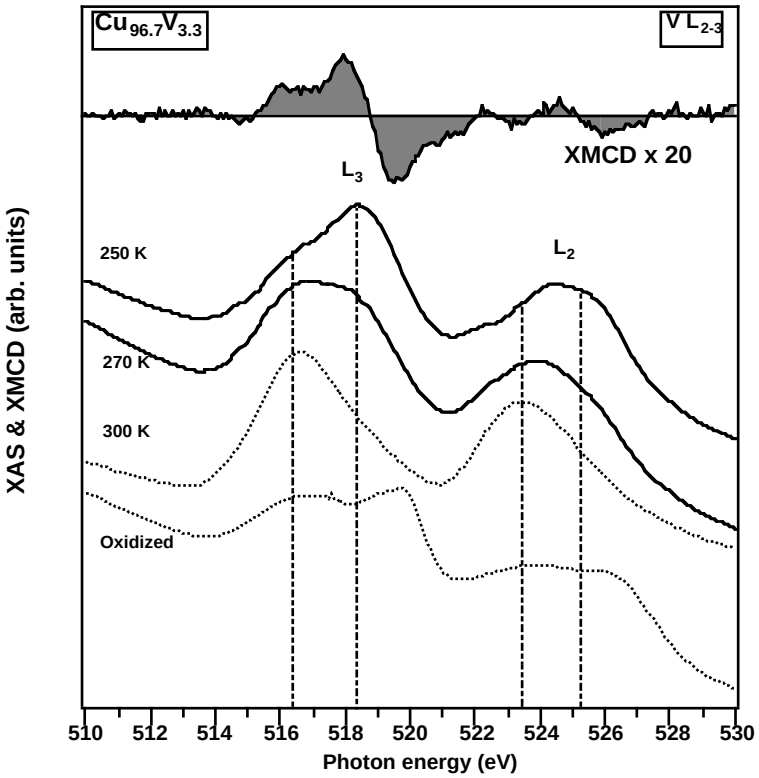
The study of the magnetic properties of vanadium in other forms than its well known bcc paramagnetic structure, such as in free and supported clusters, surfaces, multilayered compounds and alloys, is subject of *intense debate and extensive research*. Such debate is due to contradictory results [*1-7*]. A well-established result is that the magnetic properties of vanadium on surfaces, in clusters and alloys are strongly related to the local geometry (i.e. the coordination number and neighbor distances) [*1,6,8*] and the resulting electronic structure. This dependency is such that vanadium, which is non magnetic in its bulk form, could become magnetic when associated with other non-magnetic elements such as copper. Furthermore, the theoretical prediction of the violation of Hund's third rule in VAu_4 [*9*] and the discrepancy between different theoretical approaches [*10*] have made the magnetic properties of V compounds and alloys one of the challenging problems in solid-state physics and material science. Also the understanding and tailoring of the magnetic properties of small particles for their further integration into magneto-optical and high-density storage devices [*11*] has been an important motivation for the current study. As a consequence, there is an urgent need of new studies and in particular new experimental results on the magnetic properties of V systems [*9-10*]. In this report we present results for alloys having the stoichiometry $Cu_{96.7}V_{3.3}$. The VCu alloys were grown on Cu(100) by co-evaporation in a preparation chamber attached to the analysis chamber on beam line ID08. After preparation the samples were transferred quickly under UHV into the analysis chamber where magnetic characterization was performed using x-ray magnetic circular dichroism (XMCD) monitored in total electron-yield mode. The applied magnetic field (7 T) was parallel to the incident x-ray beam, and its direction was reversed between successive photon-energy scans. Apart from the reported study of the VCu alloys, we have also studied the V/Cu(100) system by evaporating small amounts of V on the Cu(100) surface at room temperature (as we intended to do following the original proposal). Credit to the high flux of beam line ID08 we were able to measure the absorption spectra of these highly reactive surface before they contaminated with residual gases. However, despite serious attempts, no XMCD could be observed even at very low coverages (down to 10^{-2} monolayer). The absence of XMCD arises from the fact that the V atoms have high migration rates due to their thermal mobility and can form non-magnetic clusters of large size. We then evaporated V on "pyramide" like surfaces [*12*] in order to reduce the clustering of V atoms but again no XMCD signal was measured. Finally, we reduced even more the clustering of V atoms by trapping them in a Cu matrix performing a V-Cu co-evaporation on Cu(100). This provided the result that we had hoped for. Figure 1 displays the V $L_{2,3}$ x-ray absorption spectrum (XAS) measured for alloys prepared at different temperatures and for comparison an oxidized alloy is shown. The top curve shows the XMCD obtained for the alloy prepared at 250 K. The spectral shape of the



