**EE 5200 - Lecture 4** (lectures 1 & 3 don't exist) Mon Sep 9, 2019

**Topics for Today**:

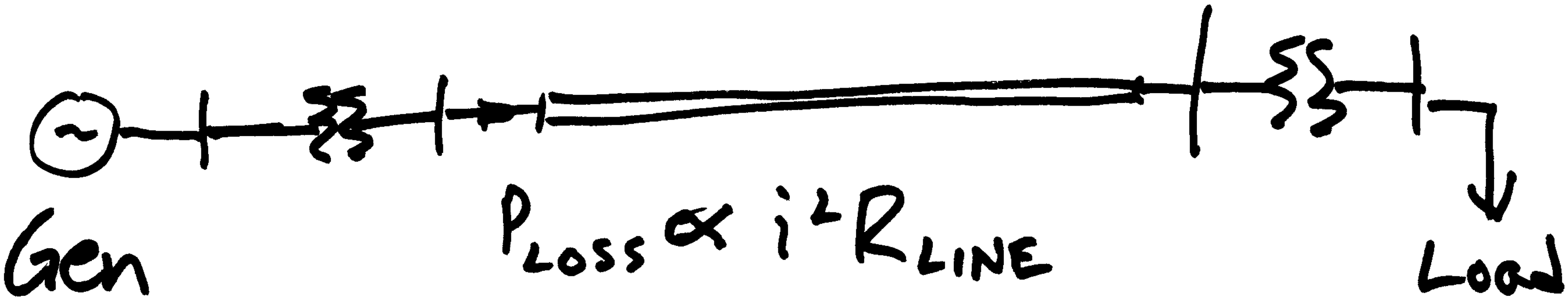
- Announcements
  - EE5200-L@mtu.edu is soon up and working. Use it.
  - Web page: http://www.ece.mtu.edu/faculty/bamork/ee5200/
  - Bring calculator to lectures, for in-class sample calculations.
  - Buy a 3-ring binder for course materials, print 2/page 2-sided.
  - Office hrs: initially set for M,W,F 2-3pm Eastern Time
  - Office: EERC 614. Phone: 906.487.2857
  - Ch.1 Solutions posted on web page, finish review Sept. 13th.
  - First set of graded exercises is posted, due Mon Sept 11th.
  - Ch.2 material - aggressively review it, Ch.2 solutions posted.

- Coverage for Review:
  - Chapter 2 problems (phasors, 3 phase analysis)
  - Click on Pre-Req Mat'ls - Euler's Idenity, EE3120 Review
  - Matlab quickstart tutorial, will be using Matlab starting Week 3.
  - Plan on initiating a survey to get a handle on your skill levels.

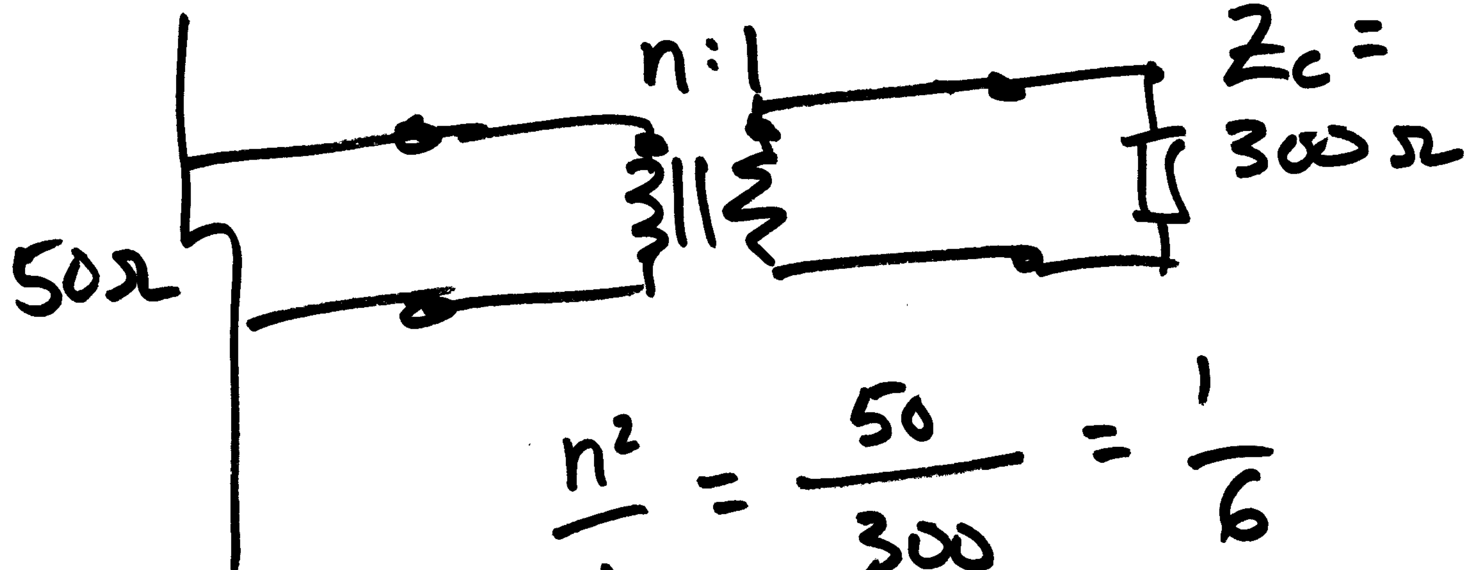
## **Prerequisite Material, Useful References** (see course web page)

