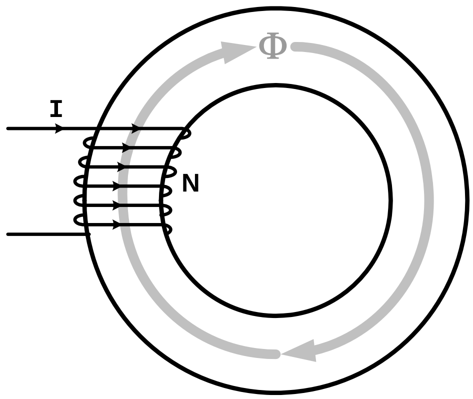
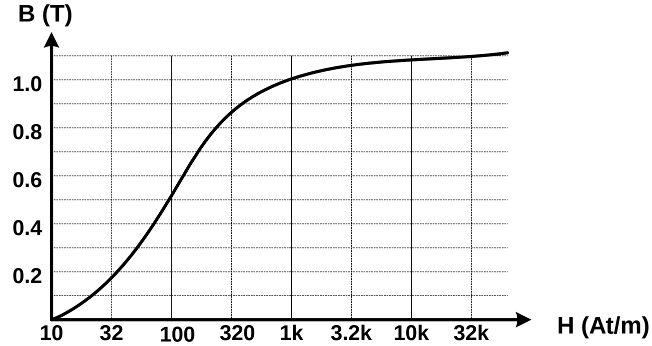
Instructions: Show all of your work, making sure your work in legible and that your reasoning can be followed. No credit will be given for illegible or illogical work, or for final answers that are not justified by the work shown. This exam is closed book, except for one 8.5"x11" handwritten sheet of notes that may NOT contain any numerically solved problems.

Problem #1) The toroidal (doughnut-shaped) magnetic core shown below has a mean length of **50cm** and a cross-sectional area of **2cm^2**. A coil consisting of **80 turns** of wire is wrapped around the core and supplied with **200 milliamps** of DC current. If the core material has a B-H curve as also shown below,
Determine the magnitude of the **flux (Wb)** within the core, the **relative permeability** of the core, and the **reluctance of the core** under the specified conditions.





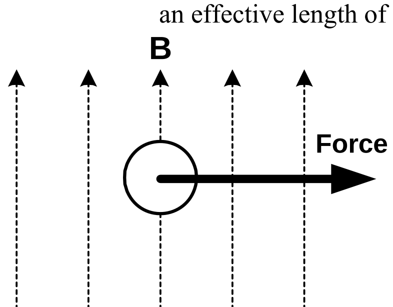
Depends on the exact value of B from plot ➔
(My calculated value for H resulted in B=0.17)

Φ = _____34x10^{-6}______Wb

μ_r = _____4228___________

$\mathcal{R}$= ______470588_________

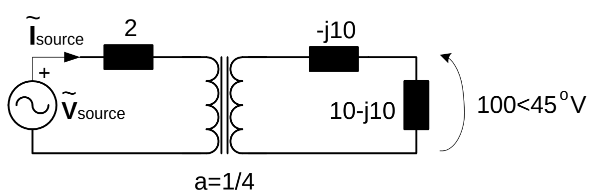
Problem #2) Given a conductor sitting within a uniform, externally-created magnetic field as shown in the figure below, if the conductor is oriented such that it is orthogonal (perpendicular) to this page, determine the direction of current flow in the conductor ("**into**" or "**out-of**" the page) that would result in a force upon the conductor to the left (as shown in the figure). Also, determine the **magnitude of the current** required such that the force upon the conductor is 0.05N if the flux density of the external field is 0.8 Tesla and the conductor has an effective length of 40cm.



Current Direction: _______into________

I: ____________0.15625_____________ A

Problem #3) Determine both the **source voltage** *and* **current** (in phasor form) in the following circuit that contains an ideal iron-core transformer. Also, determine the value of ***impedance*** that could be used to model the input impedance of the transformer with the specified loads connected to the secondary winding.

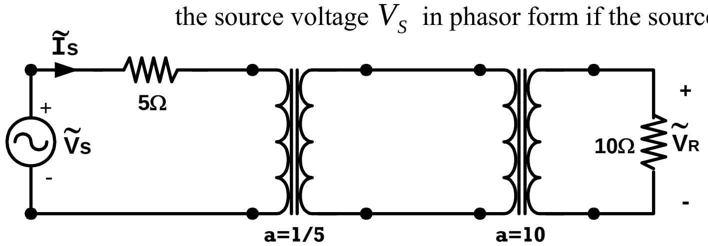


$\tilde{V}_{source}$ = ______ $82.23\angle 64.54°$ _______ **V**

$\tilde{I}_{source}$ = ________ $28.28\angle 90°$ ________ **A**

$Z_{in\,Transformer}$ = _____**0.625-j1.25**_________ **Ω**

Problem #4) Given the following circuit that contains two identical ideal transformers, determine the load voltage $\tilde{V}_R$ and the source voltage $\tilde{V}_S$ in phasor form if the source current is $\tilde{I}_S = 20\angle 0°$ amps.



