

# Transformers

L1

## 1) Intro

Transformers are everywhere, but you usually don't notice them — just like in the movies. — They are enclosed for safety reasons.  
Those things with ceramic horns that are fenced in  
small one everywhere too

They are the devices that change the potential level.

Generation, transmission, and myriad use of electricity are optimized for different potential levels — so one has to be able to transform potential levels.  
e.g.,

Transmission  $\sim 10^5$  V

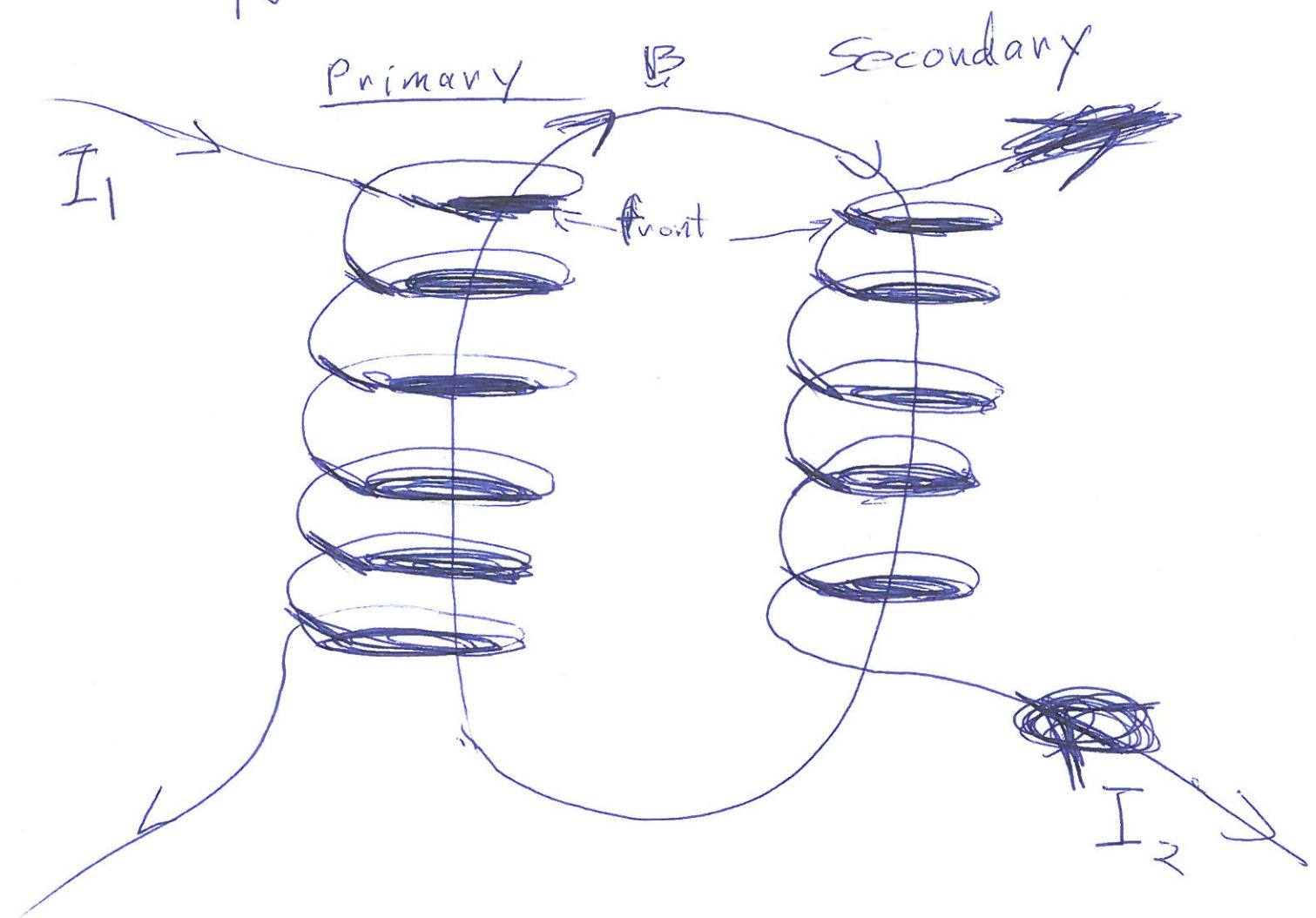
household use 120V

2)