- Euler's Identity - The foundation of phasor analysis, as well as hyperbolic functions (used for long transmission lines)
- Basic Circuit Analysis, Thevenizing, Phasor Analysis, Impedance, P,Q,S, etc.: EE3120 pre-req practice problems | Solutions
- Basic 3-Phase Phasor Analysis - Review problem from EE3120
- Magnetic Circuits - quick review and introduction of how a transformer works
- Mutual Inductance - concept handout from EE3120 (refer to Section 2.2 of your text)
- Transformers 101 - Everything you wanted (or suddenly need to know) about transformers but were afraid to ask...
- Delta-Wye Transformer - detailed example with solution from EE3120
- EE 4221 Pre-Req Course Description
- EE 4222 Pre-Req Course Description
- Pre-Req Review Videos with Notes (from 2003 Archives)
    - Basic Circuit Analysis, Phasors, Three Phase Phasors: Lect 1 (skip first 12 mins) | Lect 1 Notes
    - Phasor Diagrams, Ideal Transformers, Nodal Analysis: Lect 2 (skip first 6:20) | Lect 2 Notes
    - Nodal Analysis, 3-phase circuits, Deltas and Wyes, Per Unit System: Lect 3 (skip first 3 mins) | Lect 3 Notes
    - Active & Passive Sign Convention for power flow, Per Unit, Transformers, Symmetrical Components: Lect 4 (skip first 2 mins) | Lect 4 Notes
    - Transformers, Induced Voltage & Polarity Marks, Phase Shift: Lect 5 (skip 3:45 - 5:20) | Lect 5 Notes
    - Phase Shift in Transformers, Phasor Diagrams, Application of Symmetrical Components: Lect 6 (skip first 3 mins) | Lect 6 Notes
- Matlab Programming (fundamentals). Tutorials: [ Part 1 Notes | Part 1 Video ]; [ Part 2 Notes | Part 2 Video ]
    - Sample .m files from above tutorials: | for_ex.m | r2p.m | for_if_ex.m | while_ex.m | ft.m |
- Symmetrical Components - the basics.

# Transformers -

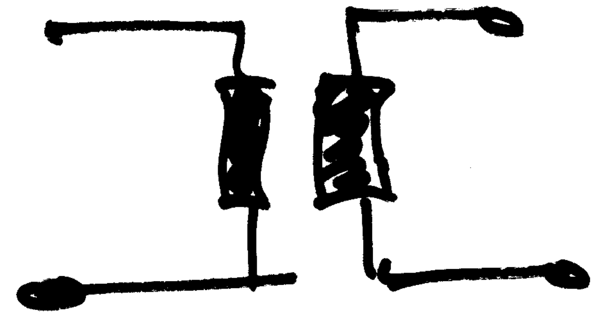



$P_{LOSS} \propto i^2 R_{LINE}$




$$\frac{n^2}{1} = \frac{50}{300} = \frac{1}{6}$$

$$n^2 = \frac{1}{6} \Rightarrow n = \frac{1}{\sqrt{6}}$$

$$\bar{S}_1 = \bar{S}_2$$

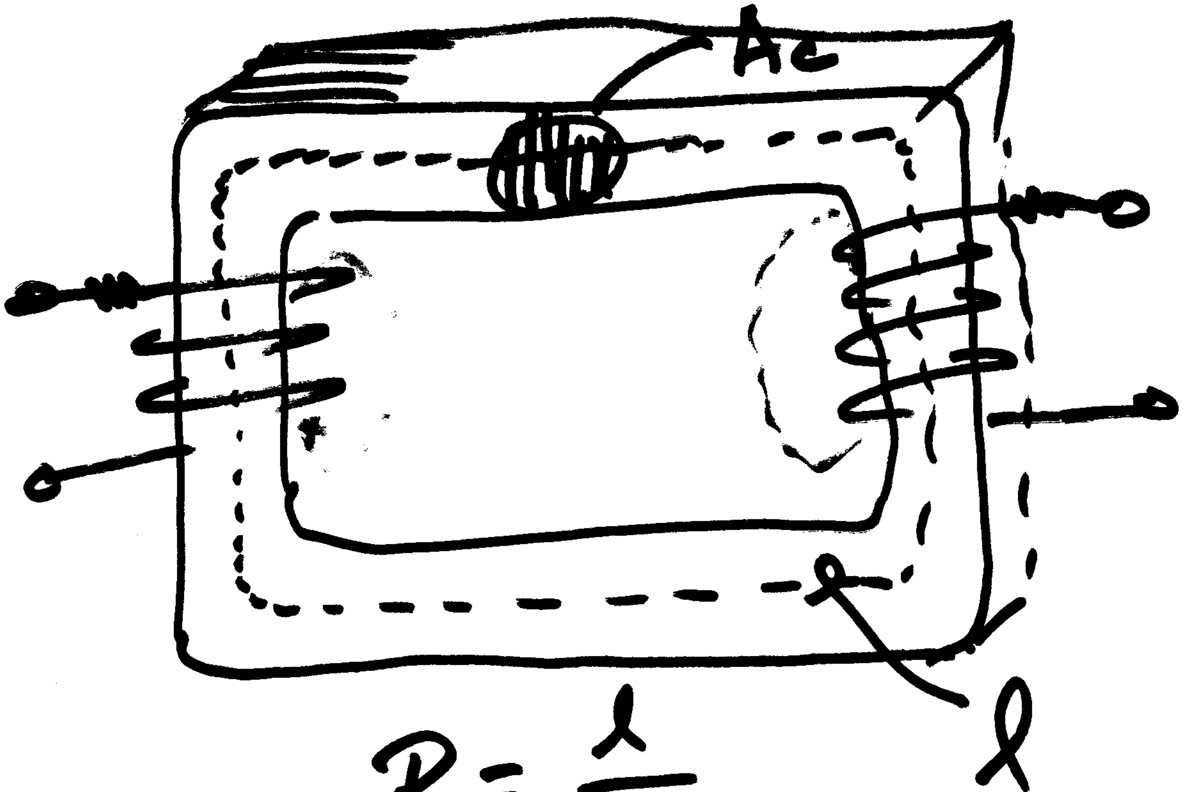
(in) (out)

$$\tilde{V}_1 \tilde{I}_1^* = \tilde{V}_2 \tilde{I}_2^*$$

IDEAL!