$\tilde{V}_S$ = ________900∠0°__________ V

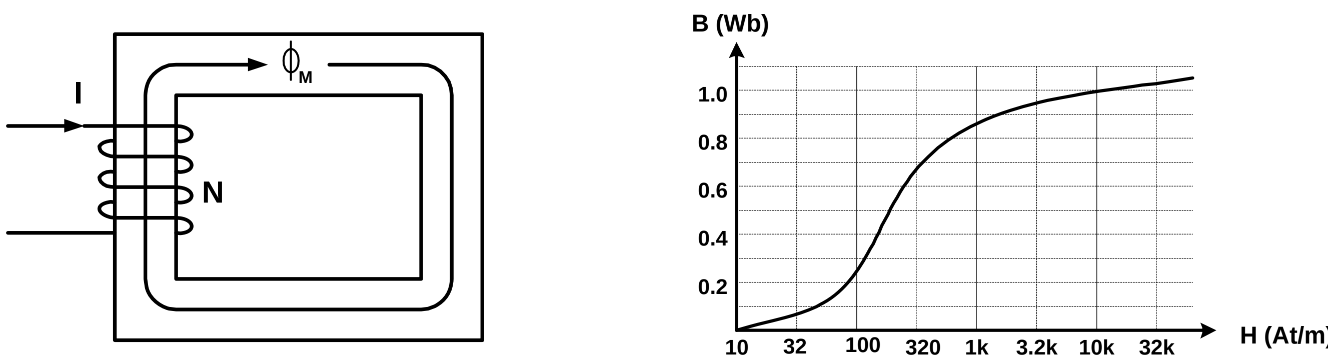
$\tilde{V}_R$ = ________400∠0°__________ V

Problem #5) Determine the **effective length** of a conductor required to generate 10 volts when passing through and normal (⊥) to a magnetic field of 1.0 Tesla at a speed of 10 m/sec. Given the same conductor exposed to the same magnetic field, if a DC current of 250mA is applied to the conductor, determine the magnitude of the **force** created on the conductor. Note that you will need to use your calculated length to solve the force.

l_{eff} = ____________1______________m

F = __________0.25____________Nm

Problem #6) A 150-turn coil is wound around a ferromagnetic core having an average core length of 25 cm. The magnetization curve for the core material is shown below. A current of 0.5 amps flows through the coil. Determine the **mmf** created by the coil, the **magnetic field intensity** within the core, and the **relative permeability** of the core under these conditions.

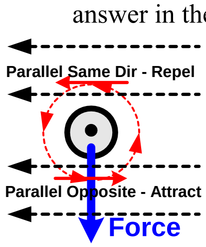


mmf = _________75______________At

H = ___________300___________At/m

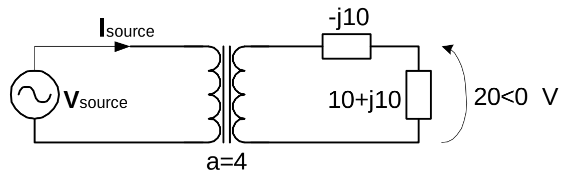
μ_r = ____________1724______________

Problem #7) A conductor carrying a current is sitting within a uniform magnetic field, as shown in the figure below. Determine the **direction** of the force upon the conductor and briefly **explain** the reasoning behind your answer in the space below. **Draw** an arrow on the figure below to specify your chosen direction.



Conductor field shown in red.
Force shown in blue.

Problem #8) Determine the **source voltage and current** (in phasor form) in the following circuit that contains an ideal iron-core transformer. Also, determine the value of an impedance that could be used to model the input impedance or the transformer with the specified loads connected to the secondary winding.

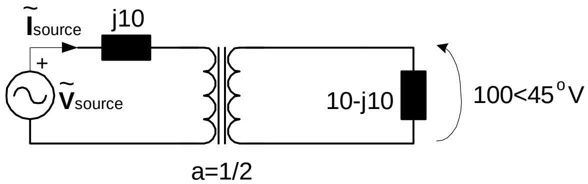


Vsource = **56.57<-45º** V

Isource = **0.354<-45º** A

Zin = **160+j0** Ω

Problem #9) Determine the **source voltage and current** (in phasor form) in the following circuit that contains an ideal iron-core transformer. Also, determine the **real power** consumed by the load impedance connected to the secondary winding of the transformer.