Transformers work  
only with AC current  
and in the 1880's  
the fact that transformers  
need AC lead to  
AC's victory in the  
<sub>(over DC)</sub>  
war of the currents  
used in power grid  
transmission and most user.  
But the victory was never total.  
There are DC current ways  
to transform potential level  
and DC is especially  
efficient for very long range  
power transmission — and  
the power grid of the future  
may use DC for long range transmission

## a) Essentials of Transformers (3)

A transformer consists of two coils and NO current flows between them.



- a) Say  $I_1$  is increasing and goes downward.
- b)  $I_1$  creates a ~~B~~ field an increasing B-field that increases upward in the primary

4)

- (e) ~~This B-field loops~~  
Some of the magnetic  
flux created in the  
primary loops  
through the  
secondary increasing  
downward.
- (f) The B-flux in the  
secondary by  
Faraday's law of  
induction creates  
an ~~EMF~~ induced  
BMF that drives  
a current in coil  
that goes downward.

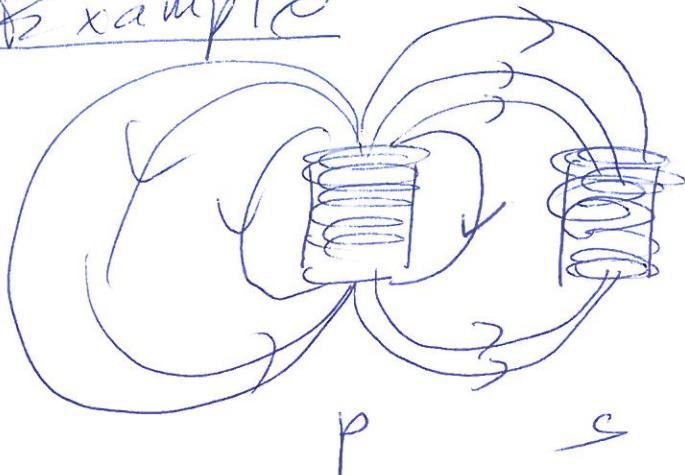
(Q) Without proof here, L5  
we will just state  
an AC current in the  
primary drives  
an AC current of the  
same frequency in the  
secondary.

How much power is transferred by transformer?

We'll first off this depends on how much magnetic flux of the primary is linked by secondary.

6)

