DOCUMENT RESUME

ED 099 506 CE 002 583

TITLE	Module Nine: Relationships of Current, Counter EMF, and Voltage in LR Circuits; Basic Electricity and Electronics Individualized Learning System.
INSTITUTION	Bureau of Naval Personnel, Washington, D.C.
REPORT NO	NAVPERS-94558-9a
PUB DATE	Jan 72
NOTE	134p.; For other modules in the series, see CE 002 573-589
EDRS PRICE	MF-$0.75 HC-$6.60 PLUS POSTAGE
DESCRIPTORS	Course Content; *Electricity; *Electronics; Individualized Instruction; Individualized Programs; Industrial Education; Military Training; Post Secondary Education; *Programed Instruction; *Programed Materials; Study Guides; Trade and Industrial Education; Units of Study (Subject Fields)

ABSTRACT

The student will study the ways that inductance affects voltage and current in Direct Current (DC) and Alternating Current (AC) circuits and why and how inductors cause these actions. The module is divided into six lessons: rise and decay of current and voltage, LR (inductive-resistive) time constant, using the universal TC (time constant) chart, inductive-reactance, relationships in inductive circuits, and phase relationships. Each lesson consists of an overview, a list of study resources, lesson narratives, programed instructional materials, and lesson summaries. (Author/BP)

ED 099 506

NAVPERS 94558-9a

BASIC ELECTRICITY AND ELECTRONICS

INDIVIDUALIZED LEARNING SYSTEM

MODULE NINE

RELATIONSHIPS OF CURRENT, COUNTER EMF, AND VOLTAGE IN LR CIRCUITS

Study Booklet

BUREAU OF NAVAL PERSONNEL

January 1972

O V E R V I E W

MODULE NINE

Relationships of Current, Counter EMF, and Voltage in LR Circuits

In this module, you will study the ways that inductance affects voltage and current in DC and AC circuits and why and how inductors cause these actions.

For you to more easily learn the above, this module has been divided into the following six lessons?

TURN TO THE FOLLOWING PAGE AND BEGIN LESSON I.

NAVPERS 94558-9a

BASIC ELECTRICITY AND ELECTRONICS
INDIVIDUALIZED LEARNING SYSTEM

MODULE NINE
LESSON I

Rise and Decay of Current and Voltage

Study Booklet

Bureau of Naval Personnel
January 1972

OVERVIEW

LESSON I

Rise and Decay of Current and Voltage

In this lesson, you will study and learn about the following:

- rise of current
- how CEMF affects current
- rate of change of current and voltage
- decay of current
- collapsing of flux lines

BEFORE YOU START THIS LESSON, PREVIEW THE LIST OF STUDY RESOURCES ON THE NEXT PAGE.

LIST OF STUDY RESOURCES

LESSON 1

Rise and Decay of Current and Voltage

To learn the material in this lesson, you have the option of choosing, according to your experience and preferences, any or all of the following:

STUDY BOOKLET:

- Lesson Narrative
- Programmed Instruction
- Lesson Summary

ENRICHMENT MATERIAL:

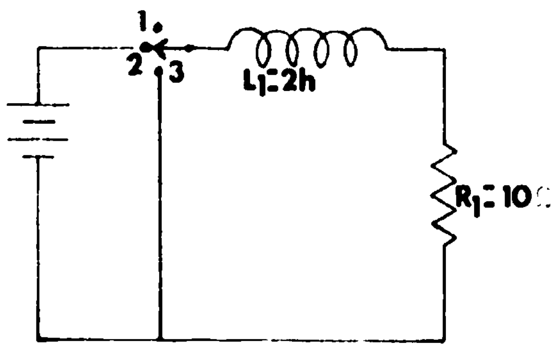
NAVPERS 93400a-1b "Basic Electricity, Alternating Current." Fundamentals of Electronics. Bureau of Naval Personnel. Washington, D.C.: U.S. Government Printing Office, 1965.

YOU MAY NOW STUDY ANY OR ALL OF THE RESOURCES LISTED ABOVE. YOU MAY TAKE THE PROGRESS CHECK AT ANY TIME.

NARRATIVE
LESSON 1

Rise and Decay of Current and Voltage

Rise of Current



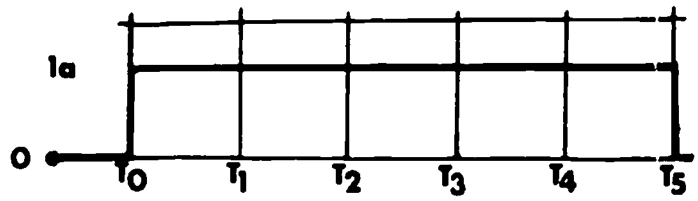
In this circuit, we are analyzing via an idealization. The 10 ohms of resistance does not necessarily indicate a physical resistor with a 10-ohm value. Instead the 10-ohms represents all the resistance in the circuit lumped into one value of resistance; it includes the coil resistance, the resistance of the conductors, and the internal resistance of the battery.

This schematic also shows an inductor with 2h of inductance, a three-way switch, and a 10-volt DC source. Since all the resistance in the circuit adds up to 10 ohms, we know that maximum current

will be 1 amp. $\left(I = \frac{10v}{10\Omega} = 1a.\right)$

When the switch is in position 1, it is open, and there is no current flow.

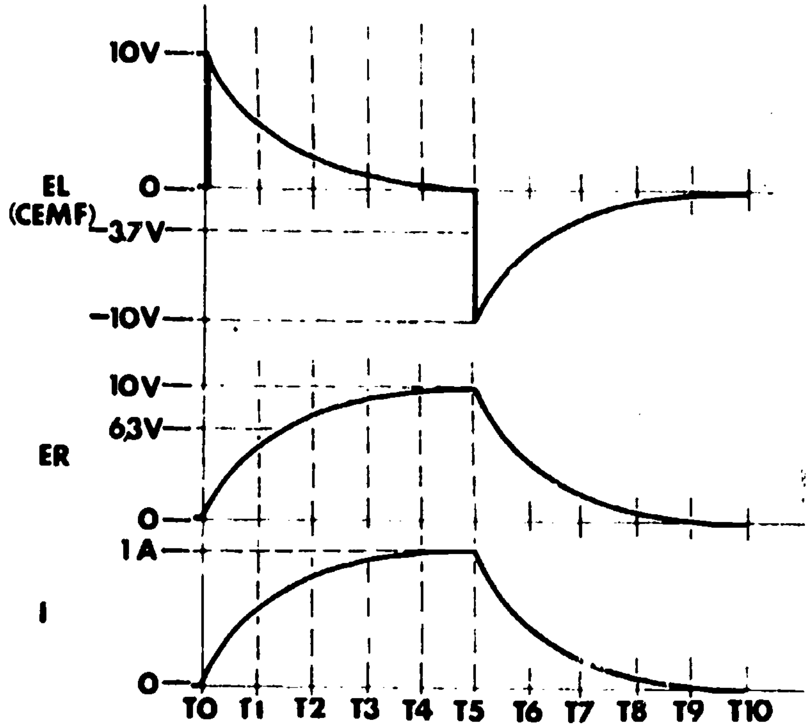
Now if we flip the switch to position 2, current starts to flow from the source. If this were a purely resistive circuit, without inductance, current would immediately reach its maximum of 1 amp, and then remain constant until the switch was opened again, as shown in this graph:



However, we are now looking at a circuit which has inductance as well as resistance. As we analyze this LR circuit (inductive-resistive) let us observe on a time-base graph what happens to the quantities.