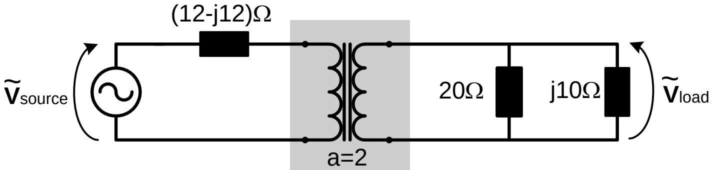


$\tilde{V}_{source}$ = **111.8∠161.6°** V

$\tilde{I}_{source}$ = **14.14∠90°** A

P_{load} = **500** W

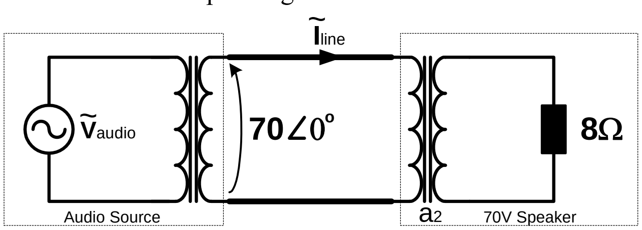
Problem #10) The following circuit that contains an ideal transformer having an effective turns-ratio, **a=2**, as connected. If the source voltage is $\tilde{V}_{source} = 120\angle 0°$ volts, determine the **load voltage** $\tilde{V}_{load}$ as shown in the figure.



$\tilde{V}_{load}$ = **62.4∠27.9°** V

Problem #11) The figure below shows an audio distribution source with a 70V output connected to a 70V distribution speaker by means of a transmission-line (wire pair). The audio source is driven with a 1 kHz sine wave and is adjusted such that the voltage at its output terminals is $70\angle 0°$ volts. The 70V speaker consists of a multi-tap transformer that feeds an 8Ω speaker (load). Changing the "tap" of its transformer effectively changes the transformer's turns-ratio (**a2**).

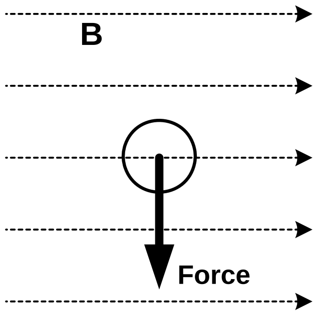
Determine the required turns-ratio for the distribution speaker such that 50 watts of power is provided to the actual 8Ω speaker. Also determine the current $\tilde{I}_{line}$ that will flow on the transmission-line under these operating conditions.



a = **3.5**

$\tilde{I}_{line}$ = **0.714** A

Problem #12) Given a conductor sitting within a uniform, externally-created magnetic field (B=0.8 T) as shown in the figure below, if the conductor is oriented such that it is orthogonal (perpendicular) to this page, determine the direction of current flow in the conductor ("**into**" or "**out-of**" the page) that would result in a force upon the conductor to the left (as shown in the figure). You must show work on the figure that justifies your answer. Also, if the conductor has an effective length of 40cm and is moving with a velocity of 2m/sec through the field in the Force direction, determine the magnitude of the voltage induced across the conductor.

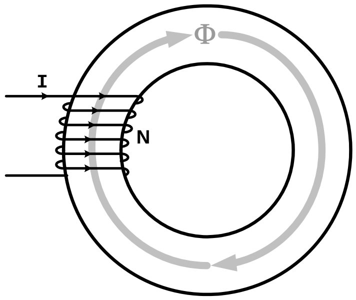


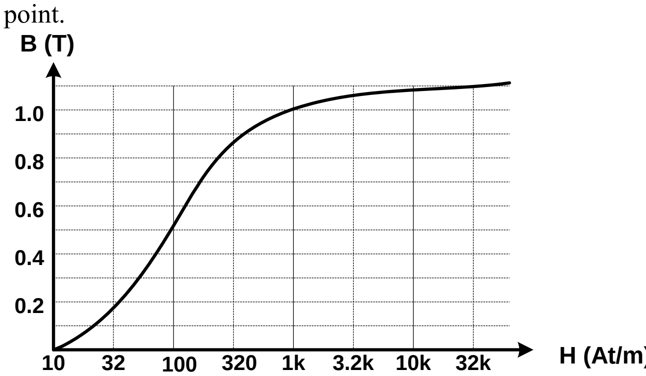
Current Direction: ____Into____

e = ____0.64____ volts

Problem #13) A toroidal (doughnut-shaped) magnetic core having a mean length of **16cm** and a cross-sectional area of **1.3cm²** is equipped with a 90-turn coil of wire. The B-H curve for the core material is shown below,