## Non-Ideal

- Flux Leakage
- Winding Resistance
- Magnetic Saturation
- Core Losses < Eddy Currents, Hysteresis



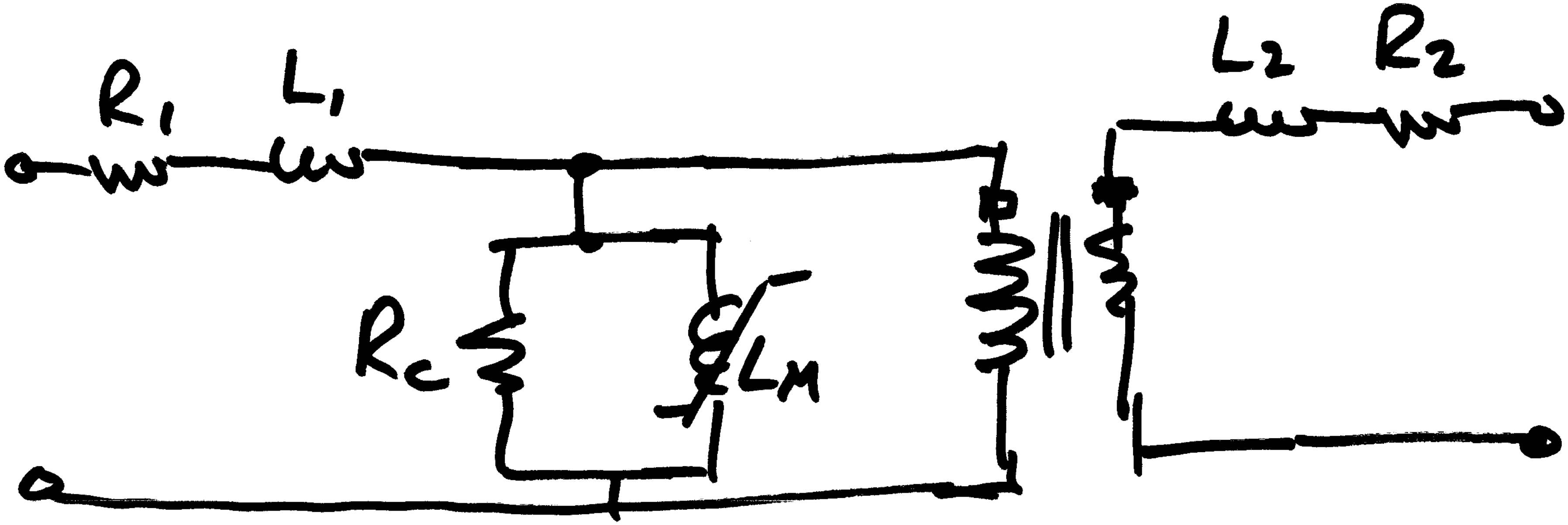

Laminations

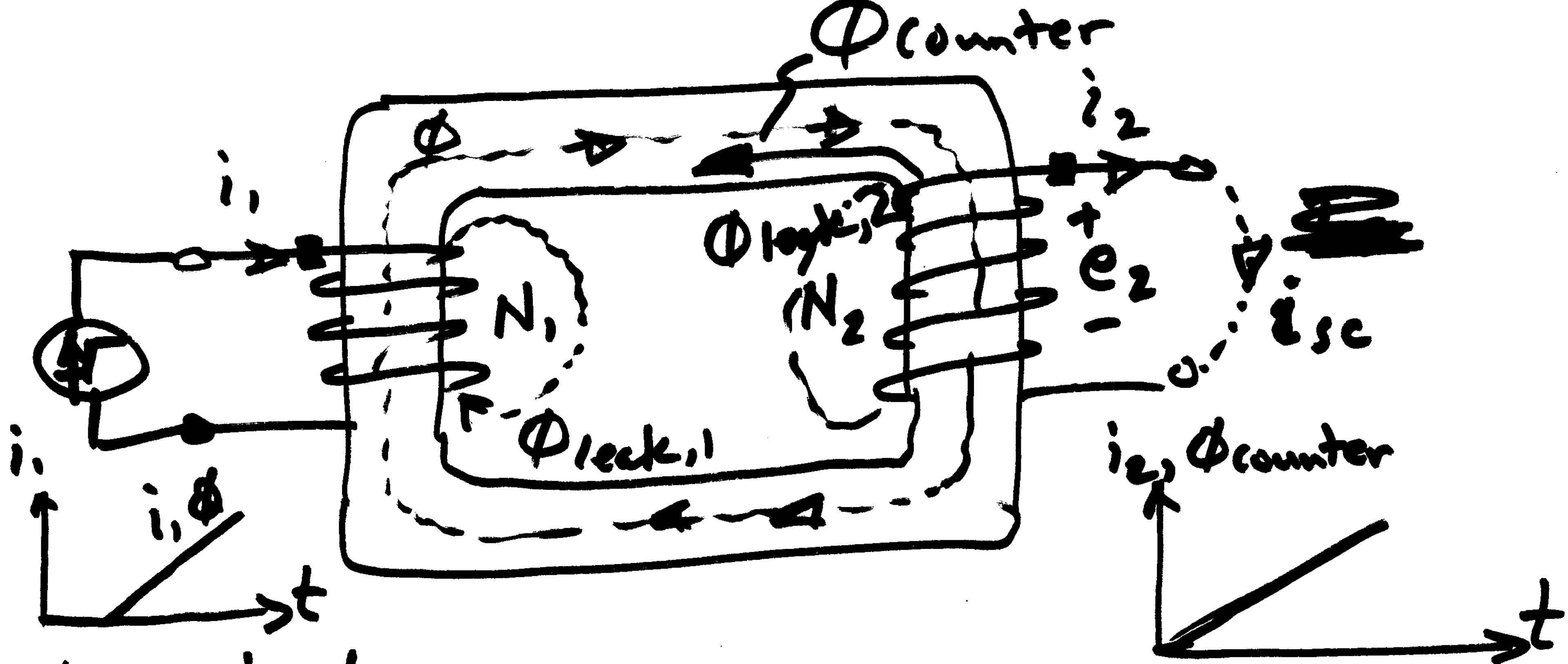
$$P_E \propto \frac{1}{\tau^2}$$

$$R = \frac{l}{\mu A_c}$$

$4\pi \times 10^{-7}$

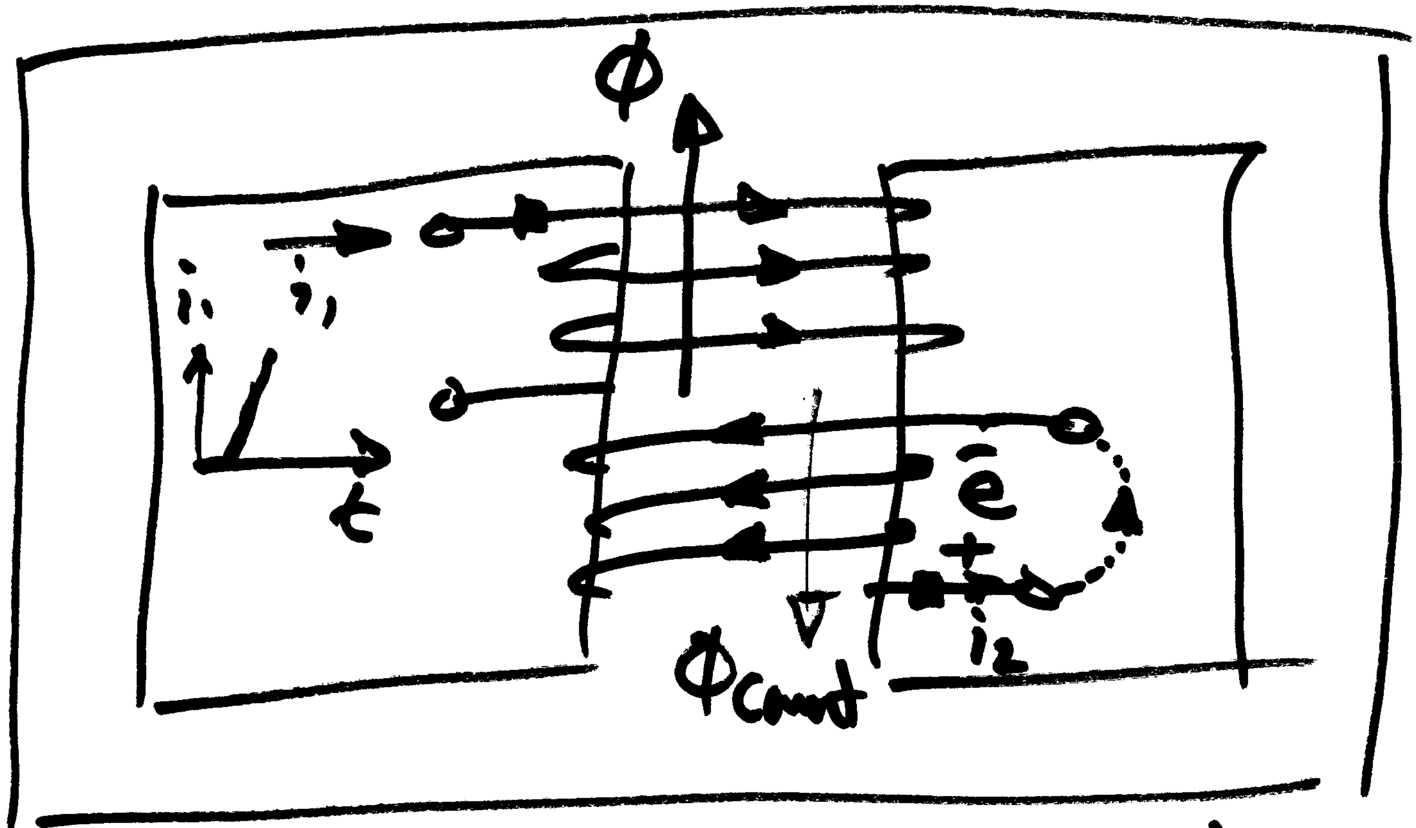
$$\mu = \mu_r \mu_0$$





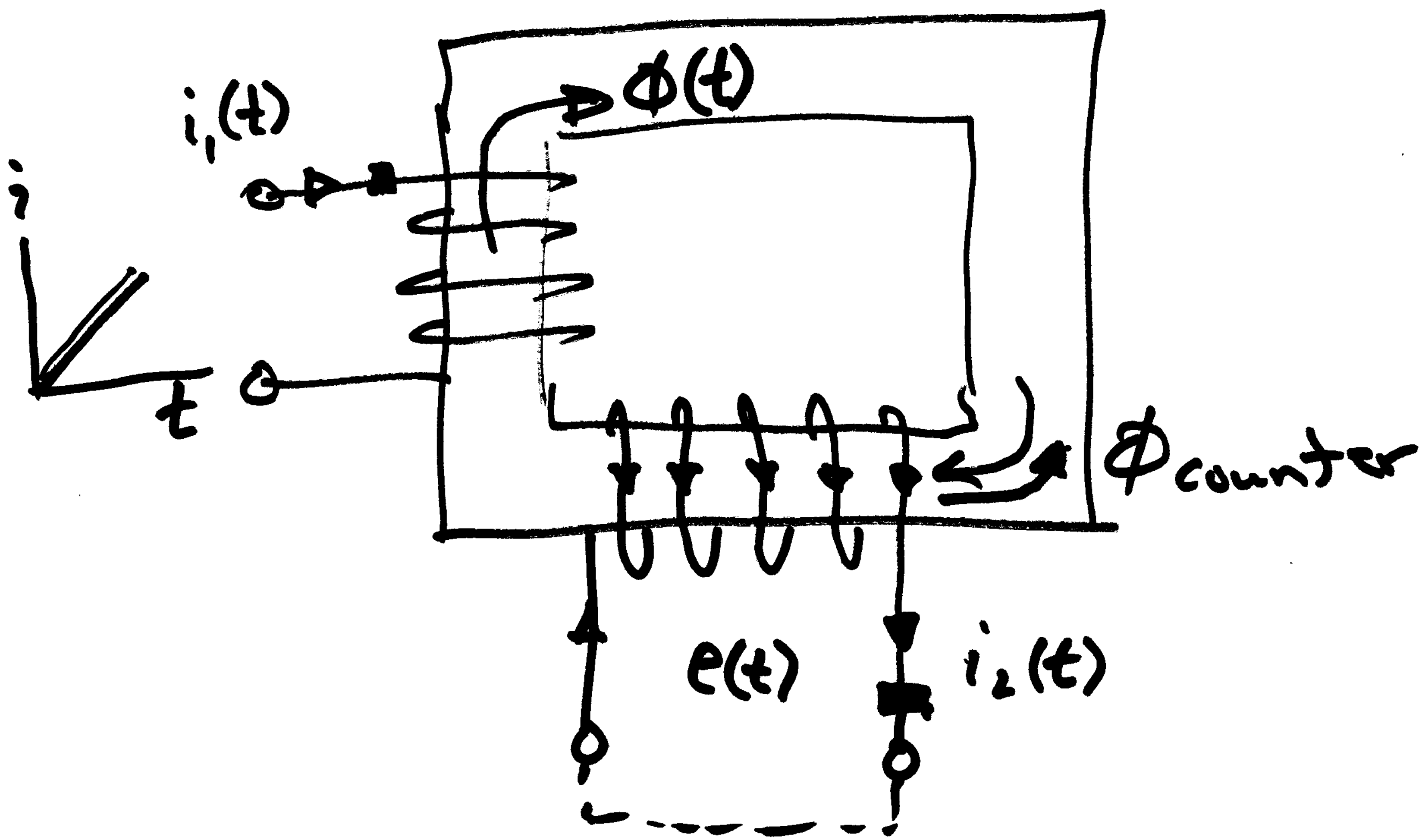

