Physics 114 - March 23, 2010

- Hope to hand back EXAM 2 next Tuesday
- P.S. 8 (Short) posted

Induction

$$\Phi_M = \int_{loop} \vec{B} \cdot d\vec{A}$$

$$\mathcal{E} = \int_{loop} \vec{E} \cdot d\vec{l} = -\frac{d\Phi_M}{dt}$$

↑ induced EMF

All very Important

Lenz's Law - An induced current in a closed conducting loop will appear in such a way as to oppose the change that created it

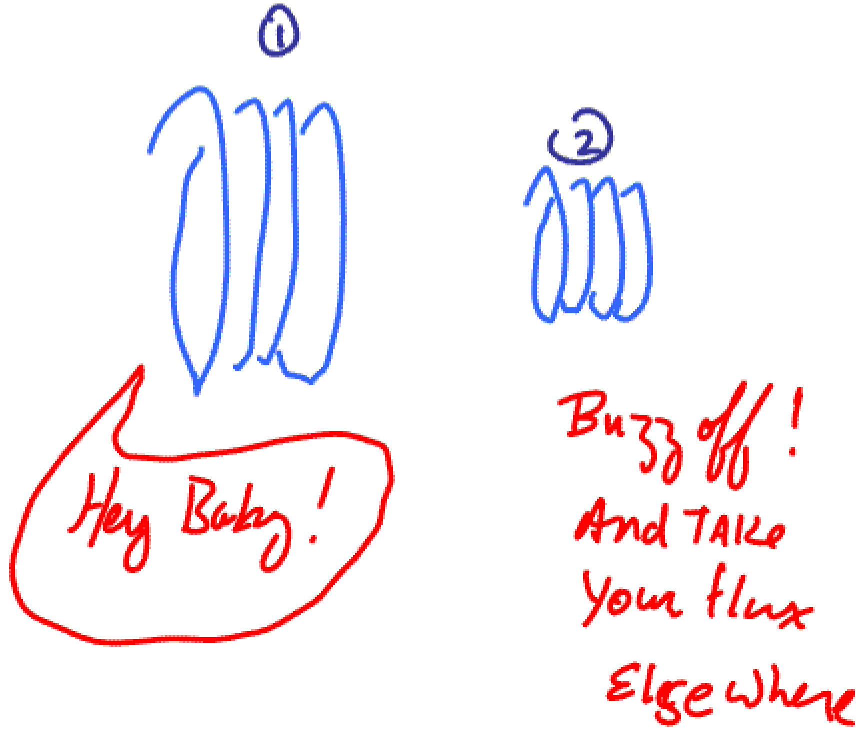
Gives the direction of induced effect

Self inductance

$$\phi_M \propto i$$

$$EMF \propto \frac{d\phi_M}{dt} \propto \frac{di}{dt}$$

Mutual inductance



$$\phi_{M_{2\ \text{due to}\ 1}} \propto i_1$$

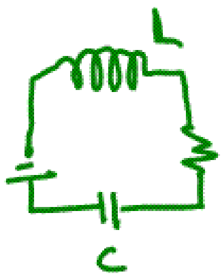
$$EMF_{\substack{\text{in}\ 2 \\ \text{due to}\ 1}} \propto \frac{di_1}{dt}$$

Self Inductance

$$\phi_m = L\,i$$

L ≡ constant of self-inductance

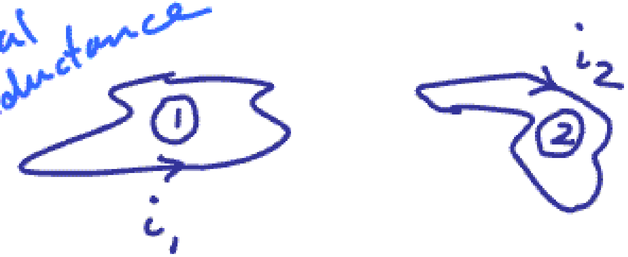
$$\mathcal{E} = -\frac{d\phi_m}{dt} = -L\frac{di}{dt}$$