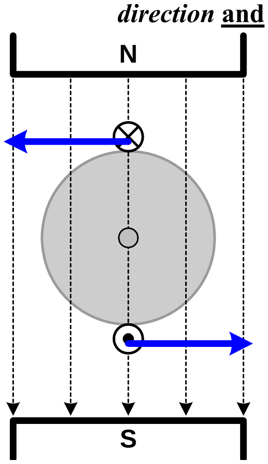
a) Determine the magnitude of the **current (I)** required to produce a **flux density of 0.5 Tesla** in the core.
b) Given the current from part "a", determine the magnitude of the **flux (Φ)** created within the core along with the **self-inductance (L)** of the coil at this operating point.



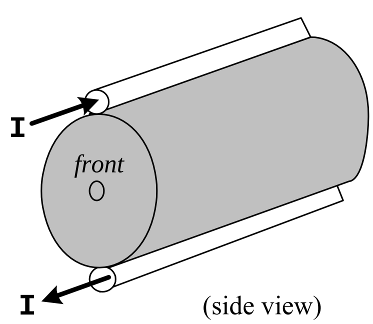


I = ______178_____mA Φ = ___65x10^{-6}___Wb L = ____0.0329_____ H

Problem #14) A pair of 25cm long conductors are mounted on each side of a cylinder that is sitting between a pair of permanent magnets, as shown in the figure below. The flux density of the field passing through the cylinder is 0.65 Tesla. A current of 4 amps is flowing "into the page" in the top conductor and "out of the page" in the bottom conductor. **Determine the force upon each of the current-carrying conductors**. ***Graphically indicate your result by drawing an arrow on the "end view" diagram showing the force direction and provide the force magnitude in the answer-blank provided below.***



(end view)



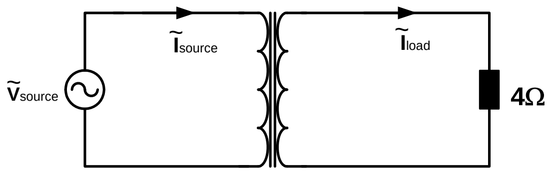
(side view)

F = **________0.65__________ N**

Problem #15) The figure below shows a voltage source connected to the primary winding of a transformer whose secondary winding is used to supply power to an 4Ω load.

With the source voltage is set to $\tilde{V}_{source} = 70\angle 0°$ volts, the 4Ω load consumes 25 watts.

Determine the actual turns-ratio for the transformer, and determine the actual current flowing through the 8Ω load and the current flowing out of the source.



$a =$ ___________**7**_____________

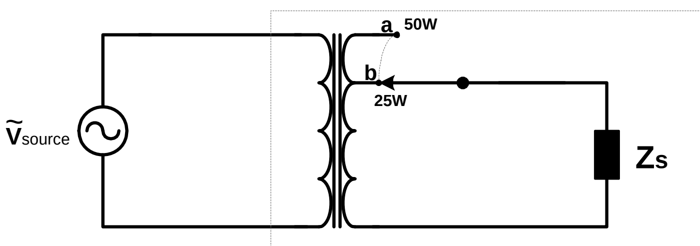
$\tilde{I}_{load} =$ _________**2.5∠0°** _________ **A**

$\tilde{I}_{source} =$ ________**0.357∠0°** _________ **A**

Problem #16) A speaker that includes a two-tap transformer operates on a 70V audio-distribution system. A switch allows the user to choose either tap "a" or tap "b". Tap "b" is known to have a turns-ratio of seven (7). When set to tap "b", the speaker is "rated" to receive 25 watts of power from the audio source (assuming a 70 volt, 1kHz sinusoidal source). When set to tap "a", the speaker is rated to receive 50 watts of power.

