Magnetic Materials and Devices Problem Set

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15.1a) $\chi_m = \frac{M}{H} = -\mu_0 \frac{q^2 Z r^2}{4 m_e V}$ (Equation 14.15)

$$= -(4\pi \cdot 10^{-7}) \frac{(1.602 \cdot 10^{-19} C)^2 (1) (10^{-10} m)^2}{4 \cdot (9.11 \cdot 10^{-31} kg)(10^{-10} m)^3} \approx 10^{-4}$$

15.1b) $F = -V \mu_0 \chi_m H \frac{dH}{dz}$ (Equation 14.7) $= ma$ for frog

$$= -V \mu_0 \chi_m \frac{H^2}{d}$$

Rearranging and plugging in $F=ma$: $H^2 = \frac{-dma}{V \mu_0 \chi_m}$

Plugging in values: $H = \sqrt{\frac{-(0.1 m)(0.1 kg)(9.8 m/s^2)}{(0.1 m)^3 (4\pi \cdot 10^{-7})(-10^{-4})}}$

$$H = 8.83 \cdot 10^5 A/m$$

Plug into $B = \mu_0 H = (4\pi \cdot 10^{-7})(8.83 \cdot 10^5) = 1.11 T$

15.2) Plugging values into Equation 13.42 given in the problem:

$$\vec{B} = \frac{\mu_0}{4\pi} \left[\frac{3\hat{x}(\hat{x} \cdot \vec{m}) - \vec{m}}{|\vec{x}|^3} \right]$$

becomes

$$\vec{B} = \frac{\mu_0}{4\pi} \left(\frac{3\hat{x}(\hat{x} \cdot \vec{m}) - \vec{m}}{|\vec{x}|^3} \right) = \frac{\mu_0}{4\pi} \frac{\mu_B}{|\vec{x}|^3}$$

Assuming ~1Å spacing: $U = \mu_B \frac{\mu_0}{4\pi} \frac{\mu_B}{|\vec{x}|^3}$

$$= \left(9.274 \cdot 10^{-24} \tfrac{J}{T}\right)^2 \frac{4\pi \cdot 10^{-7}}{4\pi} \cdot (10^{-10})^3$$

$$= 8.6 \cdot 10^{-24} J \rightarrow 5 \cdot 10^{-5} eV$$

Compared to electrostatic potential energy: $U = e^2 \frac{1}{4\pi\varepsilon_0} \frac{1}{r} = \frac{(1.6 \cdot 10^{-19})^2}{4\pi (8.85 \cdot 10^{-12})(10^{-10})}$

$$U = 2.3 \cdot 10^{-18} J \rightarrow 14 eV$$

15.3a) $E = \frac{1}{2\mu}\int B^2 dV$ (Equation 14.33: energy stored in a magnetic field)

The field from the permanent magnet tries to minimize its energy by increasing μ, which produces an attractive force between the permanent magnet and the unmagnetized ferromagnet caused by the gradient of the potential. Thus, the field lines bend towards the ferromagnet, causing a stronger magnetic field gradient in the region near the ferromagnet which attracts the permanent magnet since the ferromagnet is in a region of higher $\vec{B}$.

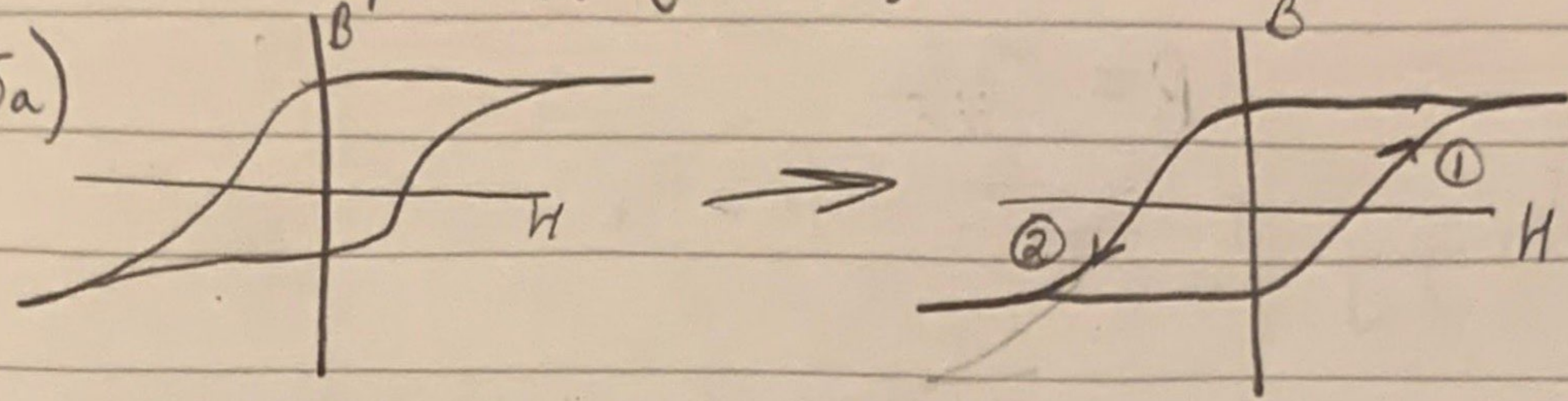
15.3b) Opposite poles attract since the dipoles move in order to minimize $U = -\vec{m}\cdot\vec{B}$. Energy minimization is the primary goal here. Since the field is stronger near the other magnet's pole, a net force pulls each dipole into the region of stronger field, and thus, they attract.