E_L or CEMF refers to the coil-induced voltage.
E_R is the voltage drop across the resistor.
I is current.
T0, T1, T2, etc., refer to time periods.
(T0 = Time zero, T1 = time one, etc.)

The action begins at time 0 (T), the instant we close the switch to position 2. Immediately current begins to rise from 0 amps to some value. This is a change in current, and whenever there is a change in current, CEMF will be produced in the inductor.



Rate of change is greatest from T0 to T1 as you can observe in the bottom chart which indicates rise of current.

E_L, The Coil-Induced Voltage

At the time the switch is closed, because there is a maximum rate of change, maximum relative motion occurs between the field and coil, and the maximum value of E_L or CEMF is produced. The top chart indicates E_L is 10v. This CEMF immediately opposes the rise in current and consequently current is choked back from immediately reaching its maximum.

As time passes, the rate of change of the current slows, and less CEMF is produced. The graph of E_L shows this decrease. The voltage drop across the resistance increases as more current flows in the circuit.

We can analyze what is happening after <u>T0</u> in this way:

Rate of change $\downarrow$

$E_{L1} \downarrow$

$I \uparrow$

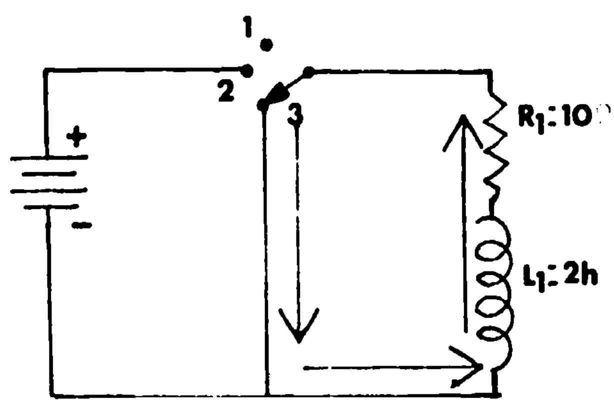
$E_{R1} \uparrow$ because there is more current through the circuit.

Current continues rising until (at T5) it reaches its maximum value of 1 amp. When I is maximum it stabilizes; it does not change measurably after that, and it always requires 5 time periods or time constants for current to rise from 0 to maximum. When current reaches maximum, there is no further change, and therefore, no rate of change. If there is no rate of change, there is no relative motion in the inductor, and so there is no induced voltage. For all practical purposes, when there is no rate of change, the inductor offers no more opposition than a straight wire.

When we have a DC source, current reaches its maximum value after about five time constants and will continue to be steady; there will be no induced voltage until another change occurs.

Decay of Current

We speak of the fall or decline of current from maximum back to zero as decay.



Now if we move the switch from position 2 to position 3, observe we have disconnected the source from the circuit.

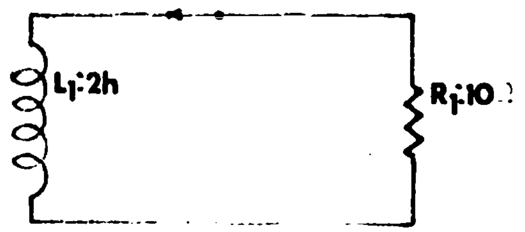
While the circuit was energized, the inductor was storing energy in an electromagnetic field around the coil; current flowing through the conductor gave rise to the energy in the magnetic field.

Now that the applied voltage is cut off, current begins to decrease. Again we have a maximum rate of change. The magnetic field around the conductor begins to collapse around the coil. This movement of the flux lines (relative motion) will induce a voltage in the inductor.

Collapsing Flux Lines

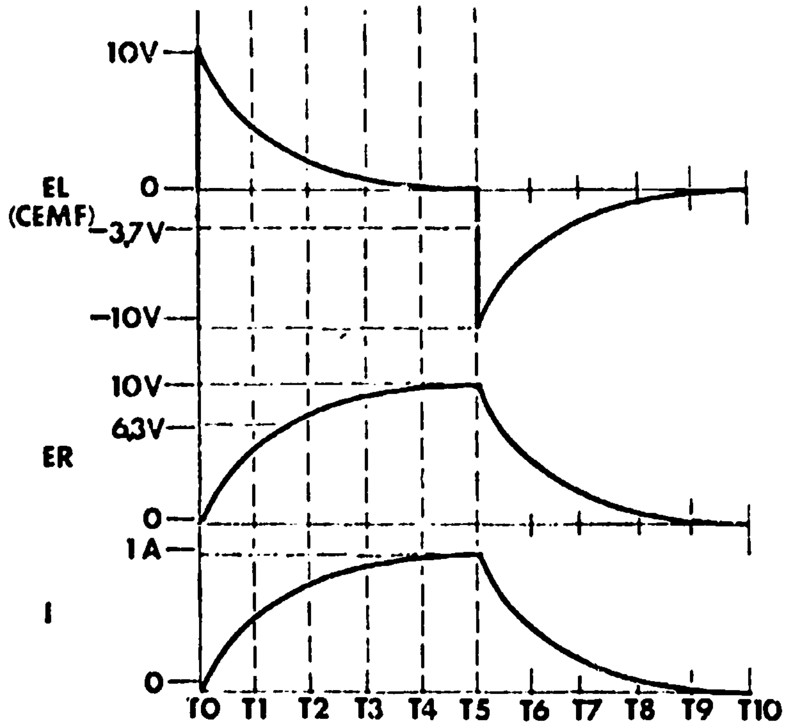
When the circuit was first energized, flux lines moved outward from the center of the conductor, and by the left-hand rule for conductors, the induced voltage tried to push current back toward the source -- counter to circuit current.

When the flux lines are collapsing, they move back toward the conductor's center and the induced voltage pushes current in the same direction it was flowing before. Instead of opposing current, the induced voltage now attempts to sustain it.



In effect, the circuit now looks like this, with the inductor acting as the source.

For our purposes, we will show current decay starting at T5 on the graph.



Notice what happens when the circuit is de-energized. The induced voltage jumps to maximum, but with an opposite polarity. It is 10 volts negative at T5.

Current begins to drop, and the voltage across the resistance drops.

As the magnetic field of the inductor decays, the induced voltage drops off to 0. As the induced voltage drops, current decays, and the voltage drop across R1 decreases.

It again takes about five time constants for the magnetic field to become completely depleted. At the end of this time, for all practical purposes, the induced voltage is at 0, current is at 0, and the voltage drop is at 0.

AT THIS POINT, YOU MAY TAKE THE PROGRESS CHECK, OR YOU MAY STUDY ANY OF THE OTHER RESOURCES LISTED. IF YOU TAKE THE PROGRESS CHECK AND ANSWER ALL OF THE QUESTIONS CORRECTLY, GO TO THE NEXT LESSON. IF NOT, STUDY ANY METHOD OF INSTRUCTION YOU WISH UNTIL YOU CAN ANSWER ALL THE QUESTIONS CORRECTLY.