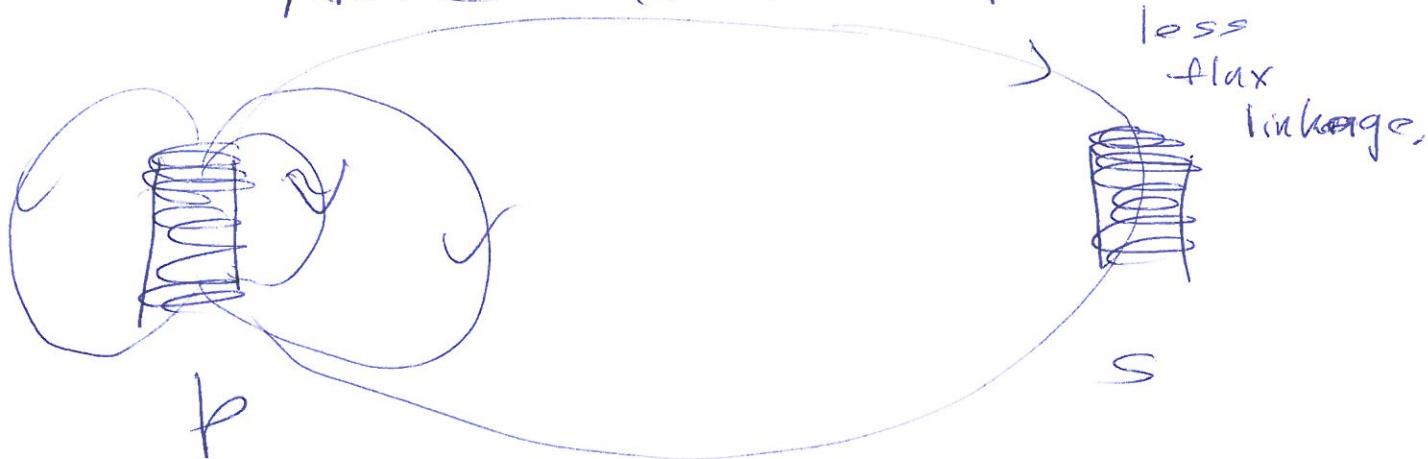
Example



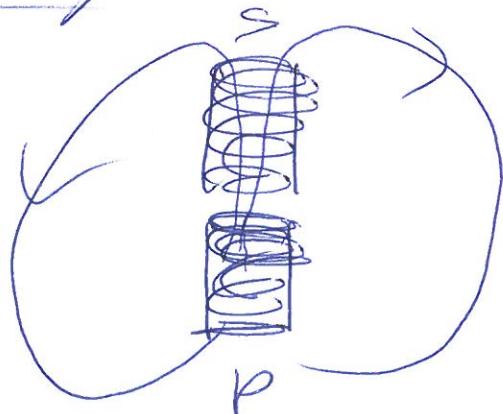
Move closer together

more flux linkage,

Move farther apart and



Stacking the coil might give  
the ~~best~~  
most flux linkage



With no  
magnetic  
core  
present.

L7

Say  $\Phi_{1\text{turn}}$  is the magnetic flux through the one turn of the primary.

Ideally  $f = 1$   
but really it's a reduction factor  $\leq 1$ .  
~~some reduction factor  $< 1$ .~~

$$f \Phi_{1\text{turn}} = \Phi_{2\text{turn}}$$

The magnetic flux through one turn of the secondary

A turn is just one turn (loop) of the coil

$$\text{Now } \Phi_1 = N_1 \Phi_{1\text{turn}}$$

$$\Phi_2 = N_2 \Phi_{2\text{turn}}$$

$N_1$  and  $N_2$  are the numbers of turns of the coils.

$\Phi_1$  and  $\Phi_2$  are the total fluxes in primary and secondary respectively.

3

Combining the equations

$$f \frac{\overline{\Phi}_1}{N_1} = \frac{\overline{\Phi}_2}{N_2}$$

Recall Faraday's law

$$E = -\frac{d\overline{\Phi}}{dt},$$

Now we take the derivative  
of the top equation and get

$$f \frac{\frac{d\overline{\Phi}_1}{dt}}{N_1} = \frac{\frac{d\overline{\Phi}_2}{dt}}{N_2}$$

$$\text{or } f \frac{E_1}{N_1} = \frac{E_2}{N_2}$$

but this is one of those cases  
where one usually just calls  
the EMFs potentials

$$\text{So } f \frac{V_1}{N_1} = \frac{V_2}{N_2}$$

In the primary, the induced potential opposes whatever is driving the <sup>primary</sup> current.

In the secondary, induced potential drives the secondary current.

$$V_2 = f\left(\frac{N_2}{N_1}\right) V_1$$

The turn ratio  $\frac{N_2}{N_1}$   
dictates a step up  
~~or down~~ step down  
in potential.

10)

If  $f = 1$ ,

$\frac{N_2}{N_1}$  gives the step up/down factor.

We will now assume energy conservation

$$P_1 = P_2$$

This is an ideal since resistance in the wires and eddy currents in the magnetic core can cause power loss.

$$I_1 V_1 = I_2 V_2$$

$$I_1 V_1 = I_2 f \left( \frac{N_2}{N_1} \right) V_1$$

$$N_1 I_1 = f N_2 I_2$$

$$\text{or } I_2 = \frac{N_1}{f N_2} I_1$$

L11

If  $f=1$

$$I_2 = \frac{N_1}{N_2} I_1.$$

So if potential  
steps up/down,  
current steps down/up.

### 3) Magnetic Core

The effectiveness of  
transformers is

vastly enhanced by

using magnetic cores

— often called iron cores

since the cores are  
usually iron or some alloy.