units Henrys

$$\mathcal{E} = -L\frac{di}{dt}$$

Mutual Inductance



$$\phi_{m_{2}} = M\,i_{1}$$

$$\phi_{m_{1}} = M\,i_{2}$$

same "M" cross-talk dictated by geometry

M ≡ constant of mutual inductance

$$\mathcal{E}_{2 \text{ by } 1} = -M\frac{di_1}{dt}$$

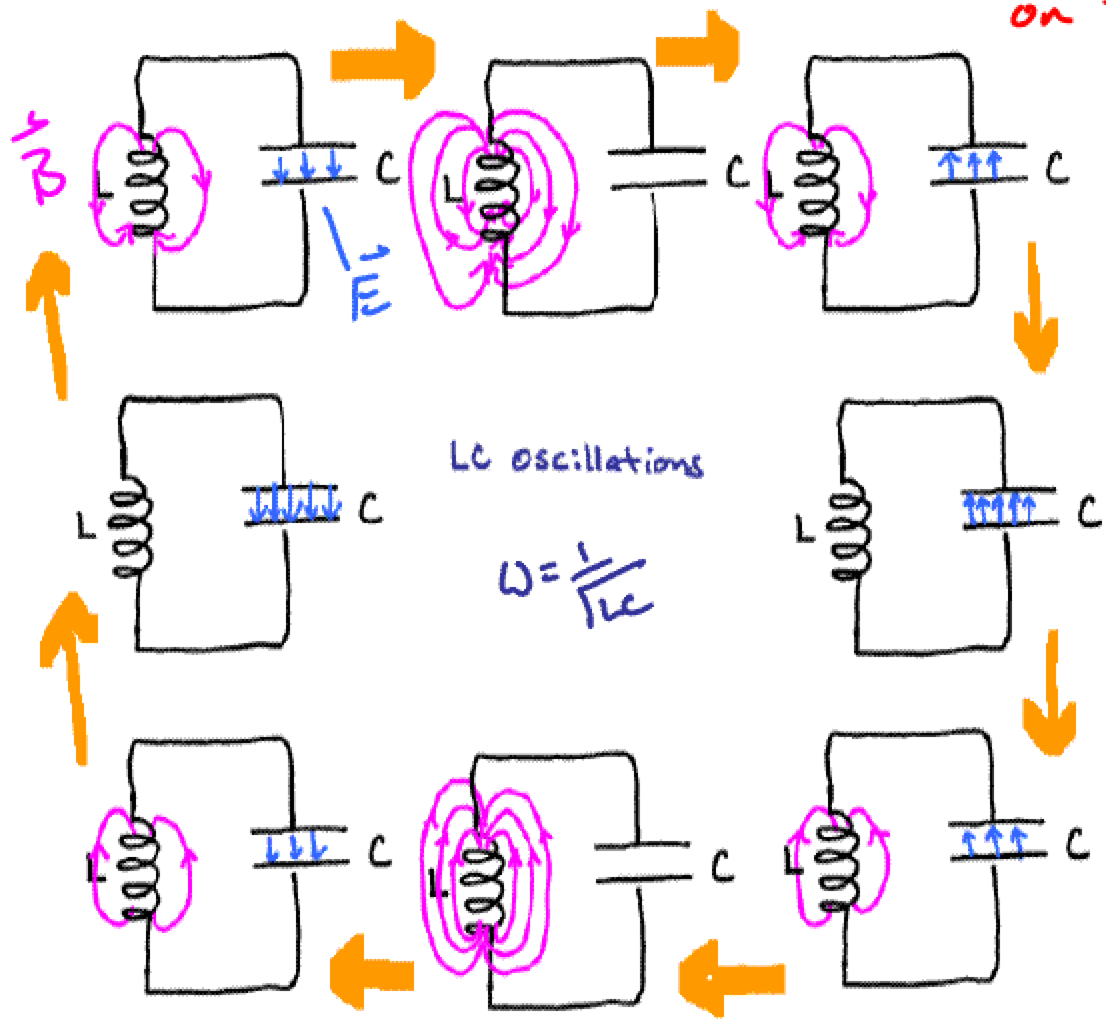
$$\mathcal{E}_{1 \text{ by } 2} = -M\frac{di_2}{dt}$$

unless problem is specifically about mutual inductance ... usually treat inductance in a circuit as self-inductance