PROGRAMMED INSTRUCTION
LESSON I

Growth and Decay of Current and Voltage

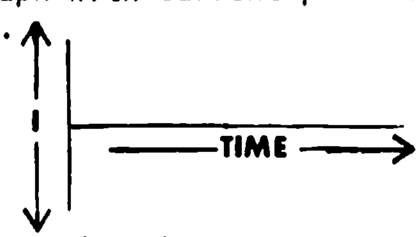
THIS PROGRAMMED SEQUENCE DOES NOT CONTAIN TEST FRAMES.

1. Recall that in an ideal circuit containing only resistance, circuit current will start to flow at its maximum value:

___a. in 5 seconds.
___b. in 4 seconds.
___c. instantaneously.
___d. in 2 seconds.

(c) instantaneously

2. To better illustrate this, a graph with current plotted against time can be used as shown below.

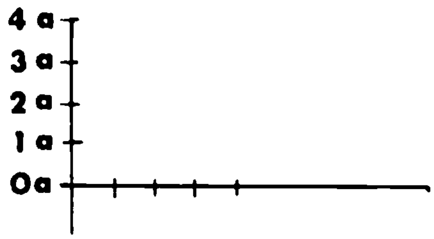


The horizontal line of our graph represents ________ and the vertical line represents ________.

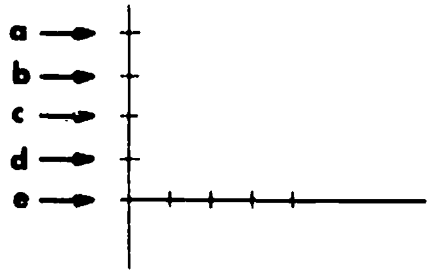
(time - current)

3. The vertical line is divided into increments of current.

For example:



In the graph below, each division equals 3 amps. Fill in the value of current for each point on the graph.



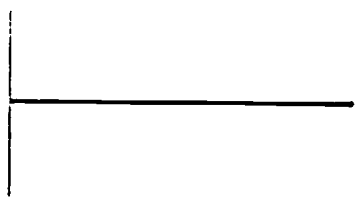
a. ______
b. ______
c. ______
d. ______
e. ______

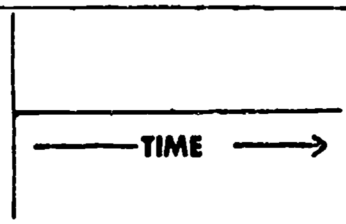
(a. 12a; b. 9a; c. 6a; d. 3a; e. 0a)

4. The maximum current which can be plotted on the graph in frame 3 is ____________ amps.

(12)

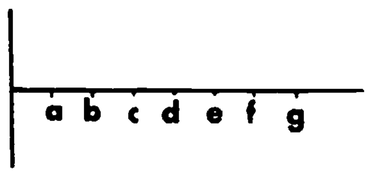
5. The horizontal line is divided into increments of time. Label the time line below.





6. Time is plotted starting at the left-hand side of the time line and increasing to the right.

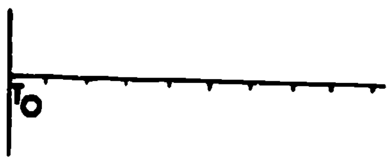
Select the letter designating the largest amount of time. _____

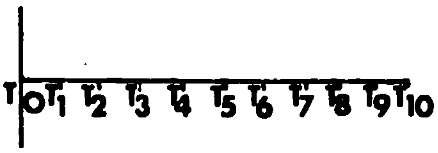


(g)

7. The space between time divisions is known as a time period or a time constant. The time periods are labeled time zero (T0), time one (T1), time two (T2), time three (T3), etc., with T0 at the beginning of the time line.

Label the remaining time periods on the graph below.





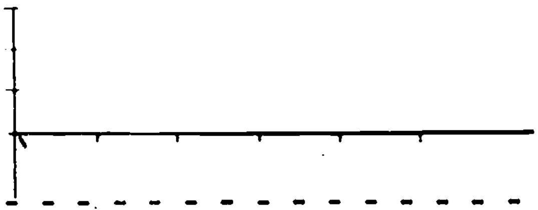
8. The first time period would start at time 0.

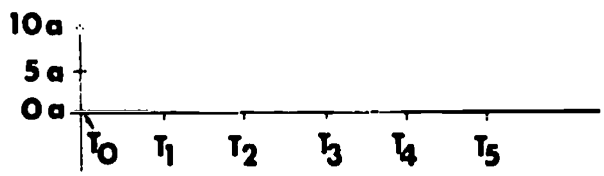
The fourth time period starts at time ____.

(3)

9. Label the current and time divisions on the following graph.

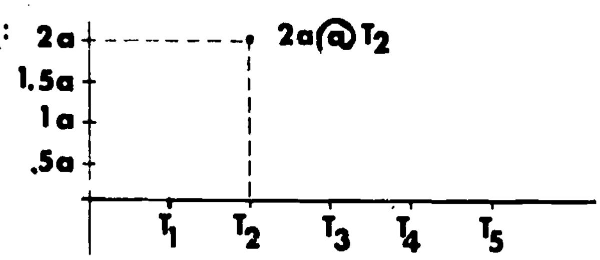
Each current division is 5 amps.



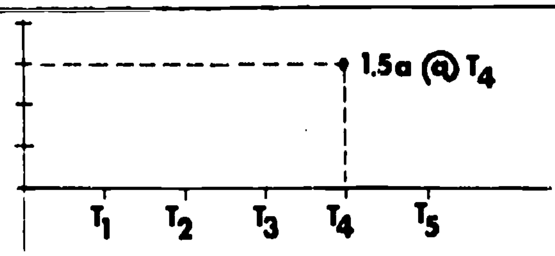


10. To plot a point on the graph, visualize perpendicular lines from the desired current and time. Where the two lines cross, place a dot.

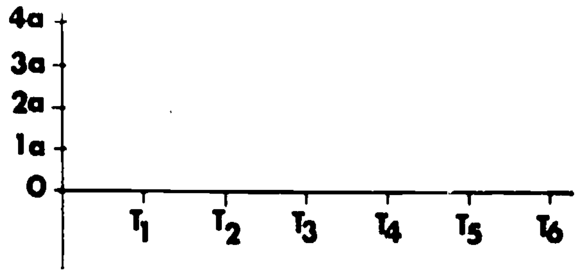
For example: 2 amps at T2:

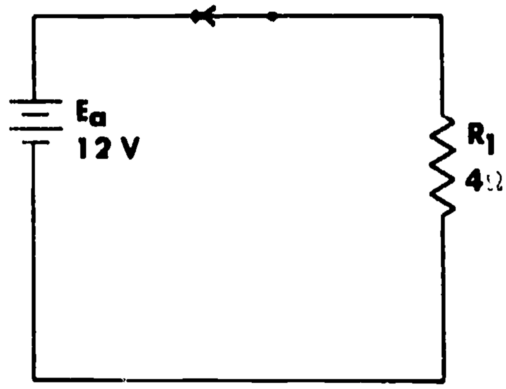


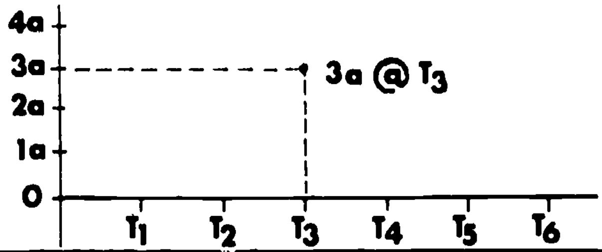
Plot 1.5a at time 4 on the above graph.