## Lenz's Law

- Induced voltage causes a current, if coil is shorted, that produces a flux which cancels the $\frac{d\phi}{dt}$ that induced the voltage in first place.




$$e_{ind} = N\frac{d\Phi}{dt} = -\frac{d\lambda}{dt}$$

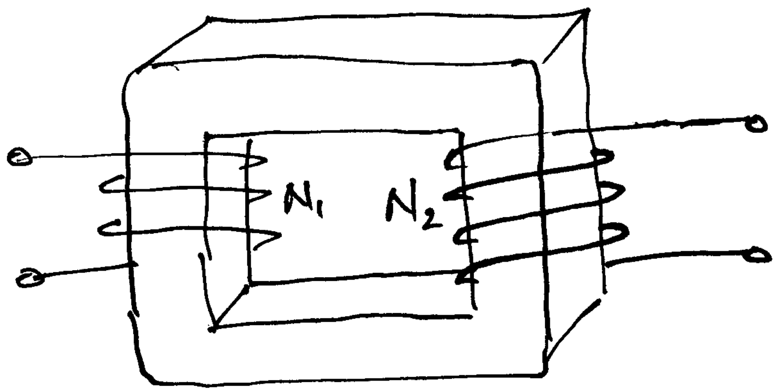
Faraday ↑ Lenz



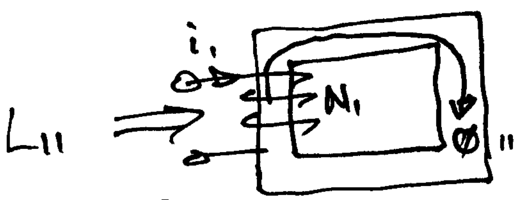
i₁(t)
Φ(t)
i
t
Φcounter
e(t)
i₂(t)