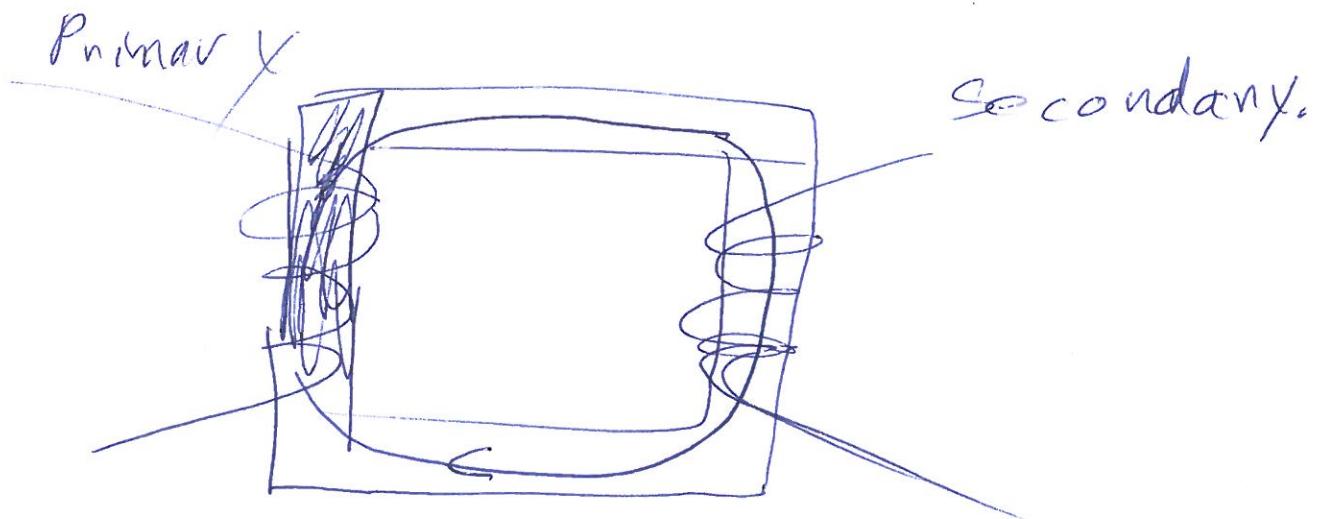
— the core is made

of a soft magnetic

(Wiki: soft iron) material.

12)

In the magnetic material context "soft" means does NOT become permanent magnet.  
"hard" means does become a permanent magnet.



With a magnetic core, the B-field created for a given current is

Much, much ~~fainter~~<sup>stronger</sup> than without the core.

L13

Of course, it takes more energy to construct this stronger field.

Also, the field is channelled in the core and relatively little is in the air.

So the magnetic flux linkage of the secondary approaches 100%

$$\text{and } V_2 = \frac{N_2}{M_i} V_1 \text{ to}$$

high accuracy for well-designed modern transformers

14)

with efficiencies appro-

Power efficiencies

also approaching 100%.

Our Magnetic cores

may be electrical  
steel.

(but no one is  
telling).

~~They also~~

#### 4) Questions

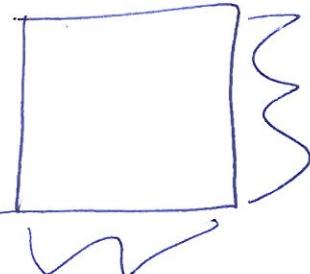
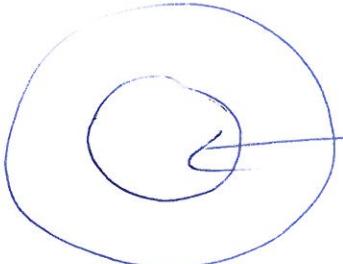
1) Why are ~~iron~~ cores  
laminated?

2) Why do the cores  
vibrate when an AC  
current flows?

3) Why do the ~~magnetic~~

Coves have holes? L15

## 5) Oscilloscopes

- Every oscilloscope is a bit different.
- People remember how to use them by pushing the buttons.
-  Voltage  
division  
  
Time division
- { Actual outlined box on the screen.  
  