11. The current in the circuit is 3 amps. Plot 3 amps at T3 on the following graph.

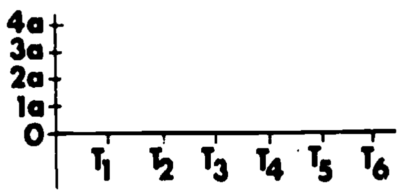


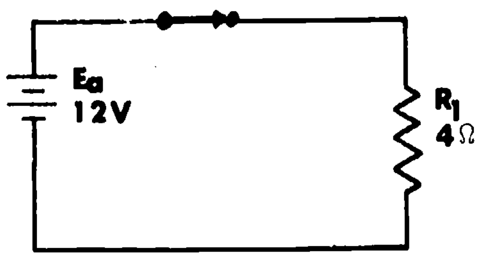


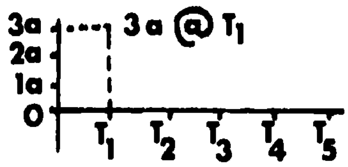


12. The current rise in a DC resistive circuit makes a straight vertical line from the time line to its maximum value.

Draw a line showing the current increase of the circuit below. (Switch is closed at T1.)







13. In a purely resistive circuit, how long does it take from the time the circuit is energized until current reaches its maximum value?

___ a. 3 periods of time
___ b. 5 periods of time
___ c. almost instantaneously
___ d. 1 period of time

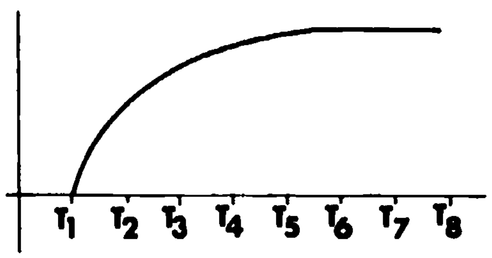
(c) almost instantaneously

14. To aid in understanding how an inductor will affect circuit current when placed in series with a resistor, recall that an inductor holds back or chokes the change in current.

Select the graph showing the current curve for an inductive-resistive (LR) circuit.

A

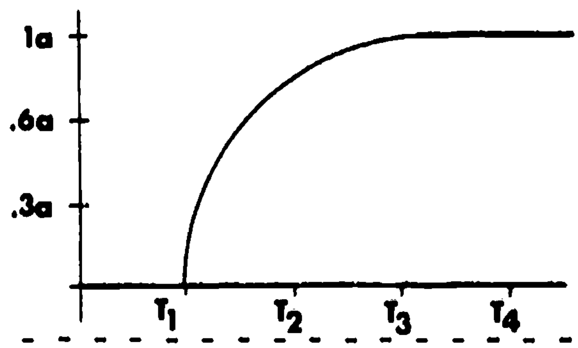
B



(B)

15. Looking at the illustration of current rise in an LR circuit, notice that the greatest rate of change in current takes place between: (Switch is closed at T1.)

____ a. T0 - T1
____ b. T1 - T2
____ c. T2 - T3
____ d. T3 - T4



(b) T1 - T2

16. Upon energizing an LR circuit, the maximum rate of change of current will occur during the ________ after the switch is closed.

____ a. first period of time or first time constant
____ b. second period of time or second time constant
____ c. third period of time or third time constant
____ d. fifth period of time or fifth time constant

(a) first period of time or first time constant

17. Recall that in a coil a CEMF is induced in opposition to the current flow. This CEMF results in more time being required for current to reach its ____________ value.

(maximum)

18. You have learned that the greatest rate of change in current flow occurs at the instant the circuit is energized.

The greatest change in magnetic flux around a coil will take place when current is ______________________.

(changing the fastest)

19. The changing magnetic flux at the first instant the circuit is energized results in:

____ a. maximum current flow.
____ b. maximum voltage induced (CEMF).

(b) maximum voltage induced (CEMF)

20. The CEMF at the first instant the circuit is energized will be about equal to and opposite in polarity to the source voltage, tending to cancel out the source voltage.

Immediately upon energizing an inductive circuit, current will be ____________________.

(minimum or zero)

21. Since current flow is nearly 0 at the first instant after energizing the circuit, almost the entire circuit voltage will be dropped across the coil.

The voltage drop across the resistor in an LR circuit at the first instant the circuit is energized will be ________________.

(minimum or nearly zero)

22. When an inductive circuit is first energized, which of these is maximum?

____ a. current
____ b. CEMF
____ c. voltage across R

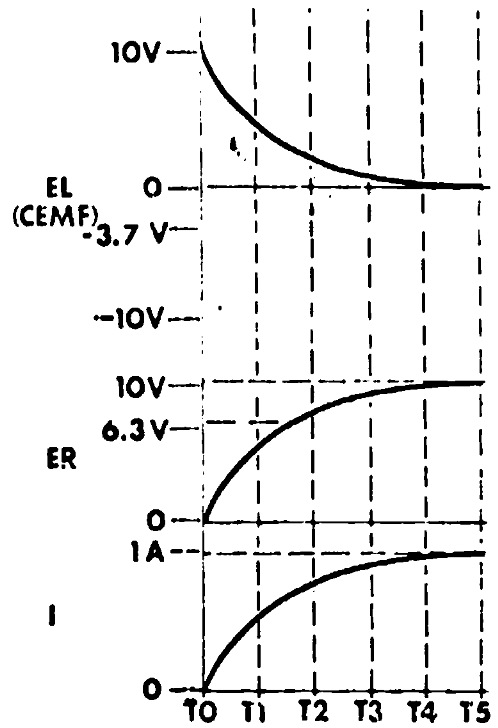
(b) CEMF

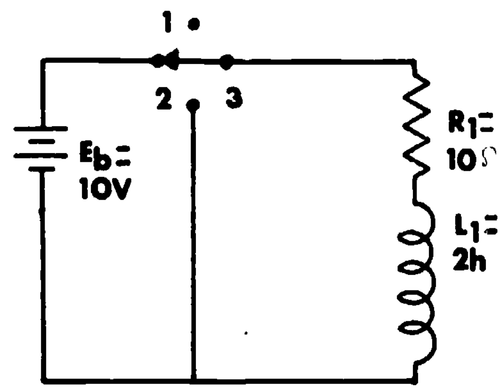
23. When current is rising in an inductive circuit, what effect does CEMF have on current?