15.4) saturation magnetization: when all spins point in the same direction
iron has 2 free e^- per atom which each contribute one Bohr magneton:

$$\left(\frac{6.022\cdot10^{23}\text{ atoms}}{55.85\text{ g}}\right)\left(\frac{7.86\text{ g}}{1\text{ cm}^3}\right)\left(\frac{100\text{ cm}^3}{1\text{ m}^3}\right)\left(2\cdot\frac{9.27\cdot10^{-24}\text{ J/T}}{1\text{ atom}}\right)$$
$$= 1.57\cdot10^{6}\text{ A/m}$$

$$M \rightarrow \frac{1}{\mu_0}\left(\vec{B} - \vec{H}\right)$$

15.5a)

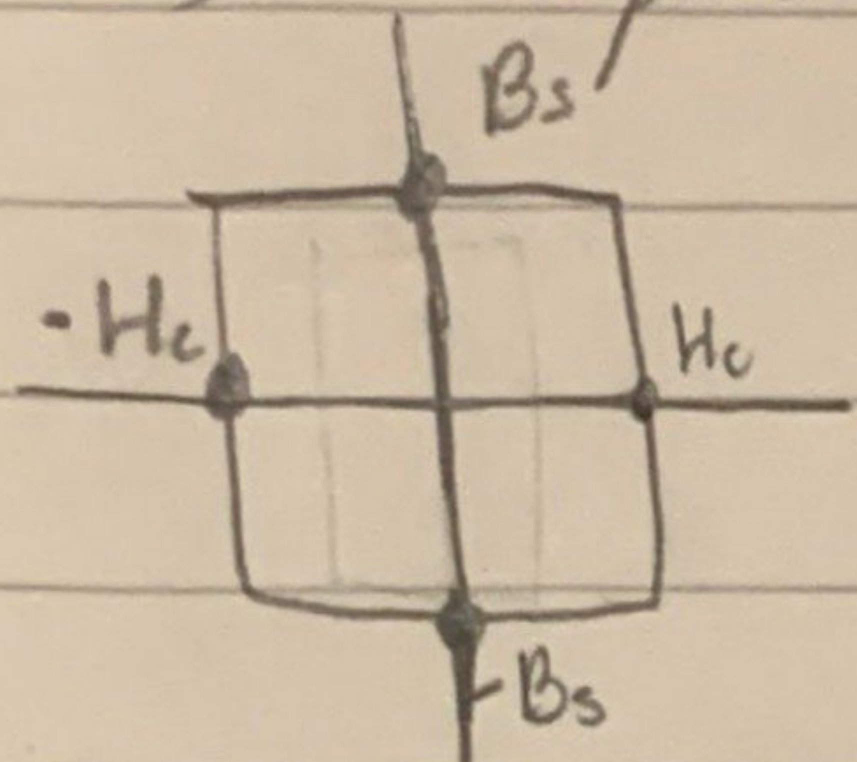


$$\frac{\partial U}{\partial t} = \vec{E} \cdot \frac{\partial \vec{D}}{\partial t} + \vec{H} \cdot \frac{\partial \vec{B}}{\partial t}$$

For energy dissipated around the loop:

$$\underbrace{\oint \frac{\partial U}{\partial t}\, dt}_{\text{energy}} = \oint H \frac{\partial B}{\partial t}\, dt = \overbrace{\int_{①} H\,dB - \int_{②} H\,dB}^{\text{area}}$$

15.5b) Since power dissipated = loop's area, assume a square loop.



$B_s = 1.57 \cdot 10^6\ \frac{A}{m}$ from Problem 15.4

$H_c = \mu_0 \cdot 4 \cdot 10^3\ A/m$

$$E = 2 \cdot 1.57 \cdot 10^6\,A/m \cdot 2 \cdot 4\pi \cdot 10^{-7}\,H/m \cdot 4 \cdot 10^3\,A/m$$

$$E = 3.16 \cdot 10^4\ J/m^3$$

$$P = \frac{3.16 \cdot 10^4\,J}{1\,m^3} \cdot \left(\frac{1\,m^3}{7860\,kg}\right)(60\,Hz) = 241\,W$$

14.2.1

15.6) coercivity of γ- Fe_2O_3 is 300 Oe with a Curie T of 600°C

Assuming an infinite straight wire: $\oint B \cdot d\vec{l} = \mu_0 \int \vec{J} \cdot d\vec{A}$

$$B \cdot 2\pi r = \mu_0 I$$

$$B = \frac{\mu_0 I}{2\pi r}$$

Rearranging: $I = \frac{B \cdot 2\pi r}{\mu_0} = H 2\pi r$

For erasing to occur, the field must be on the order of the coercivity (300 Oe for $\gamma - Fe_2O_3 \approx 23873\ A/m$)

Plugging in: $I = (23873\ A/m) \cdot 2\pi \cdot 0.01\,m = 1500\,m$