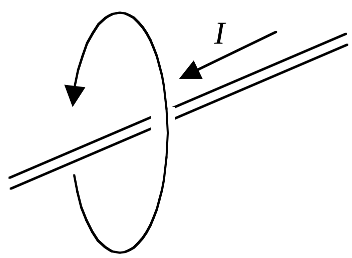
3.45 Quiz, Spring 2004 **NAME** I. M. Magnetician

April 8, 2004

(Answer questions on this sheet of paper)

1. a) Draw in briefly (1phrase) describe the direction of the magnetic field about the infinitely long, current- carrying wire below.



ANS: *H* or *B* field circular in right-hand sense about *I* .

or Field is counterclockwise when current flows toward viewers.

b) What is the magnitude (and units) of the *H* field at a distance of 1 cm from the wire if *I* = 6.3 Ampère.

ANS:

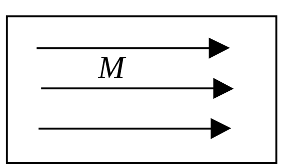
$$H = \frac{I}{2\pi R} = \frac{6.3\text{A}}{6.28\times 0.01\text{m}} \qquad\qquad B = \frac{\mu_0 I}{2\pi r} = \frac{1.25\times 10^{-6}\times 6.3\text{A}}{6.28\times 0.01\text{m}}$$

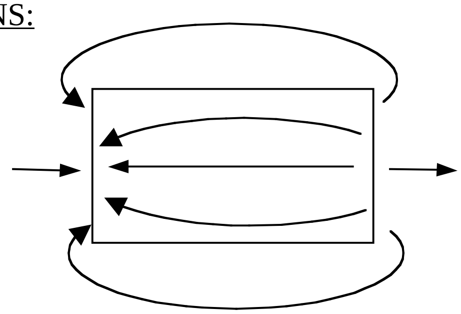
or

$$H = 100\frac{\text{A}}{\text{m}}(1.25\text{Oe}) \qquad\qquad B = 1.25\times 10^{-4}\,\text{T}\ (1.25\text{Oe})$$

2. Given the permanently magnetized sample shown below left, with no external field, sketch at right the form of the *H* field inside and outside the sample.

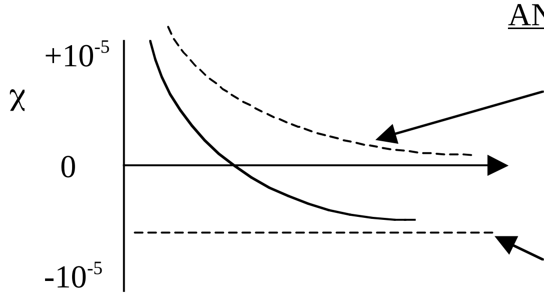
ANS:





3. You measure the susceptibility vs. temperature in an unknown sample, getting the results shown below. Describe the type(s) of magnetism responsible for this data and indicate where they contribute to the data.

ANS:

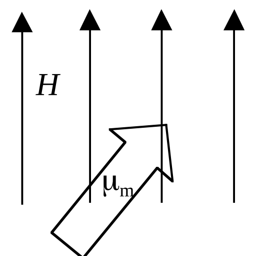


Paramagnetism $\chi = \frac{C}{T}$

plus

Diamagnetism $\chi = -\frac{ne^2\mu_0 \sum \langle r^2 \rangle}{6m}$

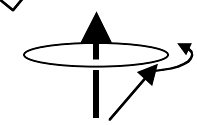
4. a) What is the mathematical form for the potential energy of a magnetic moment in a uniform magnetic field shown at right?
   b) If the moment is free to rotate, would its first motion (in picoseconds) be into or out of the plane of the paper?



ANS:

a) $u = -\vec{\mu}_m \cdot \vec{H} = -\mu_m H \cos\theta$

b) $\vec{\omega}_L = +\frac{e}{2m}B$; right hand rule says moment rotates into the plane first.



5. a) What would you expect the magnitude of the magnetic moment to be on the A (tetragonal) and B (octahedral) sites in $FeO{\cdot}Fe_2O_3$ (atomic No. of Fe is 26) (an inverse spinel).

ANS:

A (tet)	B (oct)
Fe^{3+}	Fe^{3+}, Fe^{2+}
$\mu_m = 5\mu_B \downarrow$	5, $4\mu_B \uparrow$

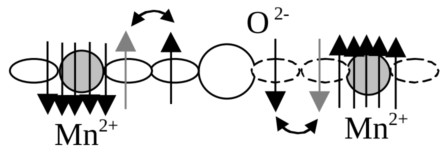
Fe^{3+} $3d^5 \Rightarrow \mu_m = 5\mu_B$

Fe^{2+} $3d^6 \Rightarrow \mu_m = 4\mu_B$

b) What is the magnitude of the net moment per formula unit?

$$B(5 + 4\mu_B) - A5\mu_B = 4\mu_B / Formula\ unit$$

6. Sketch the molecular orbitals and describe briefly how the magnetic moments on two transition metal ion sites couple magnetically if they are separated by an oxygen ion between them.