____ a. attempts to sustain
____ b. chokes it back

(b) chokes it back

24. Use the graphs below to answer frames 24-27. These graphs show CEMF, circuit current, and the voltage drop across the resistor in the LR circuit shown below. (Circuit is energized at time 0.)





At T0, CEMF will be at its ________ value.

(maximum)

25. Circuit current at T5 will be at its ________ value.

(maximum)

26. The curve for circuit current and E_R are said to be identical because they both reach their ________ and ________ values at the same time.

(minimum, maximum -- either order)

27. This type of curve is called a growth curve because it plots the growth of circuit current.

The increase of current in an LR circuit is known as current ______.

(growth)

28. Match the following for conditions existing after current has reached its maximum value.

____ 1.	CEMF	a.	constant and maximum
____ 2.	E_R	b.	zero
		c.	changing

(1. b; 2. a)

29. Current will decrease at its maximum rate at the instant the circuit is de-energized by moving the switch to position 3.

The current-produced magnetic field around a coil collapses at the maximum rate upon ______________ the circuit.

(de-energizing)

30. Current will attempt to instantaneously decrease to 0 upon de-energizing the circuit, but due to the EMF induced by the collapsing magnetic field, it will slowly decay, or decrease, to zero.

Upon de-energizing the circuit, the induced EMF will attempt to:

____ a. stop current flow.
____ b. maintain current flow.
____ c. decrease current flow.

(b) maintain current flow

31. The magnetic field, in collapsing, moves through the coil in the direction opposite to that when the circuit was energized.

The induced voltage will now be of a polarity which tends to _________ current flow.
aid/oppose

- -

(aid)

32. Upon de-energizing the circuit, current decays to zero.

From this you might infer that the curves used to show this decrease are called _______________ curves.

- -

(decay)

33. When does the greatest rate of change take place during decay?

____ a. at the time the circuit is energized.
____ b. at the time the circuit is de-energized.

- -

(b) at the time the circuit is de-energized.

34. The decay curves will be mirror images of the growth curves.

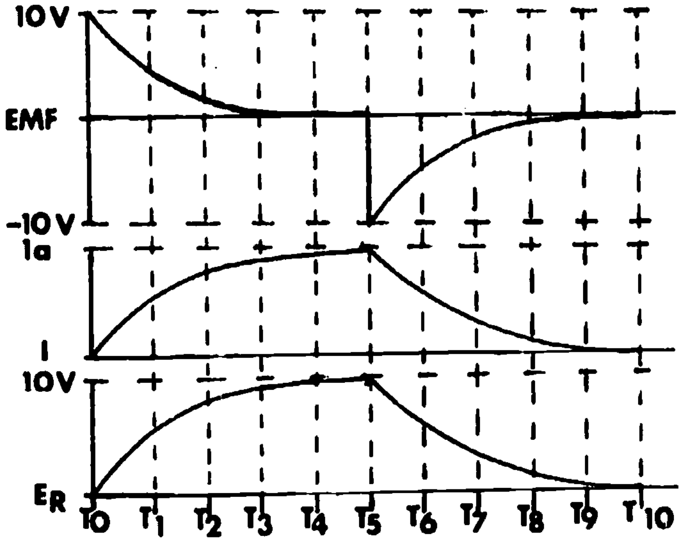
In the illustration below, the decay curve is plotted between:

____ a. T0 - T5

____ b. T5 - T10

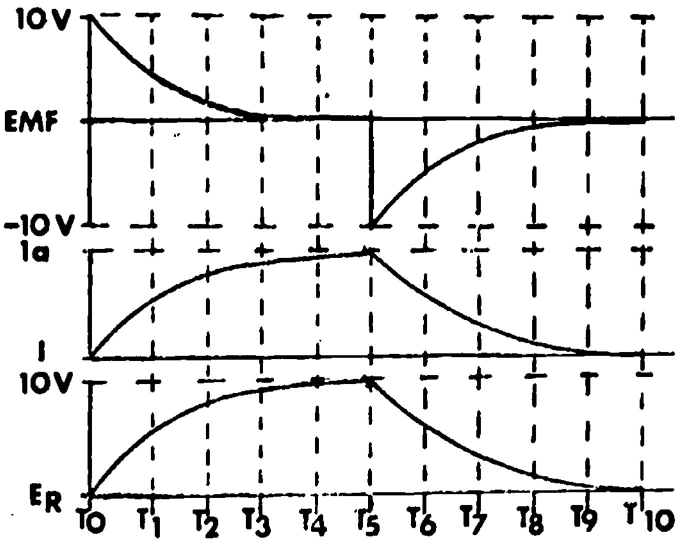
____ c. T10 - T12

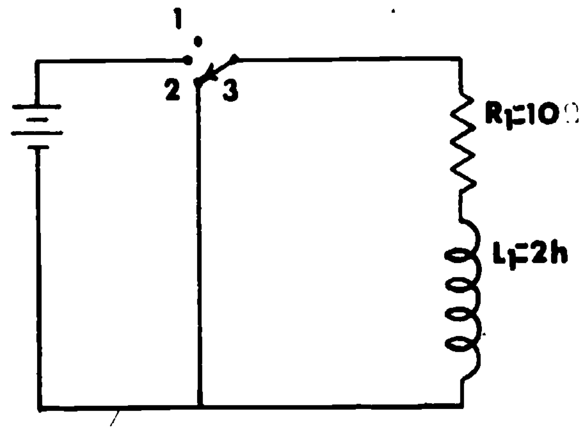
____ d. T5 - T9



(b) T5 - T10

35. Use the decay portion of the curves below to answer frames 35-38. Switch is placed in position 3 to de-energize the circuit at time 5.





The greatest rate of change takes place at:

____ a. T5 - T6
____ b. T6 - T7
____ c. T7 - T8
____ d. T9 - T10

(a) T5 - T6

36. At what time will CEMF be maximum?

____ a. T5
____ b. T6
____ c. T9
____ d. T10

- -

(a) T5

37. The greatest voltage drop across the resistor is at:

____ a. T5
____ b. T6
____ c. T9
____ d. T10

- -

(a) T5

38. The greatest rate of change in current and the voltage across the resistor occurs during the time between:

____ a. T5 - T6
____ b. T7 - T8
____ c. T8 - T9
____ d. T9 - T10

- -

(a) T5 - T6

39. Check all the items that are true.

During the period of the greatest rate of change on decay in a DC LR circuit:

____ a. CEMF is maximum and decreasing.
____ b. CEMF is minimum and increasing.
____ c. current is increasing from zero.
____ d. current is decreasing toward zero.
____ e. E_R is minimum and increasing.
____ f. E_R is maximum and decreasing.

(a. CEMF is maximum and decreasing; d. current is decreasing toward zero; f. ER is maximum and decreasing.