Volt div nob
- The inner nob should be turned all the way to the right //

(6)

for the Volt/div to  
read it's proper amount.

- Triggering is a bit of an art.

## 6) Extra Tasks

I think we can all  
agree this lab is  
too easy as it stands  
for an extended lab.

So we need a couple  
extra bits to beef it up.

17.

a) Use the smaller turn coil as the primary and the larger as the secondary.



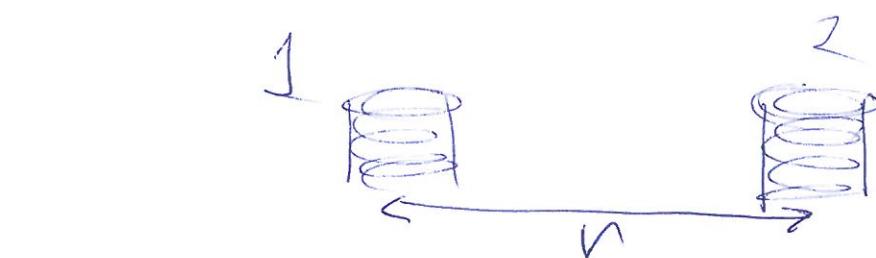
coil as

the primary

and the larger as the secondary.

With no core measure

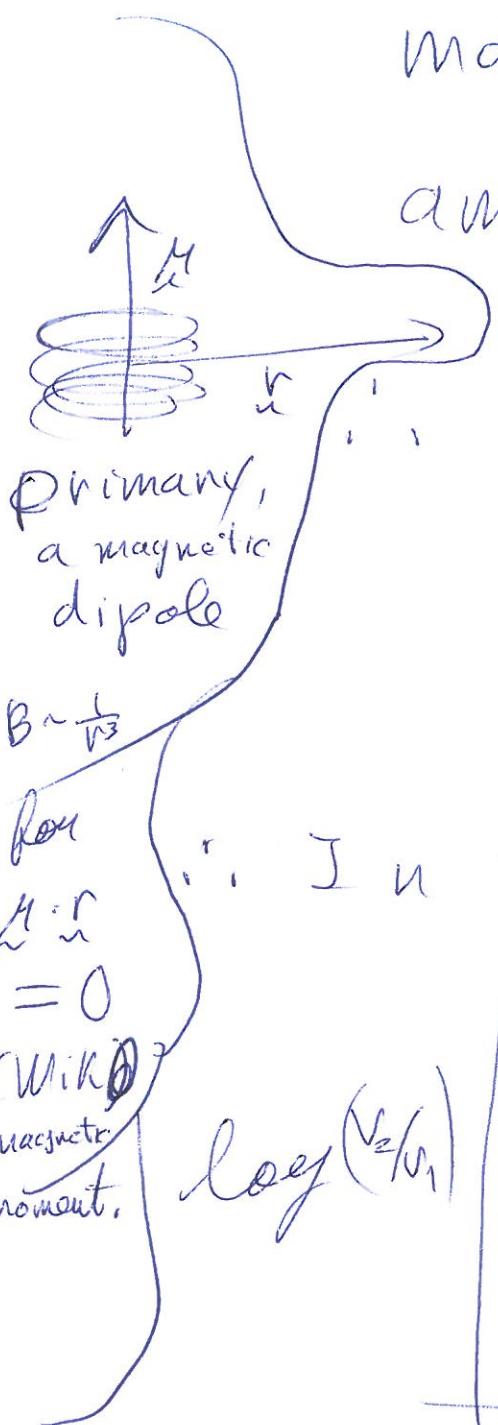
$V_2/V_1$  as a function  
of distance between the  
coils on the table.