# MUTUAL INDUCTANCE

- Section 4.4 in text, pp. 73-77.
- see also handout on Basic Magnetic Circuits

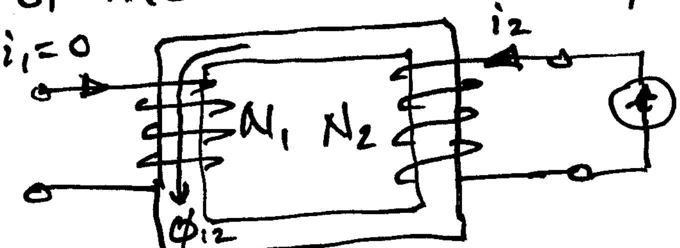



- Fundametal definition of inductance: $L = \frac{\lambda}{i} = \frac{N\Phi}{i}$



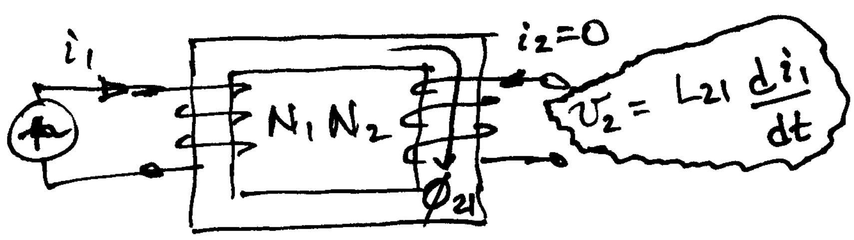

Self-Inductance

$$L_{11} = \frac{N_1 \Phi_{11}}{i_1} = \frac{\lambda_{11}}{i_1} = \frac{N_1^2}{\mathcal{R}}$$