If the audio source voltage is $\tilde{V}_{source} = 70\angle 0°$ volts and the speaker is operating at it's specified ratings;

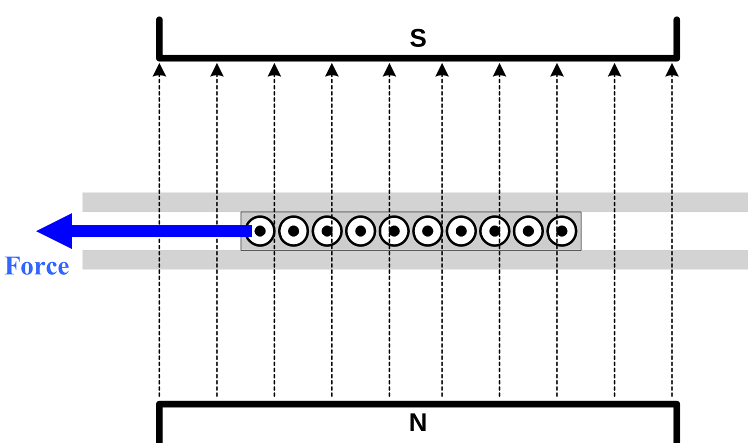
Determine the **impedance of the speaker** and the **turns ratio of the transformer when it is set to tap "a"**.



$Z_S =$ ________**4**________ **Ω**

$a =$ ________**4.95**________

Problem #17) A device containing ten (10) conductors, each 15cm in length, all mounted in parallel with each other, is placed between two permanent magnets as shown in the figure below. The flux density of the field passing through the device is 0.8 Tesla. A current of 2.0 amps is flowing through each of the conductors ("out of the page") as shown in the figure. **Determine the net force upon the device** due to the current-carrying conductors. ***Graphically indicate your result by drawing an arrow on the device showing the force direction*** **<u>and</u>** ***provide a numerical result for the force magnitude in the answer-blank provided below.***



$F =$ ________**2.4**________ **N**

PRACTICAL TRANSFORMERS

Problem #A) Given a 30 KVA, 60 Hz, 2400—600 V transformer with the following winding and excitation impedances:

Windings: $R_{HV} = 2.6\ \Omega$, $X_{HV} = 2.8\ \Omega$, $R_{LV} = 0.15\ \Omega$, $X_{LV} = 0.2\ \Omega$

Excitation: $R_{fe(HV)} = 1600\ \Omega$, $X_{M(HV)} = 600\ \Omega$

If the transformer is used to connect a 2400∠0° volt source to a load of $Z_{Load} = 20\ \Omega$, determine the **actual load voltage** (in polar form) and the **real power** supplied to the load.

V_{Load} = __________590<-1º______________volts

P_{Load} = ___________17444_______________watts

Problem #B) Given a 30 KVA, 60 Hz, 2400—600 V transformer with the following winding and excitation impedances:

Windings: $R_{HV} = 2.6\ \Omega$, $X_{HV} = 2.8\ \Omega$, $R_{LV} = 0.15\ \Omega$, $X_{LV} = 0.2\ \Omega$

Excitation: $R_{fe(HV)} = 1600\ \Omega$, $X_{M(HV)} = 600\ \Omega$

If the transformer is supplied by a 2400∠0° volt source and a load of $Z_{Load} = 15\ \Omega$ is connected to the low-voltage winding, determine the actual **input current** to the transformer (in polar form), as well as the "**rated**" **input current**.

$\tilde{I}_{input}$ = ___________**12.05∠-20.6°** ___________**A**

I_{rated} = _____________**12.5**________________**A**

Problem #C) Given a 20 KVA, 60 Hz, 2400—600 V transformer with the following winding and excitation impedances:

Windings: $R_{HV} = 4.0\ \Omega$, $X_{HV} = 5.6\ \Omega$, $R_{LV} = 0.25\ \Omega$, $X_{LV} = 0.35\ \Omega$

Excitation: $R_{fe(LV)} = 225\ \Omega$, $X_{M(LV)} = 75\ \Omega$

If the transformer is used to step-up the voltage from a 600∠0° volt source in order to provide the voltage to a load whose impedance is $Z_{Load} = 640\text{-}j160\Omega$, determine the actual load voltage and the input current, both in polar form.

$\tilde{V}_{Load}$ = ___________**2381∠-1.10°** ___________ **V**

$\tilde{I}_{In}$ = ____________**17.4∠-15.9°** ___________ **A**

Problem #D) Given a ½KVA, 60 Hz, 240V—12V transformer with the following model parameters:

Windings: $R_{HS} = 1.2\ \Omega$, $X_{HS} = 1.6\ \Omega$, $R_{LS} = 0.003\ \Omega$, $X_{LS} = 0.004\ \Omega$

Excitation: $R_{fe(HS)} = 2000\ \Omega$, $X_{M(HS)} = 800\ \Omega$

The transformer is being used to step-down the voltage of a high-voltage source to supply a much lower rated voltage load having an impedance $Z_{Load} = 0.5\text{+}j0.02\ \Omega$.