40. During decay, when the magnetic field around the inductor has fully collapsed, what will be the values of:

current? ____________

CEMF? ____________

E_R? ____________

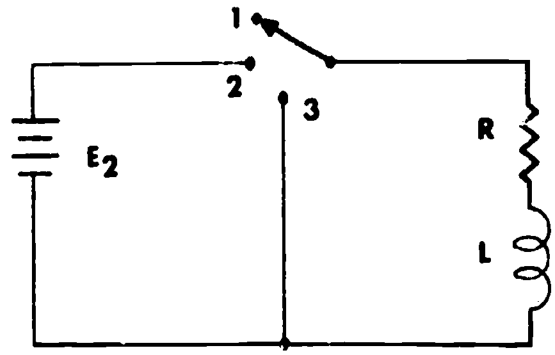
(all zero)

IF YOU TAKE THE PROGRESS CHECK AND ANSWER ALL THE QUESTIONS CORRECTLY, GO ON TO THE NEXT LESSON. IF NOT, STUDY ANY METHOD OF INSTRUCTION YOU WISH UNTIL YOU CAN ANSWER ALL THE QUESTIONS CORRECTLY.

SUMMARY
LESSON 1

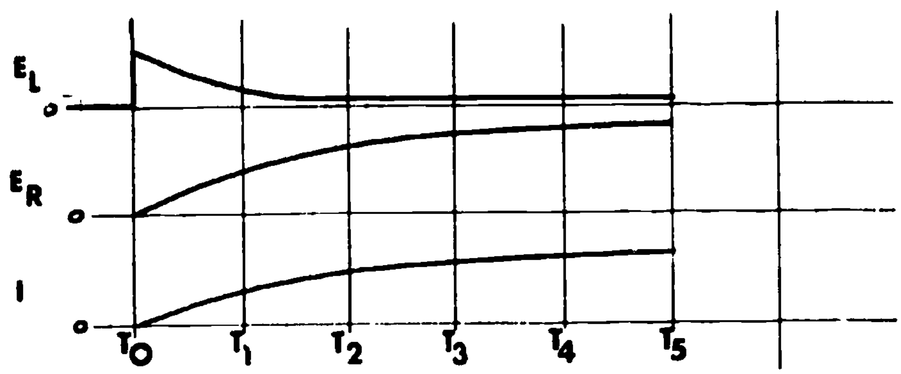
Rise and Decay of Current and Voltage

Consider the idealized circuit shown below:



Here R is assumed to be a resistor without any other property, and L a coil with inductance, but no resistance at all, etc.

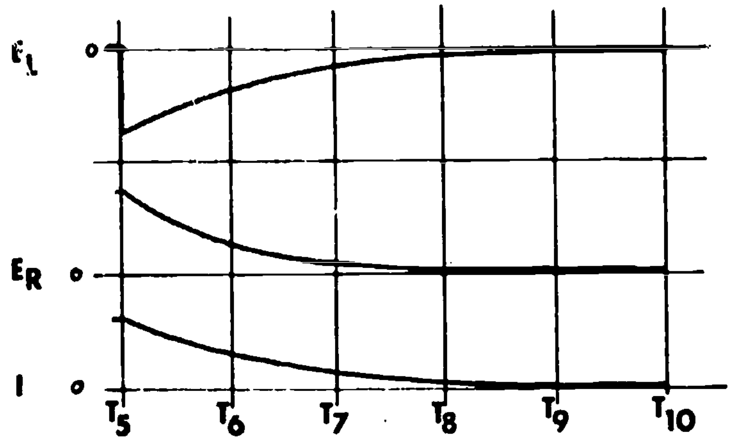
We will examine the behavior of the coil-induced CEMF, E_L; the voltage drop across the resistor E_R, and the circuit current, I all versus time T. When the switch is closed to position 2 at T_o, the following graphs are produced.



The action of the CEMF produced by the expanding magnetic field of the inductor explains why the curves have the illustrated shapes. Use this as a basis for analyzing the changes in circuit current and voltages. After five periods, or time constants, for all practical, measureable purposes, the current has reached its maximum, steady value.

Decay of Current in LR Circuits

Suppose at T5 the switch is placed in position 3; the LR combination is then shorted out, and the source voltage is disconnected. The behavior shown on the next page then occurs:



The reaction of current on decay may be readily analyzed by considering the collapsing flux lines and Faraday's and Lenz' Laws.

AT THIS POINT, YOU MAY TAKE THE LESSON PROGRESS CHECK, OR YOU MAY STUDY THE LESSON NARRATIVE OR THE PROGRAMMED INSTRUCTION OR BOTH. IF YOU TAKE THE PROGRESS CHECK AND ANSWER ALL OF THE QUESTIONS CORRECTLY, GO TO THE NEXT LESSON. IF NOT, SELECT ANOTHER METHOD OF INSTRUCTION UNTIL YOU CAN ANSWER ALL THE QUESTIONS CORRECTLY.

NAVPERS 94558-9a

BASIC ELECTRICITY AND ELECTRONICS
INDIVIDUALIZED LEARNING SYSTEM

MODULE NINE
LESSON II

LR Time Constant

Study Booklet

Bureau of Naval Personnel
January 1972

OVERVIEW

LESSON II

LR Time Constant

In this lesson you will study and learn about the following:

- -determining the length of a time constant
- -how resistance affects time constants
- -how inductance affects time constants
- -formula for time constant
- -percentage of rise or decay
- -the universal time constant chart

BEFORE YOU START THIS LESSON, PREVIEW THE LIST OF STUDY RESOURCES ON THE NEXT PAGE.

LIST OF STUDY RESOURCES
LESSON II

LR Time Constant

To learn the material in this lesson, you have the option of choosing, according to your experience and preferences, any or all of the following:

STUDY BOOKLET:

Lesson Narrative

Programmed Instruction

Lesson Summary

ENRICHMENT MATERIAL:

NAVPERS 93400A-1b "Basic Electricity, Direct Current." Fundamentals of Electronics. Bureau of Naval Personnel. Washington, D.C.: U.S. Government Printing Office, 1965.

AUDIO-VISUAL:

Slide/Sound - "Inductive Time Constants."

YOU MAY NOW STUDY ANY OR ALL OF THE RESOURCES LISTED ABOVE. YOU MAY TAKE THE PROGRESS CHECK AT ANY TIME.

NARRATIVE
LESSON 11

LR Time Constant

In Lesson I we learned that an LR circuit is one which has both inductance and resistance. We also learned about the time periods called time constants (TC) within which current rises or decays.

Determining The Length of a TC

The question in our minds now is: how long is a time constant? The answer is that a time constant is the length of time that it takes current in a given circuit to rise from minimum (0%) to 63.2% of its maximum Ohm's Law value, or to decay from maximum (100%) to 36.8% of its maximum value. From this definition, we can assume that a time constant is not the same for all circuits. Instead, the time constant for a given circuit will be determined by the amount of inductance and resistance in the circuit. The time constant intervals for a given circuit will be of equal length. T0 to T1 will equal T4 to T5 and so forth.

Resistance

In a purely resistive circuit, current reaches its maximum value the instant the circuit is energized.

From this we can assume that if there is more resistance than inductance in a circuit, the time constant will be of shorter duration.