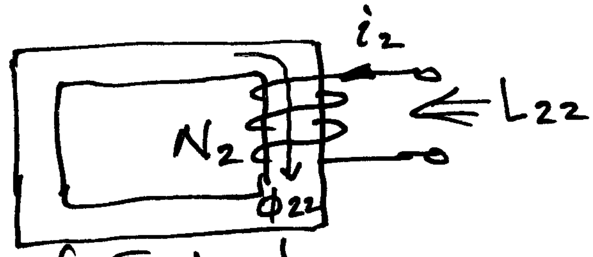

Mutual Inductance

$$L_{12} = \frac{N_1 \Phi_{12}}{i_2} = \frac{\lambda_{12}}{i} = \frac{N_1 N_2}{\mathcal{R}}$$




$$L_{21} = \frac{N_2 \Phi_{21}}{i_1} = \frac{\lambda_{21}}{i} = \frac{N_2 N_1}{\mathcal{R}}$$

Mutual Inductance

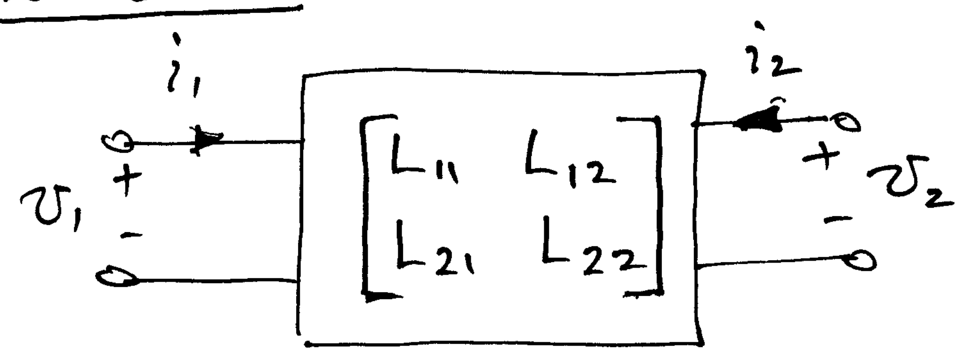



Self Inductance

$$L_{22} = \frac{N_2 \Phi_{22}}{i_2} = \frac{\lambda_{22}}{i_2} = \frac{N_2^2}{\mathcal{R}}$$

# How to Use the Concept of Mutual Inductance

<u>Two-Port Device:</u>




<u>Note:</u> Reference direction of currents is <u>into</u> terminals at (+) side of voltage.

<u>In time domain:</u>

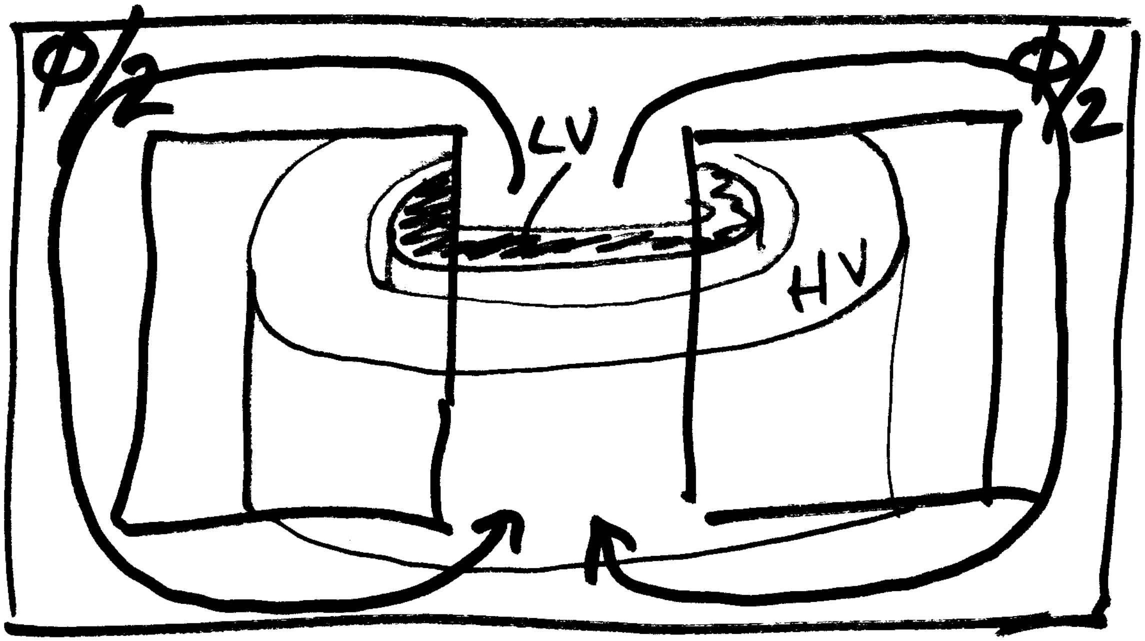
$$\begin{bmatrix} v_1 \\ v_2 \end{bmatrix} = \begin{bmatrix} L_{11} & L_{12} \\ L_{21} & L_{22} \end{bmatrix} \begin{bmatrix} \frac{di_1}{dt} \\ \frac{di_2}{dt} \end{bmatrix}$$