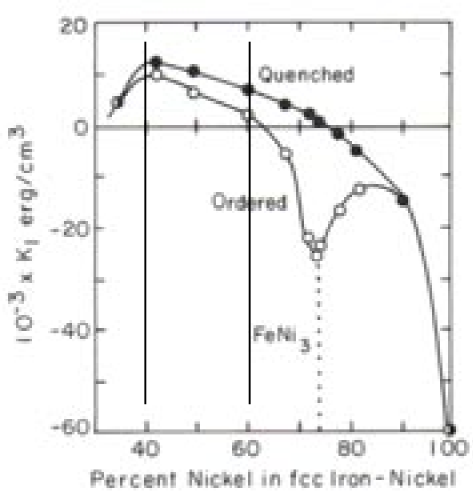


ANS:
Oxygen $^{-2}$ p orbital has 2 opposite-spin electrons, one near each Mn^{2+} ion. These electrons occasionally jump to empty states on the closest Mn^{2+} ion, insuring that the net spin on one Mn^{2+} ($3d^5$) is opposite that of the other Mn^{2+}

7. What would you expect to happen to the strength and form of the magnetic anisotropy of hexagonal cobalt metal if it were processed to solidify in the face-centered cubic phase?

   ANS: **Strength** would decrease because crystal symmetry of FCC is higher than that of HCP .
   Form of symmetry changes from uniaxial to cubic.

8. Given the magnetic anisotropy data for FCC Ni-Fe alloys shown below, and assuming the same defect distribution in two polycrystalline alloys having compositions $Fe_{60}Ni_{40}$ and $Fe_{40}Ni_{60}$,



   a) Which of them would be easier to saturate with an applied field?
   b) Which one would you expect to show a lower coercivity?

   ANS:
   a) $Fe_{40}Ni_{60}$ has lower K_1

   $\therefore$ lower H_a, easier to saturate.

   b) lower H_a puts a lower upper-limit on

   $$H_C \propto H_a \frac{\delta}{D}\left(\frac{\Delta x}{x}...\right)$$

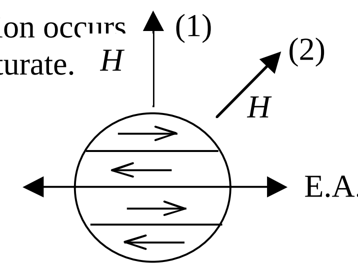
   so $Fe_{40}Ni_{60}$ should have lower H_C

9. Both of the alloys in question 8 have positive magnetostriction, will it be easier or harder to saturate them if a tensile stress is applied to the sample parallel to the field direction?

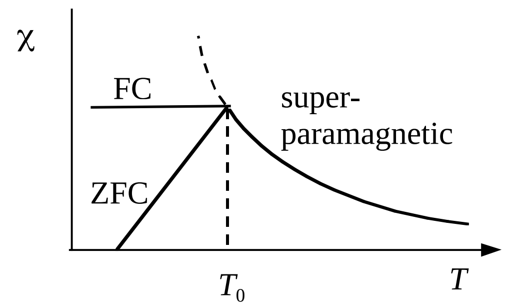
<u>ANS:</u> $\lambda > 0$ implies ***M*** tends to align with tensile direction.
Therefore, stress helps field, easier to saturate.

10. Is it easier to saturate the uniaxial anisotropy sample shown below with a field applied in direction (1) or (2)?

<u>ANS:</u> Stoner Wohlfarth curves show for case (1) saturation occurs at $H = H_a$ but for case (2) ($\theta < 90$) you can never truly saturate. Easier to saturate in case (1)



11. Describe what is going on in the data below for a group of small magnetic particles (label each solid line of the data).



<u>ANS:</u>
For $T > T_0$, the material is either paramagnetic or super-paramagnetic. The data for $T < T_0$ indicate that it must be super-paramagnetic for $T > T_0$ because spin freezing or blocking occurs below $T \propto \dfrac{KV}{k_B}$. Zero-field cooled (ZFC) particles freeze with random spins, decreasing susceptibility with T; field cooled (FC) particles freeze with spins along the easy axes most parallel to H.

12. Which material would probably have a narrower 180° domain wall thickness, hcp Co ($K_u \approx 5 \times 10^5$ J/m^3,) or Fe ($K_u \approx 4 \times 10^4$ J/m^3,)?

<u>ANS:</u>
$\delta \propto \sqrt{\dfrac{A}{K_u}}$ so cobalt has narrower domain wall. (even through Fe is cubic its domain wall is still governed by same eq.)

13. a) Given a uniaxial magnetic material $K_u \approx 10^4$ J/m^3, $\mu_0 M_s \approx 1$T, derive the equation for magnetization in a field applied perpendicular to the easy axis. (Define θ as the angle between H and M.)

<u>ANS:</u>

ANS: Fig. same as in problem 10, $H(1)$

$$g = -\mu_0 M_s H \cos\theta + K_u \cos^2\theta$$
$$g' = 0 = \mu_0 M_s H \sin\theta - 2K_u \sin\theta\cos\theta \qquad (\div\sin\theta)$$
$$\cos\theta (= \frac{M}{M_s}) = \frac{\mu_0 M_s}{2K_u} H$$

written as $\frac{M}{M_s} = \frac{H}{H_a}$ with $H_a = 2K_u / \mu_0 M_s$
or as $m = h$

b) At what field value would you expect M to be saturated?

ANS:

M saturates at $H = H_a = \frac{2K_u}{\mu_0 M_s} = \frac{2\times 10^4}{1} = 2\times 10^4 \, \frac{\text{A}}{\text{m}} (250 \text{ Oe})$