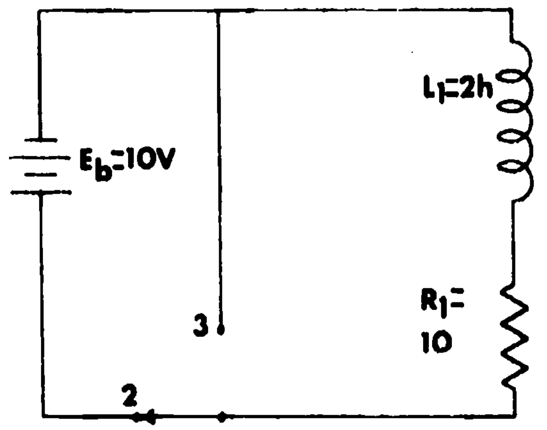
Inductance

Because inductance tends to oppose a change in current flow and hold back current when the switch is closed, it will take current a longer time to reach 63.2% of its maximum value if the circuit inductance is increased.

Mathematical Formula for TC

In a given circuit, the time constant is equal to the value of the inductance divided by the value of the resistance, or:

$$TC = \frac{L}{R}$$



1.

Using the circuit from Lesson 1, let's compute the time constant.

$$TC = \frac{L}{R}$$

$$TC = \frac{2\ h}{10\Omega}$$

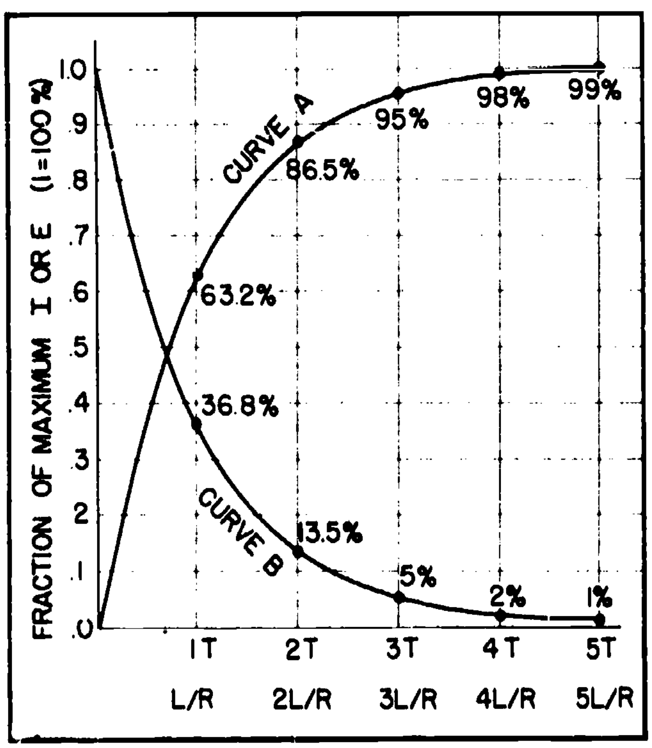
$$TC = 200\ msec$$

(Time constants are usually stated in <u>milliseconds</u> or <u>microseconds</u>.)

Our computation shows that <u>one</u> time constant is equal to 200 milliseconds; so, between T0 and T1, 0.2 seconds will elapse.

As all the time constants for any given circuit are equal, compute how long it will take (in seconds) for current in the above circuit to reach its maximum value.

Since it always takes current five time constants to reach maximum, multiplying the TC by 5 (0.2 x 5 = 1 second), 1 second will be needed for current to reach its maximum value.



Similarly, it will take five time constants for current to decay from its maximum value to zero for all practical purposes. As the time constant for this circuit is 0.2 sec., it will take current 1 second to decay from its maximum value back to zero. The only way you can change the time constant of a circuit is to change the value of <u>R</u> or <u>L</u>.

The illustration here shows the rise and decay curves the current follows from <u>T0</u> to <u>T5</u>.

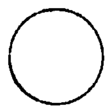
Percentage of Rise or Decay

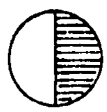
Notice in the curves of both rise and decay that the greatest rate of change occurs between T0 and T1. At T1 current will have risen to 63.2% of its maximum Ohm's Law value. At T1 current will have decayed to 36.8% of its maximum Ohm's Law value. (Notice that 63.2% subtracted from 100% gives us the 36.8% figure.)

During each time constant after T1, current will increase (decrease) 63.2% of the amount of current that is left to reach the maximum (minimum amount.)

To understand this let's think about a cake. The whole cake can be equated to maximum current, or 1 amp in this case.

Consider each cut of the cake to be a time constant.
Each time we cut the cake, we will take 50% of that remaining.

Whole cake - maximum 

Cut 1 - takes 50% of  leaves 

Cut 2 - takes 50% of  leaves 

Cut 3 - takes 50% of  leaves 

Cut 4 - takes 50% of  leaves 

At Cut 5, for all practical purposes, there is no more cake to cut. If the cake is maximum current, and each cut is a time constant during which current increases 63.2% of the remaining current, at T5 it is assumed there is no more increase; maximum has been reached.

Computing Percent of Increase

There is a universal time constant chart which tells us what percent of the maximum current will be reached at each time constant and the value of current at each time constant. Let's compute this ourselves.

Computing for T1 At T1 we know that current will have increased to 63.2% of maximum (1 amp) so that current at T1 = 63.2% of 1 amp.

$$I \text{ @ } T1 = 0.632 \times 1a$$
$$= 0.632a$$

Time	% of I_T	Amps
T1	63.2%	0.632 a

To compute for T2 We need to know how much current is left before maximum is reached.

Maximum is 1.000 amp

We have 0.632 amps at T1 or
0.368 amps left to reach maximum

During each time constant, current will increase 63.2% of what is left.

$$0.632 \times 0.368 = 0.233 \text{ amps}$$

We already have 0.632a + 0.233 = 0.865 amps

To find what percent 0.865a is of maximum current, divide:

$$\frac{0.865a}{1a \text{ (max I)}} = 0.865$$
$$= 86.5\%$$

Time	% of I_T	Amps
T2	86.5%	0.865

To compute for T3

How much current is left? 1.000 - 0.865 = 0.135

63.2% of what is left (0.135a)

0.632 x 0.135 = 0.085a

Add to current at T2 0.085 + 0.865 = 0.950

Time	% of I_T	Amps
T3	95.0	0.950

Compute for T4.

How much I is left? ________________

Increase by 63.2% of what is left.

Add to I at T3.

Time	% of I_T	Amps
T4	______	________

Answer:

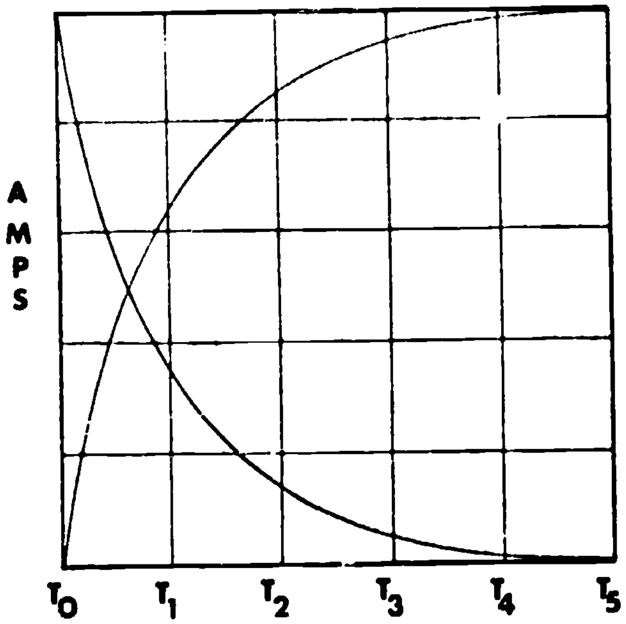
Time	% of I_T	Amps
T4	98.1	0.98

You know that at T5 the current has, in effect, achieved 100% of its maximum value and 1 amp of current is flowing. Actually, as long as current is rising at 63.2% of the remainder, 100% will never be achieved. Practically, we assume 100% is reached at T5.