a) Calculate the actual voltage that will appear across the load and the input current for the transformer assuming that the transformer is supplied at rated primary voltage.
b) Calculate the rated current for both the "high-side" and "low-side" windings.

a) $\tilde{V}_{Load}$ = ___________**11.85∠-0.88°** ___________**V**

$\tilde{I}_1$ = ____________**1.35∠-15.7°** ___________**A**

b) $I_{HS(rated)}$ = ____________**2.08**________________**A**

$I_{LS(rated)}$ = ____________**41.7**________________**A**

Problem #E) The following short-circuit test data was obtained for a 50 KVA, 2400—600V, 60 Hz **transformer**:

$V_{SC} = 76.4$ V, $I_{SC} = 20.8$ A, $P_{SC} = 954$ W

Determine the parameters $\mathbf{R_{eq}}$ and $\mathbf{X_{eq}}$ of the transformer model referred to the high voltage side.

R_{eqHS} = ______2.2_______ Ω

X_{eqHS} = ______2.94______ Ω

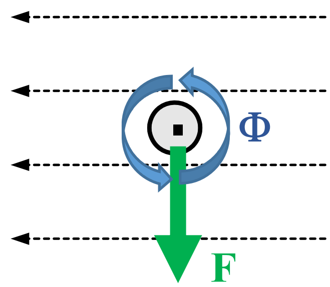
Problem #18) Given a balanced, positive-sequence, 3Φ source having phase voltage $\tilde{V}_b = 120\angle 60°$ *volts*, specify all of the phase voltages and the line voltages of the source.

$\tilde{V}_a =$ **120∠180°** V $\tilde{V}_{ab} =$ **208∠210°** V

$\tilde{V}_b =$ **120∠60°** V $\tilde{V}_{bc} =$ **208∠90°** V

$\tilde{V}_c =$ **120∠-60°** V $\tilde{V}_{ca} =$ **208∠-30°** V

Problem #19) A conductor carrying a current (flowing "out-of" this page) is sitting within a uniform, externally-created magnetic field as shown in the figure below. ***Draw the field created around the conductor*** by the current, and determine the **direction** of the force upon the conductor. **LABEL** your ***conductor-field*** with a "**Φ**" and specify your ***force direction with an arrow*** labeled with an "**F**".

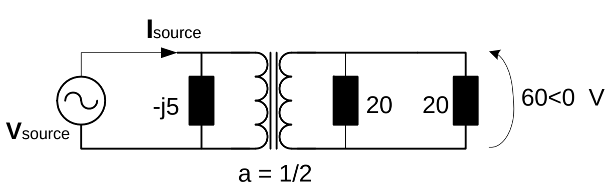


Problem #20) Given the system specified in problem 19, if the flux density of the external field is **0.5 Tesla** and the conductor has an effective length of **4 meters**, determine the **current** required in the conductor to create a force of **3.2 N** on the conductor, along with the **voltage induced** on the conductor if it is traveling orthogonally through the field at a velocity of **17.8 m/sec**.

$I =$ **1.6** A

$V =$ **35.6** V

Problem #21) Determine both the **source voltage** *and* **current** (in phasor form) in the following circuit that contains an ideal iron-core transformer. Also, determine the value of ***impedance*** that could be used to model the input impedance of the transformer with the specified loads connected to the secondary winding.



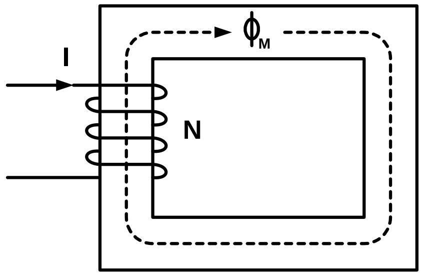
$\tilde{V}_{source} =$ **30∠0°** V

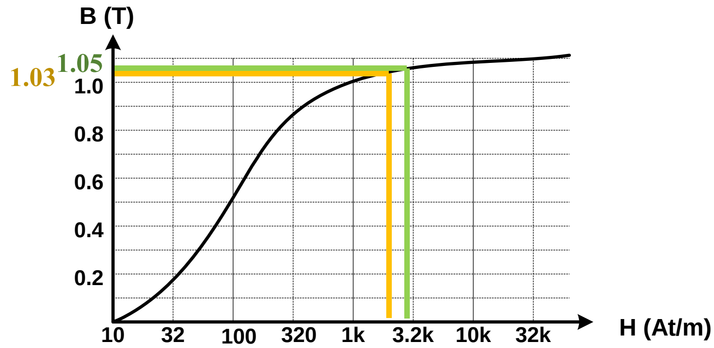
$\tilde{I}_{source} =$ **13.4∠26.6°** A

$Z_{in\,Transformer} =$ **2.5+j0** Ω

Problem #22) The magnetic core shown below has a mean length of **20cm** and a cross-sectional area of **2cm**x**2cm** ($4cm^2$). A coil consisting of **400 turns** of wire is wrapped around the core and supplied with **1.5 amps** of DC current. If the core material has a B-H curve as also shown below,