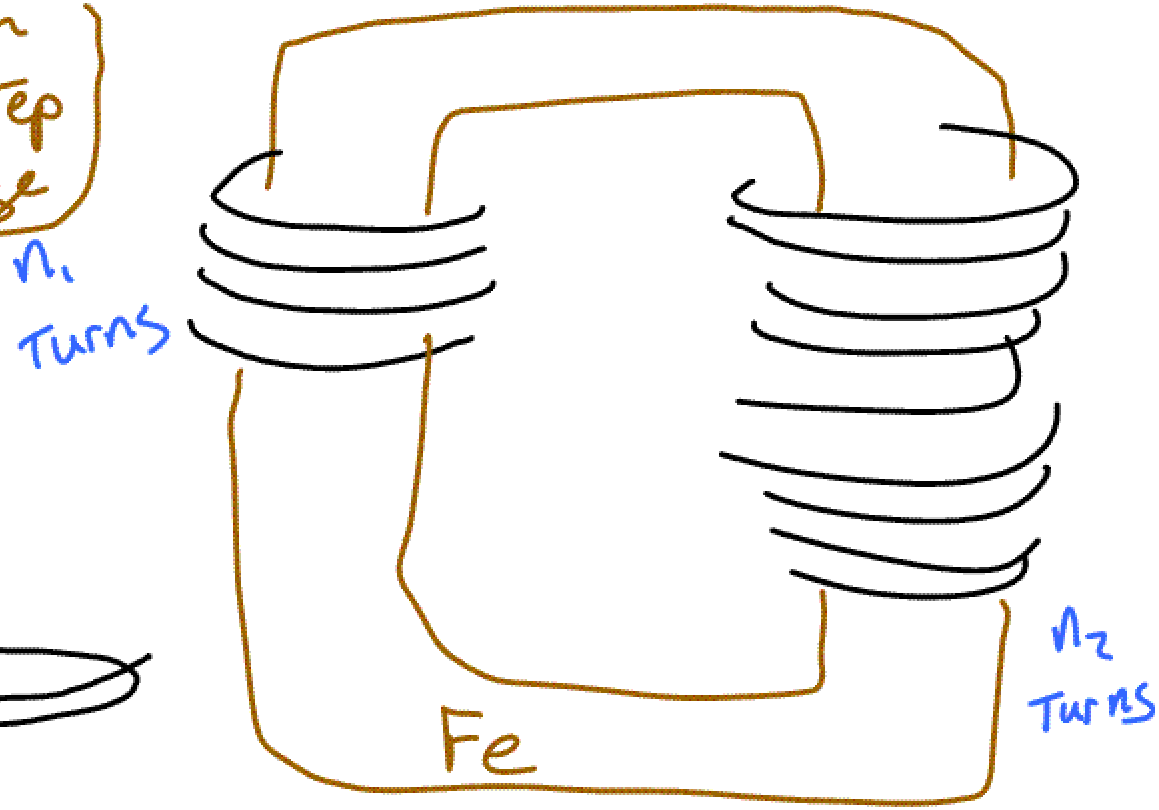
We won't spend time studying circuits with inductors. Too many other things to do ... but interesting things can happen. For example

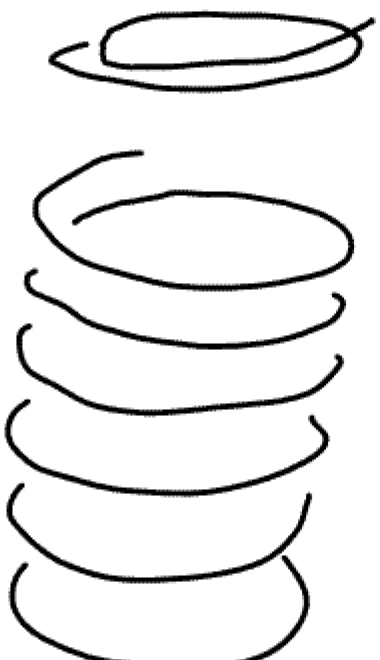
No - you are NOT responsible for LC circuits on test

Energy oscillating back + forth between $\vec{B}$ in inductor and $\vec{E}$ in capacitor in an LC circuit.

