Fall 2010 Magnetics ***Solution***

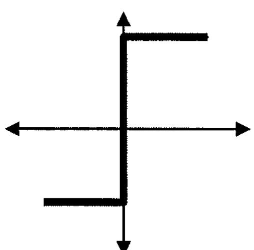
1) For high-frequency applications, nonmagnetic silicon is often added to iron. What properties are improved by this addition, what is the limit in the amount of Si that is beneficial, and why?

   The most important property enhancement is increased electrical resistivity. Anisotropy also decreases and there is no change in magnetostriction. 4 wt% is the limit before silicates may begin to precipitate out of the Fe- as shown by a 2 phase field in phase diagram below (~5% Si)- making it brittle. (0.5 points)

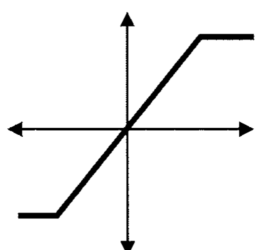
2) A 10nm oblate ellipsoid of Fe with 3% Si (10% reduction in saturation magnetization) is oriented such that its axis of symmetry is parallel and perpendicular to a magnetic field. Quantitatively plot the M vs H loop in each case for axial ratios of 0:1 1:1 and 10:1. Ignore crystalline aniostropy. (1.5 points)

   Ms(Fe) = 1740 emu/cc, Ms(alloy) = 1566 emu/cc

   0:1 - $N_z = 0$, $N_x = N_y = 4\pi$

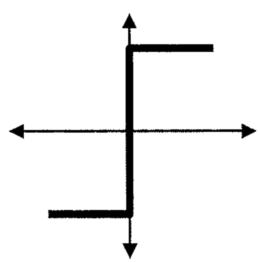


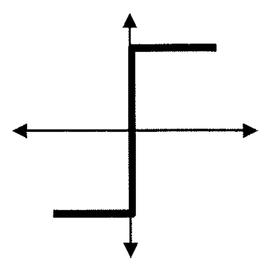
Along x or y



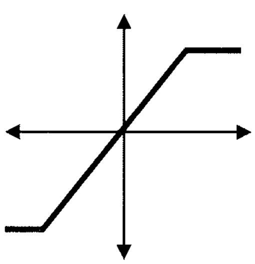
along z ($H_{sat} = 4\pi M \sim 19$kOe)

   1:1 - $N_z = N_x = N_y = 4/3\pi$ no easy axis

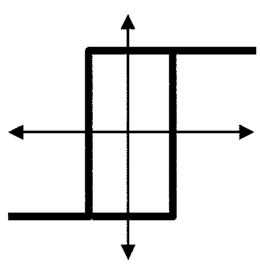




parallel and perp. are same



Along x or y



along z

10:1- Nz~0 $N_x = N_z = 2\pi$
Hsat , perp = Hc, par ~ 2π Ms ~ 10kOe

3) The magnetization of a cubic ferrite, or spinel, increases with the addition of nonmagnetic Zn. Why? (0.5 points)
   This must be a ferromagnetic oxide with Fe in two different sites whose sublattices are antiferromagnetically coupled to each other. The first sublattice has Fe's cancelling Fe's in the second (recall that the net moment of a ferromagnetic oxide is the sum of the oppositely magnetized moments on the sublattices). In particular Magnetite is an inverse spinel so one Fe^{3+} is located on the octahedral site, and the other is on one of the tetrahedral sites. The Fe^{2+}

is on the other tetrahedral site: When the Zn2+ substitutes, it goes to the octahedral site and for charge balance, a Fe2+ on the tetrahedral site oxidizes to 3+. The main point of this question was that Zn would change the balance of the magnetic sublattices such that fewer u_B were cancelled than without Zn.

4) Graph the expected saturation magnetization vs Zn^{2+} substitution. (Note: the iron is both Fe^{2+} and Fe^{3+} ($5\mu_B$), there are 8 formula units per unit cell with a 8.39 Å lattice parameter. ($1\mu_B$ = 0.927×10^{-20} emu) (1.5 points)

Undoped: $1x5u_B - 1 \times 5u_B - 1 \times 4u_B = 4u_B$ (1.5 points)

$Ms = (8\ \text{formula units})(4u_B/\text{unit})(0.927 \times 10^{-20}\ \text{emu}/u_B)/ (5.86 \times 10^{-8}\ \text{cm})^3$ *per cell*

$= 506$ *emu/cc*

Fully doped (ideal): $Ms = 10u_B = 1257$ *emu/cc (in reality it will not reach this value)*