Determine the magnitude of the **flux (Wb)** within the core, the **relative permeability** of the core, and the **reluctance of the core** under the specified conditions. Also, determine the **percent (%) decrease in flux** within the core if the coil current is decreased by 33.3% (decreased by one-third).





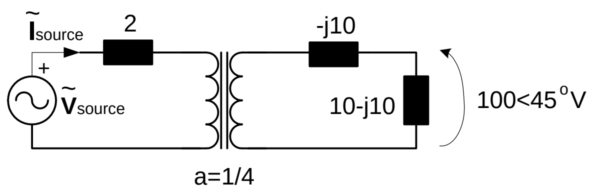
Φ = **0.00042** **Wb**

$\mathcal{R}$ = **1,429,000**

μr = **278.5**

% decrease in Φ = **1.9** **%**

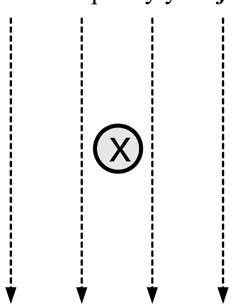
Problem #23) Determine both the **source voltage** *and* **current** (in phasor form) in the following circuit that contains an ideal iron-core transformer.



$\tilde{V}_{source}$ = **82.2∠64.5°** **V**

$\tilde{I}_{source}$ = **28.28∠90°** **A**

Problem #24) A conductor carrying a current (flowing "into" this page) is sitting within a uniform, externally-created magnetic field as shown in the figure below. ***Accurately draw the field created around the conductor*** by its current, and determine the **direction** of the force upon the conductor. **Label** your ***conductor-field*** with a "**Φ**" and specify your ***force direction with an arrow*** labeled with an "**F**".



Problem #25) Given the system specified in problem 3a, along with the fact that the external field has a flux density of **0.25 Tesla** and the conductor has an effective length of **10 meters**;

Determine the **voltage** induced on the conductor if it is traveling orthogonally through the field at a rate of **37.7 m/sec**. Also, assuming that the conductor is maintaining a constant speed, determine the **force** being applied to the conductor is there is a current of **1.6 amps** flowing within the conductor at this speed.

V = ____________________ **V**

F = ____________________ **N**

For each of the following statements, specify whether they are **TRUE** or **FALSE**.

___**TRUE**___ The ***magnetization current*** in a transformer is the current required to create the no-load magnetic field in a lossless magnetic core.

___**FALSE**__ The ***turns ratio*** of a transformer is specified by the ratio of the rated high-side voltage compared to the rated low-side voltage.

___**TRUE**___ The ***turns ratio*** of a transformer is specified by the ratio of the rated primary voltage compared to (divided by) the rated secondary voltage.

___**TRUE**___ For a practical conductor in the air, the **strength of the magnetic field** formed around the conductor will double if the current flowing through the conductor itself is doubled.

___**TRUE**___ For a practical conductor in the air, the **strength of the magnetic field** formed around the conductor is directly proportional to the current flowing in the conductor.

___**TRUE**___ The ***relative permeability*** of a material is the ratio of the actual permeability of the material at a specific operating point compared to (divided by) the permeability of free-space (air).

___**TRUE**___ The ***actual permeability*** of a material at a specific operating point is defined by the ratio of the flux density in the material compared to (divided by) the magnetic field intensity in the material.

___**FALSE**__ As a magnetic core becomes **saturated**, the core's permeability will increase.

___**TRUE**___ As a magnetic core becomes **saturated**, the core's permeability will decrease.

___**FALSE**__ The ***magnitude of the currents*** in the primary and secondary coils of an "ideal" transformer will have the ***inverse ratio*** of the impedances of the primary and secondary coils.

___**TRUE**___ The ***magnitude of the currents*** in the primary and secondary coils of an "ideal" transformer will have the ***inverse ratio*** of the voltages across the primary and secondary coils.