ig. 1: V $L_{2,3}$ XAS for VCu alloys prepared at different temperatures
The lower curve gives the XAS for an oxidized alloy.
he XMCD (upper curve) is shown for the sample prepared at 250 K

XAS differs considerably with deposition temperature and is at lower photon energy than that of the oxidized sample (as it should be). The sample prepared at 250 K presents a dominant L_3 feature centered at 518.3 eV, whereas the sample prepared at 300 K has a dominant L_3 feature at 516.5 eV. The sample prepared at 270 K shows both features in the absorption spectrum. The distinction in the XAS reveals the different electronic structures, i.e. different V species. The influence of the formation temperature of different samples can be understood in terms of vanadium migration. The electronic structure and the magnetic properties, which are very dependent on the cluster size [*1,3,6*], are expected to change strongly with the formation temperature. The existence of XMCD is a clear proof that the V atoms carry a magnetic moment (and due to the small quantities involved it would have been difficult to measure this by any technique). Interestingly, we also found a non-zero XMCD signal for the sample prepared at 270 K whereas the sample prepared at 300 K as well as the oxidized sample did not show any observable magnetic signal. This is consistent with the abovementioned idea of migration of V atoms at high temperatures and the formation of large V clusters up to the limit of non-magnetic bulk vanadium. The spectral shape of the XMCD for the two magnetic samples was the same and resembled the shape measured for V deposited on Fe(100) [*5*], VFe alloy [*13*], Fe/V multilayers [*14*], and superlattices [*15*].

We now turn to Fig. 2 that displays the evolution of the V magnetic moment with temperature for the two alloys that were magnetic. Their total magnetic moments were extracted from the XMCD signals following the procedure already used for V/Fe(100) and Fe/V(001) superlattices [*5,15*]. The dashed lines are guides to the eye only. It is clear that the formation temperature has a strong influence on the V magnetic moment and that the sample prepared at lower temperature is more magnetic. Again this can be understood in terms of the tendency of the V atoms to form non-magnetic clusters at higher temperatures. As a general trend, we observe a very strong vanadium susceptibility and a magnetic moment that decreases very fast with temperature in the low-temperature regime and then decays slowly for T>50 K. Furthermore, the highest value for the vanadium moment per atom found in this work ($\mu \approx 1.1\ \mu_B$) compares fairly well with that measured in V/Fe superlattices [*15*] ($\mu \approx 1\ \mu_B$ and $1.1\ \mu_B$ respectively), hyperfine V particles [*3*] ($\mu = 1.25\ \mu_B$) in the dilute V limit and the calculated value for the VAu_4 alloy [*9*] ($\mu = 1.7\ \mu_B$). A more extensive experimental and theoretical study is desirable to gain further understanding in the origin of the V magnetic moment. The atomic geometry will be investigated by EXAFS and atomic calculations are in progress. We acknowledge the excellent technical assistance from ESRF staff during the experiment.