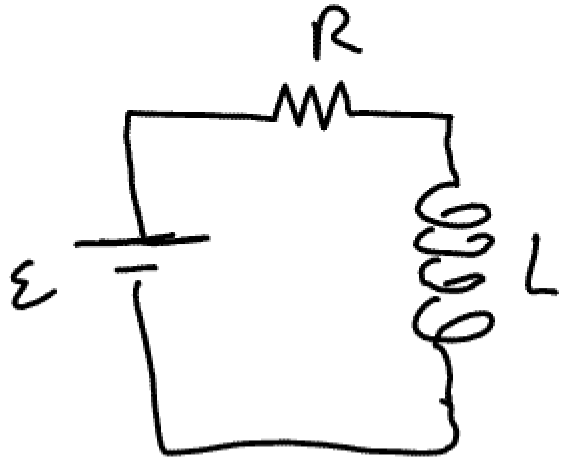


Transformers can step up or step down voltage





Energy + the Magnetic Field



$$\mathcal{E} - iR - L\frac{di}{dt} = 0$$

$$\mathcal{E} = iR + L\frac{di}{dt}$$

$$\mathcal{E}i = i^2R + Li\frac{di}{dt}$$

- $\mathcal{E}i$: Power output of Battery
- i^2R: Power dissipated in Resistor
- $Li\frac{di}{dt}$: Power going into the inductor

$$\frac{dU_B}{dt} \equiv \text{Power into inductor} = L\,i\,\frac{di}{dt}$$

Similar

Recall $U_{capacitor\ E} = \frac{1}{2}CV^2$

$$dU_B = L\,i\,di$$

Total E in B $\rightarrow$ $$U_B = \int_0^I L\,i\,di = \frac{1}{2}LI^2$$

Having determined this expression for energy stored in an inductor, lets use it to examine the special case for a solenoid and see what it can tell us energy in the B field