$r$ (cm)	$V_2/V_1$	$\log(r)$	$\log(V_2/V_1)$
$3 \pm ?$	$\pm ?$		
7			
10			
15			
20			
30			
40			

(8)

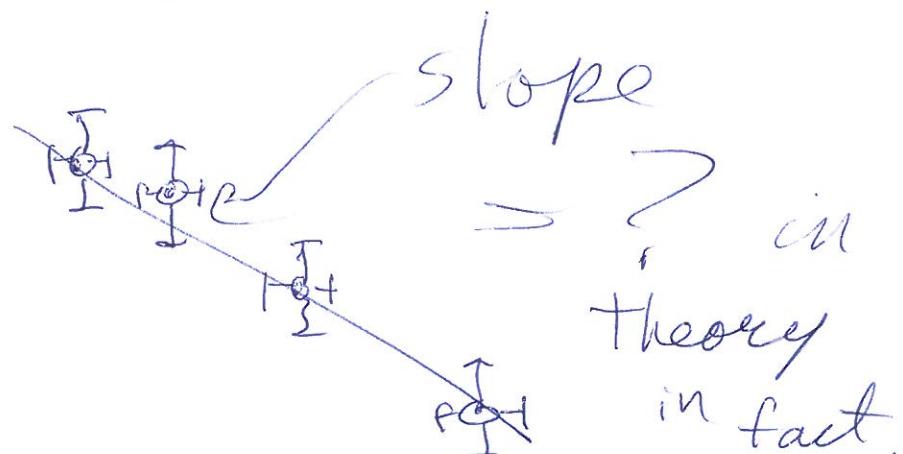
The coils are approximately magnetic dipoles



and  $B_{\text{dipole}} \propto \frac{1}{r^3}$

$V_2/V_1$  which depends on magnetic flux should go as  $\propto \frac{1}{r^3}$  in theory

i.e. In theory



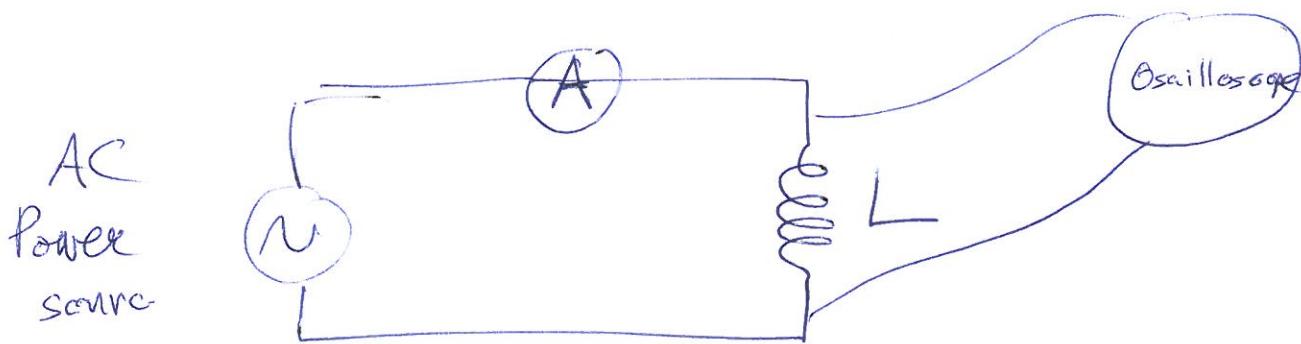
Plot  $\log(V_2/V_1)$  versus  $\log r$

Do the two agree within measurement error.

with error bars if large enough and ~~analyse~~ error analysis.

b) Inductance of a coil [19]

Dependence on Magnetic Material



$$E_L = L \frac{dI}{dt}$$

$L$  is the inductance of the induction

$$I = I_0 \cos \omega t$$

$$\frac{dI}{dt} = -I_0 \omega \sin \omega t$$

$$\underline{L} = \frac{E_{L \text{ amplitude}} / \sqrt{2}}{I_{\text{RMS}}} = \frac{E_{L \text{ RMS}}}{I_{\text{RMS}}}$$

20J

Measure  $L$  without  
iron bar



and with  
iron bar.



If all coil magnetic  
flux were in the  
~~steel~~ bar (which isn't)

$$\frac{L_{\text{bar}}}{L_{\text{no bar}}} = \mu_r$$

relative permeability

$\mu_r = 4000$

for electrical steel

but some material may not be electrical steel and all the field is not in the magnet,