___**TRUE**___ At **"no-load"**, an ideal transformer will draw no primary current.

___**TRUE**___ The ***Magneto-Motive Force*** (MMF) created by the source coil of a magnetic circuit is linearly proportional to the current flowing to the coil.

___**FALSE**__ The ***Magneto-Motive Force*** (MMF) created by the source coil of a magnetic circuit will increase by a factor of four (x4) if the current in the coil is increased by a factor of two (x2).

___**FALSE**__ The **voltage source in the laboratory** has both a constant and a variable 220/120 volt three-phase supply.

___**TRUE**___ ***Lenz's Law*** states that any induced effect will always oppose its source.

___**TRUE**___ If a voltage source is applied to the primary winding of an "***ideal transformer***", the primary and secondary windings will both have zero current in them as long as the secondary winding is open-circuited.

___**FALSE**__ ***Reactive Power*** is only consumed by resistive loads (i.e. – not by capacitors or inductors).

___**TRUE**___ ***Real Power*** is only consumed by resistive loads (i.e. – not by capacitors or inductors).

___**TRUE**___ The ***actual permeability*** of a material must be greater than or equal to that of free space (air).

___**TRUE**___ The ***actual permeability*** of a material may vary depending on the magnitude of the flux density existing within the material.

___**TRUE**___ The ***relative permeability*** of a material must be greater than or equal to that of free space (air).

___**FALSE**__ The ***relative permeability*** for a practical magnetic core material is constant and independent of the magnetic flux density within the core material.

___**TRUE**___ ***Magnetic field lines*** always form closed loops.

___**FALSE**__ ***Electric field lines*** always form closed loops.

___**FALSE**__ The ***turns ratio*** of a transformer is equal to the ratio of number of turns in the high-voltage winding compared to the numbers of turns in the low-voltage winding.

___**TRUE**___ The ***turns-ratio*** of a transformer is equal to the ratio of number of turns in the primary winding compared to the numbers of turns in the secondary winding.

___**FALSE**__ An "***ideal transformer***" will function with either an AC or a DC applied voltage.

___**FALSE**__ The ***secondary winding*** of a transformer only exists in transformers containing three or more windings.

___**FALSE**__ Given an "ideal" transformer**,** the ***coil with the largest number of turns*** is the primary coil.

___**TRUE**___ Given an "ideal" transformer**,** the ***coil with the largest number of turns*** *will* be the high-voltage coil.

___**TRUE**___ The power supplied into the primary coil of an ***"ideal" transformer*** must equal to the power delivered from the secondary coil to the transformer's load.

___**TRUE**___ When ***two magnetic field sources*** create their fields in the same region such that their field lines are parallel to each other, a mechanical force will be created upon the sources.

___**FALSE**__ When ***two magnetic field sources*** create their fields in the same region such that their field lines are perpendicular to each other, a mechanical force will be created upon the sources.

___**TRUE**___ The ***magnetization current*** in a transformer is the current required to create the no-load magnetic field in a lossless magnetic core that is assumed to have a finite relative permeability.

___**TRUE**___ Given a transformer containing a ***center-tapped winding***, if the center-tapped winding is utilized as the secondary winding of the transformer, ½ of the secondary winding voltage will appear between the center tap terminal and either of that winding's other two terminals.

___**FALSE**__ The ***excitation current*** in a transformer is the current required to create the full-load magnetic field in the magnetic core.

___**FALSE**__ The ***turns ratio*** of a transformer is specified by the ratio of the rated high-side voltage compared to the rated low-side voltage.

___**TRUE**___ The ***turns ratio*** of a transformer is specified by the ratio of the rated primary voltage compared to (divided by) the rated secondary voltage.

___**FALSE**__ ***Eddy currents*** are circulating currents in the transformer core resulting from the time-varying current in the load.

___**FALSE**__ ***Eddy currents*** are circulating currents in the transformer core resulting from the circular magnetic field in the magnetic core.

___**FALSE**__ At **"no-load"**, a non-ideal (actual) transformer will draw no primary current.

___**TRUE**___ If the primary voltage is held constant, the ***secondary voltage*** on an actual transformer will typically decrease as the resistance of a purely resistive load is decreased (thus drawing more current).

___**TRUE**___ Given a transformer containing a ***center-tapped winding***, if the center-tapped winding is utilized as the secondary winding of the transformer, ½ of the secondary winding voltage will appear between the center tap terminal and either of that winding's other two terminals.

___**TRUE**___ The ***Open-Circuit Test*** for a transformer is used to determine the excitation impedances in the transformer model.

___**FALSE**__ The ***Short-Circuit Test*** for a transformer is typically performed at rated primary voltage.