Solenoid i, n turns/length, length ℓ

Area A

$$B = \mu_0 n i \quad \text{(inside)}$$
$$= 0 \quad \text{(outside)}$$

What is Energy density in $B \equiv u_B$

$$u_B = \frac{U_B}{A\ell} = \frac{\frac{1}{2}Li^2}{A\ell}$$

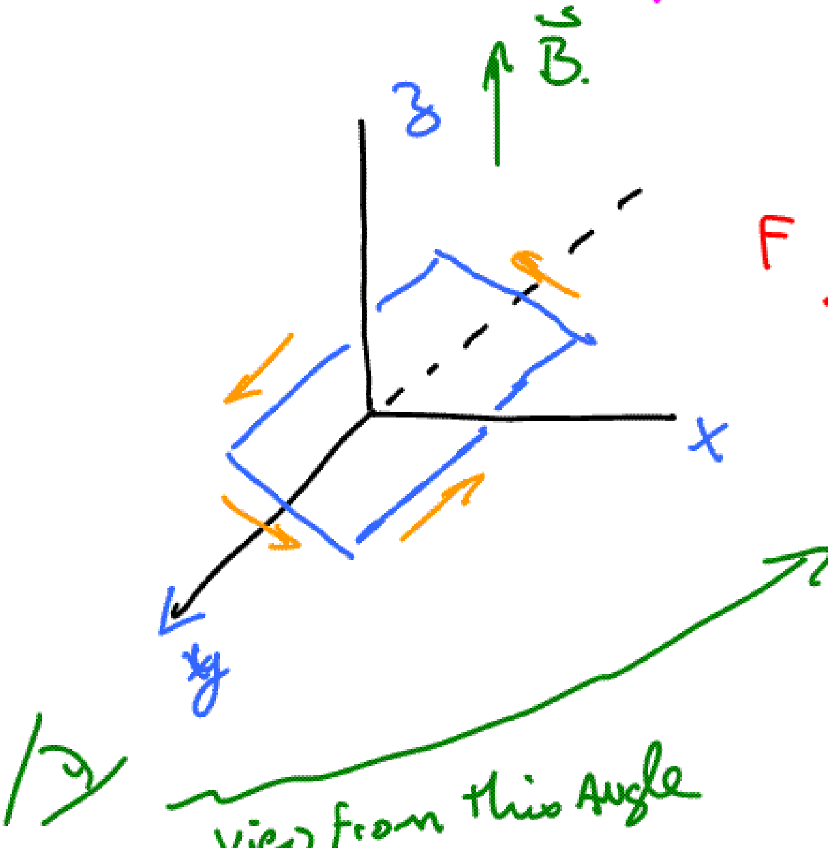
$$\phi_M = Li = BAn\ell$$

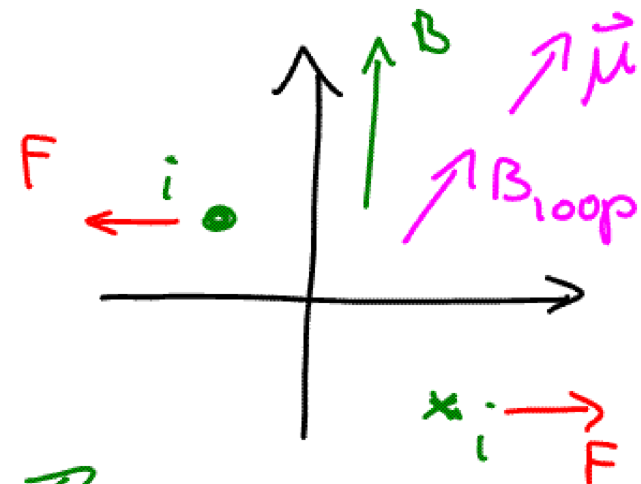
($B = \mu_0 n i$) $\Rightarrow L = \mu_0 n^2 A\ell$

$$u_B = \frac{1}{2}\frac{(\mu_0 n^2 A\ell)}{A\ell} i^2 = \frac{1}{2}\mu_0 i^2 n^2 = \frac{B^2}{2\mu_0}$$

$$u_B = \frac{|\vec{B}|^2}{2\mu_0}$$ → Energy density in B field

magnetic moment = $|\vec{\mu}| = |\vec{B}| A$



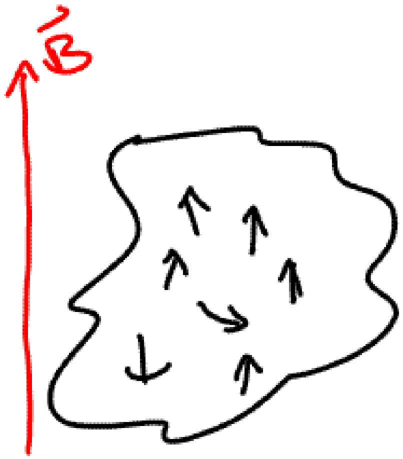


Torque = $\vec{\mu} \times \vec{B}$

Magnetism in Materials

Paramagnetic

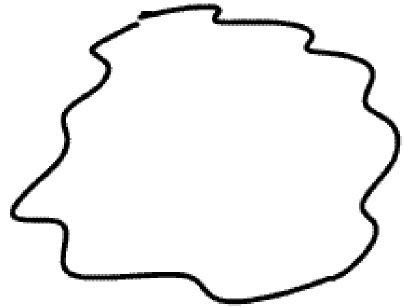
Natural Dipoles



Torque from $\vec{B}$
Aligns more Dipoles
along $\vec{B}$

→ $\vec{B}$ increased

Diamagnetic



No Dipole

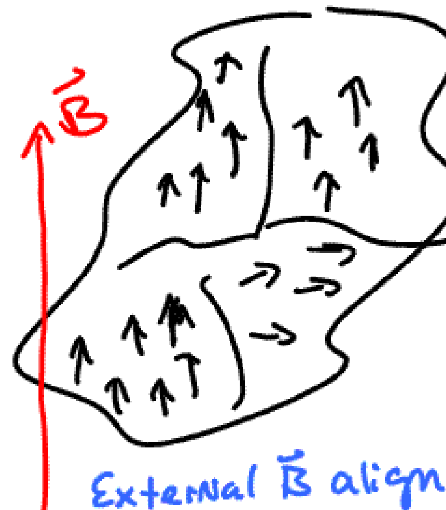
Induced Dipoles

oppose External $\vec{B}$

→ $\vec{B}$ weakened

Ferromagnetic

Strong Dipoles in Domains of local Alignment



External $\vec{B}$ aligns more Domains along $\vec{B}$

→ $\vec{B}$ increased