<u>In phasor domain:</u>

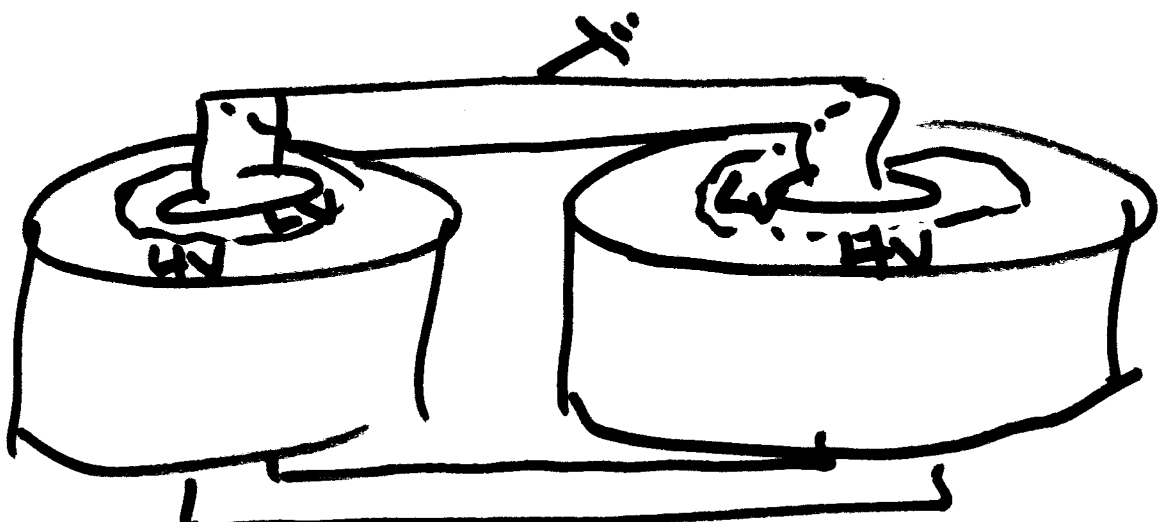
$$\begin{bmatrix} \tilde{V}_1 \\ \tilde{V}_2 \end{bmatrix} = \begin{bmatrix} j\omega L_{11} & j\omega L_{12} \\ j\omega L_{21} & j\omega L_{22} \end{bmatrix} \begin{bmatrix} \tilde{I}_1 \\ \tilde{I}_2 \end{bmatrix}$$

<u>Also of note:</u>

In some texts, since $\underline{L_{12}}$ and $\underline{L_{21}}$ are mutal inductances, they are called $\underline{M_{12}}$ and $\underline{M_{21}}$. Same thing.



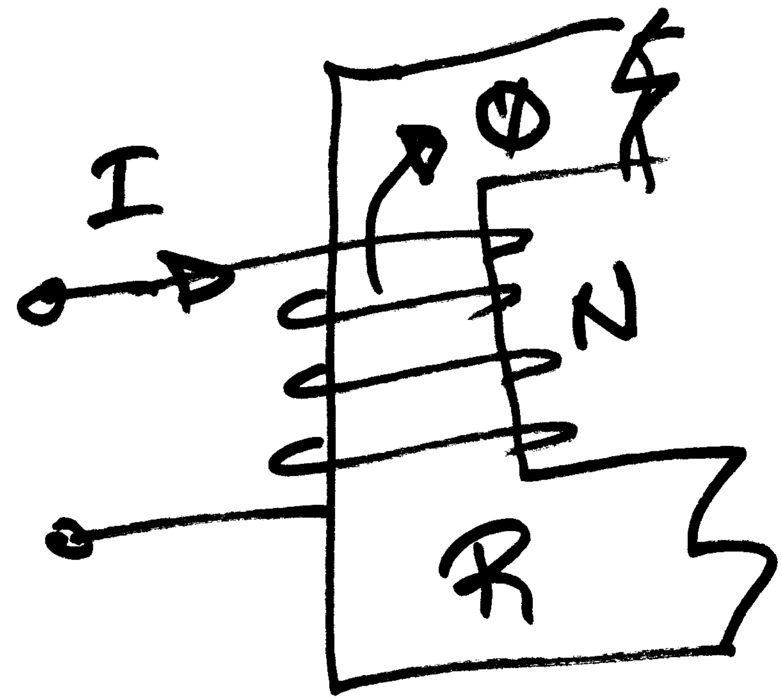

Shell-form




core form.

