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Q1) A field due to charge q, $E = \dfrac{q}{4\pi\epsilon_0 r^2}\hat{r}$

The induced dipole moment $= p = \alpha E = \dfrac{\alpha q}{4\pi\epsilon_0 r^2}\hat{r}$

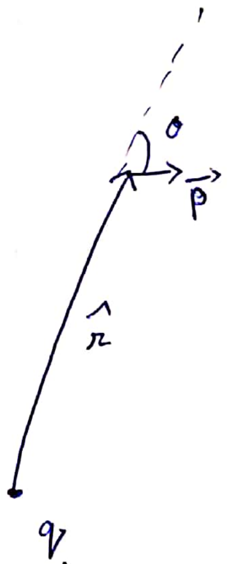
E_{dipole} at distance $r = \dfrac{-2p}{4\pi\epsilon_0 r^3}\hat{r}$

Therefore force $= F = q E_{dip}(r) = -2\alpha\left(\dfrac{q}{4\pi\epsilon_0}\right)^2 \dfrac{1}{r^5}\hat{r}$

Q2) a) The force on a dipole

$\Rightarrow F = (\bar{p} \cdot \bar{\nabla})\bar{E}$

Here $\vec{E} = \dfrac{q}{4\pi\epsilon_0 r^2}\hat{r}$



solving for F we get

$$F = \frac{q}{4\pi\epsilon_0 r^3}\left(\bar{p} - 3\left(\frac{\bar{p}\cdot\bar{r}}{r}\right)\hat{r}\right)$$

$$= \frac{q}{4\pi\epsilon_0 r^3}\left(\bar{p} - 3\, pr\cos\theta\, \hat{r}\right)$$

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b) $\bar{F}_q = q\vec{E}_{dip} = -F_{dip}$

$$= \frac{q}{4\pi\epsilon_0 r^3}\left[3pr\cos\theta\,\hat{r} - \bar{p}\right]$$

Q3) $\sigma = \frac{ne^2\tau}{m}$

$$n = \frac{6.02\times10^{23}\times 8.88\times10^6}{63.57} = 8.38\times10^{28}\ m^{-3}$$

$$\sigma = \frac{8.38\times10^{28}\times(1.6\times10^{-19})^2\times2.3\times10^{-14}}{9.11\times10^{-31}}$$

$$= 5.422\times10^7\ \Omega^{-1}m^{-1}$$

$$K = \sigma C_{WF} T = (5.422\times10^7)(2.31\times10^{-8})300$$

$$= 376\ W m^{-1} K^{-2}$$

Q4) $\varepsilon_r = 1.0024$ at NTP

$\varepsilon_0 = 8.854\times10^{-12}\ Fm^{-1}$

$N = 2.7\times10^{25}$ atom / m^3

$P = N\alpha_e E$

$\alpha_e = \frac{P}{NE}$

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$$P = \varepsilon_0 (\varepsilon_r - 1) E$$

$$\alpha = \frac{\varepsilon_0 (\varepsilon_r - 1) E}{NE} = \frac{\varepsilon_0 (\varepsilon_r - 1)}{N}$$

$$\alpha_e = \frac{8.85 \times 10^{-12} (1.0024 - 1)}{2.7 \times 10^{25}}$$

$$\alpha_e = 7.9 \times 10^{-40} \ F m^{-2}$$

Q5) $$\varepsilon_r = 1 + \frac{N \alpha_e}{\varepsilon_0}$$

$$N = N_A d / M_{at}$$

$$N = 6.02 \times 10^{23} /mol \times 1.8 \ g/cm^3 / 39.95 \ g/mol$$

$$= 2.71 \times 10^{22} \ cm^{-3}$$

$$\varepsilon_r = 1 + \frac{(2.71 \times 10^{28} m^{-3})(1.7 \times 10^{-40} F m^2)}{(8.85 \times 10^{-12} F m^{-1})}$$

$$= 1.55$$

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Q6) We know that

$$\alpha = \frac{\varepsilon_0(\varepsilon_r - 1)}{N}$$

For N we use ~~$P\cancel{V} = nRT$~~ $P_m = \rho RT$

and $$N = \frac{N_a \rho}{m}$$

Substituting we get

$$P = NKT$$

$$N = \frac{P}{KT}$$

Given $T = 273\ K$ & $P = 1\ atm = 1.01 \times 10^5\ N/m^2$

$$N = \frac{1.01 \times 10^5}{1.38 \times 10^{-23} \times 273}$$

$$= 2.68 \times 10^{25}\ m^{-3}$$

$$\varepsilon_r = 1 + \frac{\alpha N}{\varepsilon_0} = 1 + \frac{2.18 \times 10^{-40} \times 2.68 \times 10^{25}}{8.85 \times 10^{-12}}$$

$$= 1 + 0.66 \times 10^{-3}$$

$$= 1.00066$$

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Q7) Magnetisation = Magnetic susceptibility × Magnetic Field strength

$= -0.3 \times 10^{-5} \times 1500$

$M = -0.0045\ A/m$

$B = \mu_0 (M + H) = \mu_0 (1 + K) H$

$= 4\pi \times 10^{-7} \times 0.9965 \times 1500$

$= 1.884 \times 10^{-3}\ T$

Q8) Magnetic field strength, $H = \frac{Ni}{l} = \frac{400 \times 15}{0.25} = 24000\ A/m$

$\mu_r = \chi + 1 = 3.13 \times 10^{-4} + 1 = 1.000313$

Flux Density $= \mu_0 \mu_r H = 12.56 \times 10^{-7} \times 24000$

$= 301440 \times 10^{-7}\ T$

Magnetization, $M = \chi H = 3.13 \times 10^{-4} \times 2.4 \times 10^{4}$

$M = 7.512\ Am^{-1}$

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Q9) $B = \mu_0 (1 + \chi) H$

$H = 1000 \ Am^{-1}$

$B = 4\pi \times 10^{-7} \times (1 + (-0.3 \times 10^{-5})) \times 1000$

$$\boxed{B = 1.256 \times 10^{-3} \ T}$$

$M = \chi H$

$= -0.3 \times 10^{-5} \times 1000$

$$\boxed{M = -3 \times 10^{-3} \ Am^{-1}}$$

Q10) $B = \mu_0 (M + H)$

$H = \left[\frac{B}{\mu_0} - M\right]$

$= \frac{0.00314}{4\pi \times 10^{-7}} - 2300$

$$\boxed{H = 198.7326 \ Am^{-}}$$

Susceptibility $\chi = \frac{M}{H} \ (\mu_r - 1)$

$\mu_r = \cancel{12.573} \ \frac{M}{H} + 1$

$$\boxed{\mu_r = \frac{2300}{198.7326} + 1 = 12.573}$$

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