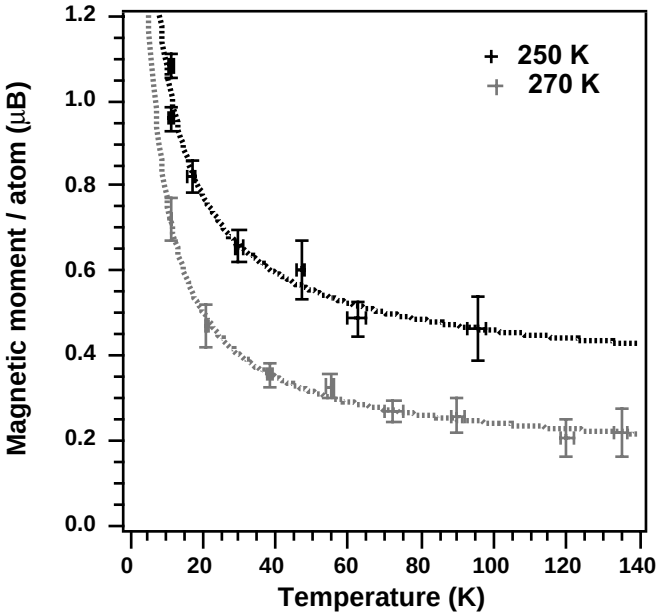


Fig. 2: Temperature dependence of the V magnetic moment as obtained from the XMCD for the two magnetic samples (those prepared at 250 K and 270 K). The dashed lines are a guide to the eye.

REFERENCES

[1] B.V. Reddy, M.R. Pederson, S.N. Khanna, *Phys. Rev. B* **55**, R7414 (1997).

[2] J. S. Moodera, R. Meservey, *Phys. Rev. B* **40**, 8541 (1989); D.R. Grempel, S.C. Ying, *Phys. Rev. Lett.* **45**, 1018 (1980); S. Bouarab et al., *J. Magn. Magn. Mat.* **104-107**, 1765 (1992); C.L. Fu, A.J. Freeman, S. Oguchi, *Phys. Rev. Lett.* **54**, 2700 (1985); S. Ohnishi, C.L. Fu, A.J. Freeman, *J. Magn. Magn. Mat.* **50**, 161 (1985); C. Rau et al., *Phys. Rev. Lett.* **57**, 2311 (1986).

[3] H. Akoh, A. Tasaki, *J. Phys. Soc. Jpn.* **42**, 791 (1977).

[4] C. Beckmann et al., *Phys. Rev. Lett.* **73**, 1715 (1994), R.L. Fink et al., *Phys. Rev. B* **41**, 10 175 (1990).

[5] M. Finazzi et al., *J. Magn. Magn. Mat.* **165**, 78 (1997).

[6] V.S. Stepanyuk et al., *J. Magn. Magn. Mat.* **165**, 272 (1997); S.E. Weber et al., *J. Phys. Condens. Matter*. **9**, 10739 (1997), K.Y. Lee, J. Callaway, *Phys. Rev. B* **49**, 13906 (1994).

[7] S.L. Qiu, R.G. Jordan, A.M. Begley, *Phys. Rev. B* **46**, 13 004 (1992).

[8] S. Blügel, Appl. *Phys. A* **63**, 595 (1996).

[9] I. Galanakis et al., *Phys. Rev. B* **63**, 172405 (2001).

[10] Iskander G.B. et al., *Phys. Rev. B* **63**, 172420 (2001), R. Robles et al., *Phys. Rev. B* **63**, 172406 (2001).

[11] I.M.L. Billas, A. Châtelain and W.A. De Heer, *Science* **265**, 1682 (1994).

[12] J.K. Zuo et al., *Phys. Rev. Lett.* **78**, 2791 (1997); M. Ritter et al., *Surface Science* **348**, 243 (1996).

[13] M. Finazzi et al., *J. Magn. Magn. Mat.* **165**, 373 (1997).

[14] G.R. Harp et al., *Phys. Rev. B* **51**, 3293 (1995).

[15] M.M. Schwickert et al., *Phys. Rev. B* **57**, 13681 (1998), A. Scherz et al., *Phys. Rev. B* **64**, 180407 (2001).