**Next:** Ampere's Law

# Next: Ampere's Law

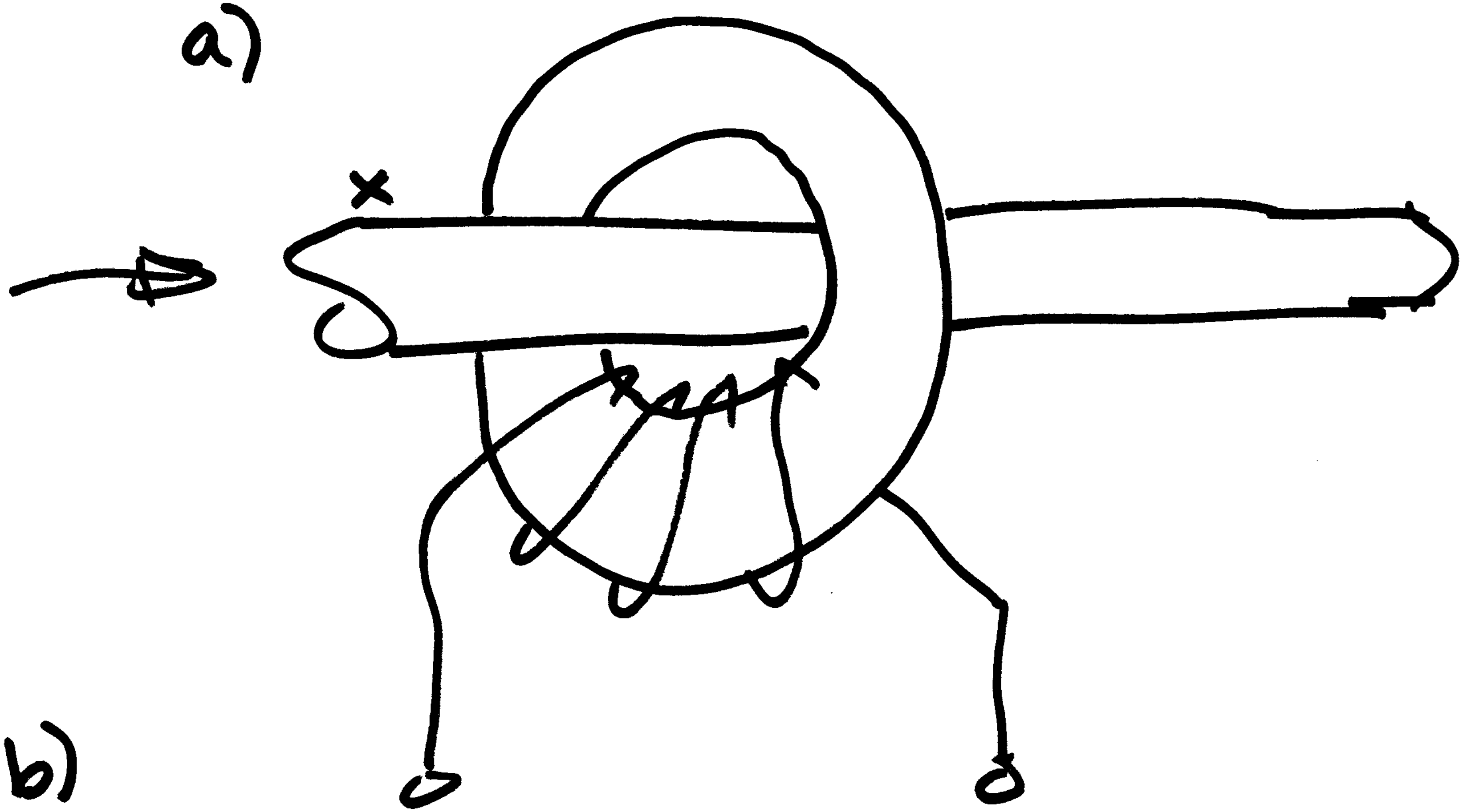



MMF

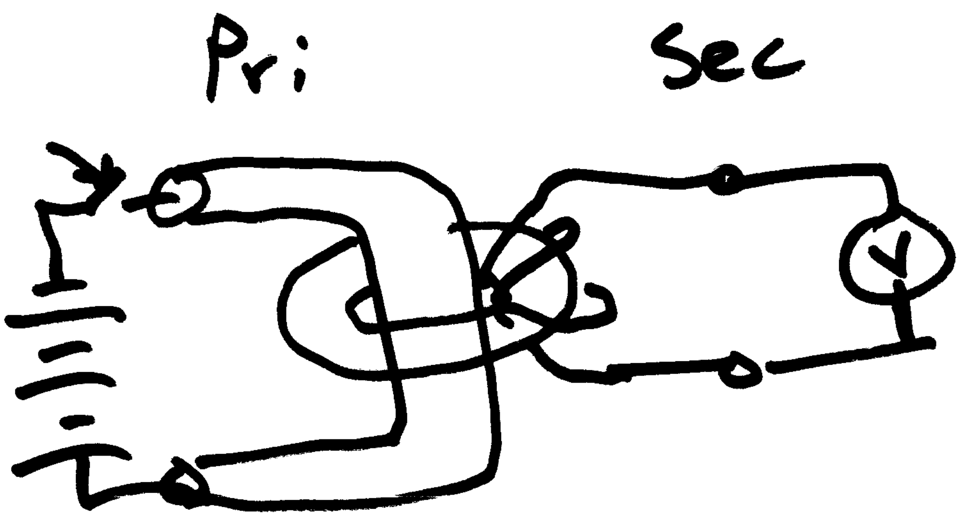
$$NI = \Phi \mathcal{R}$$

Electrical | Magnetic

a)



b)



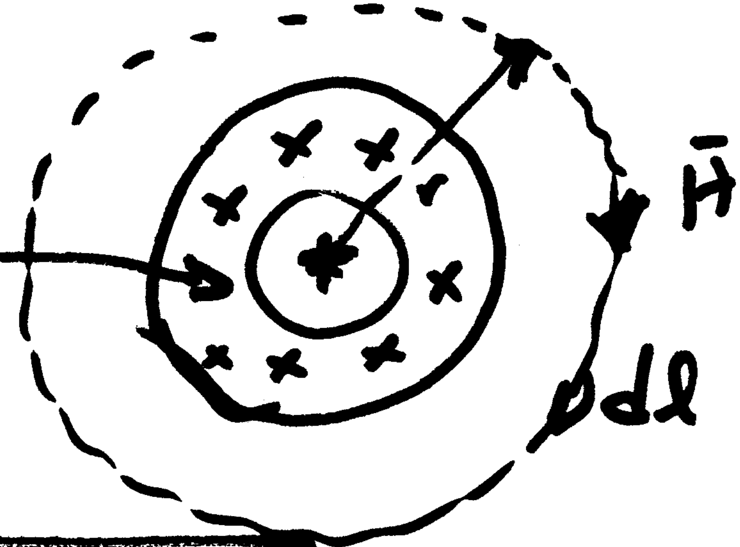
# Ampere's Law

$$NI = \phi R$$

$I = ?$

$$\bar{H} = \frac{I_{ENCL}}{2\pi r}$$

$I_{ENCLOSED}$




$$I_{ENCL} = \oint \bar{H} \cdot dl$$

Clamp-on ammeter or current probe.