Universal Time Constant Chart

The percentage that we computed for current rise for each time constant must be memorized because it would take you too long to derive the percentage each time you need to analyze values in an LR circuit.

This is the rise and decay curve showing the percentage of the maximum current which current has achieved at each of the five time constants.



If you memorize these:

@T1 -- 63.2%

@T2 -- 86.5%

@T3 -- 95%

@T4 -- 98%

@T5 -- 100%

then you can easily calculate the decay percentage by subtracting the rise percentage at that time constant from 100.

Without glancing at the Universal Time Constant Chart, if you know that the rise percentage at T2 is 86.5%, what is the decay percentage at T2? ________

That's right, the decay percentage at T2 is 100 minus 86.5 = 13.5%

Nothing can ever vary the percentage figures in the universal time constant chart.

What are the percentages of maximum current on the rise reached at:

T1? ____________
T2? ____________
T3? ____________
T4? ____________
T5? ____________

Check your answers with the Universal Time Constant Chart. If you have not memorized these figures, stop now and learn them before proceeding further.

AT THIS POINT, YOU MAY TAKE THE PROGRESS CHECK, OR YOU MAY STUDY ANY OF THE OTHER RESOURCES LISTED. IF YOU TAKE THE PROGRESS CHECK AND ANSWER ALL OF THE QUESTIONS CORRECTLY, GO TO THE NEXT LESSON. IF NOT, STUDY ANY METHOD OF INSTRUCTION YOU WISH UNTIL YOU CAN ANSWER ALL THE QUESTIONS CORRECTLY.

PROGRAMMED INSTRUCTION
LESSON II

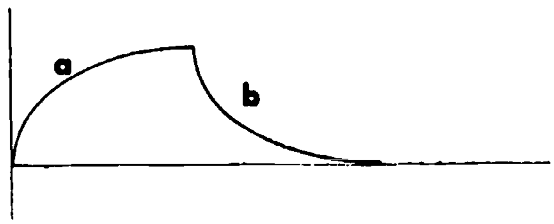
LR Time Constant

THIS PROGRAM SEQUENCE DOES NOT CONTAIN TEST FRAMES.

1. Previously you learned that current and voltage in an LR circuit could be plotted on growth and decay curves.

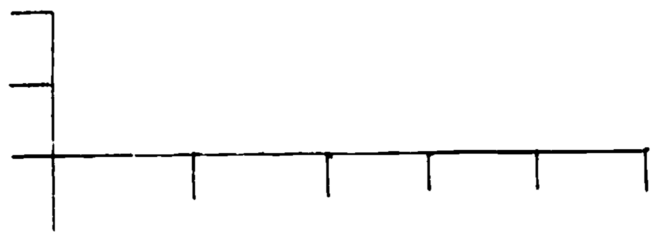
Match:

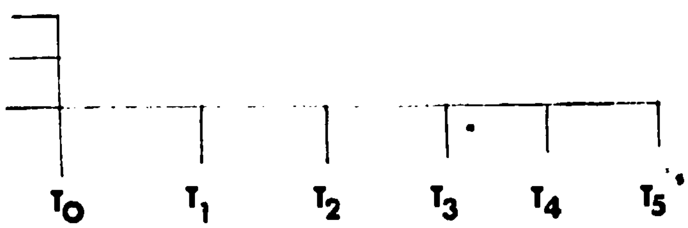
____ 1. curve a a. growth
____ 2. curve b b. decay



(1. a; 2. b)

2. Recall that the time periods are known as time constants (TC). Label the time constants below:





3. The first time constant (TC) is equal to the time required for circuit current to change by 63.2% of its' maximum Ohm's Law value in a DC LR circuit.

If current has increased by 63.2%, we say one ________ ________ has elapsed.

(time constant)

4. In your own words state what a time constant equals.

____

____

____

(The time required for current to change by 63.2% of its maximum value.) (or words to this effect)

5. A time constant, upon energizing an LR circuit, may be described as:

____ a. the time required for current to increase to its maximum Ohm's Law value.

____ b. the time required for current to decrease to 0 from its maximum Ohm's Law value.

____ c. the time required for current to rise to 98% of its maximum Ohm's Law value.

____ d. the time required for current to rise to 63.2% of its maximum Ohm's Law value.

(d) the time required for current to rise to 63.2% of its maximum Ohm's Law value

6. In any given LR circuit each TC will be equal in time to every other TC.

Select the choice which describes the relationships between time constants.

____ a. T1 - T2 = T3

____ b. $\frac{T1}{T2}$ = T3

____ c. T1 x T2 = T3

____ d. T1 to T2 = T2 to T3

(d) T1 to T2 = T2 to T3

7. State the mathematical relationship between time constants in a given circuit. ________________

(TC1 = TC2 = TC3)

8. If the TC between T2 and T3 is 5 μsec, what will be the TC between T0 and T1? ____________

(5 μsec)

9. Recall that current in a purely resistive DC circuit reaches its maximum value ____________ upon energizing the circuit.

(instantaneously)

10. In a series DC LR circuit, the time required for current to reach its maximum value as compared to a pure resistive circuit will be:

(increased/decreased)

(increased)

11. The greater the ratio of inductance to resistance the longer it will take for current to change by 63.2%.

Select the combination which will have the largest time constant.

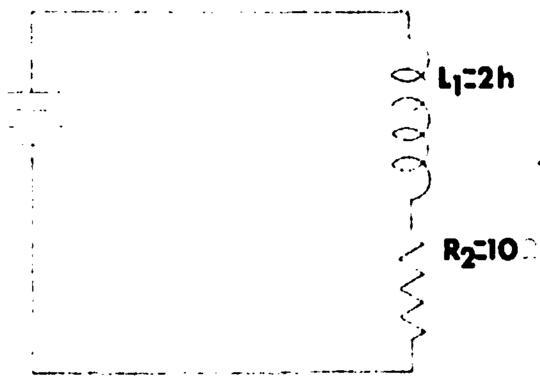
____ a. L = 1 h; R = 10Ω
____ b. L = 10 h; R = 1Ω
____ c. L = 10 h; R = 10Ω
____ d. L = 5 h; R = 5Ω

- -

(b) L = 10 h; R = 1Ω

12. The relationship between L, R, and TC can be expressed mathematically as TC = $\frac{L}{R}$

Compute the time constant.



TC ____________________

- -

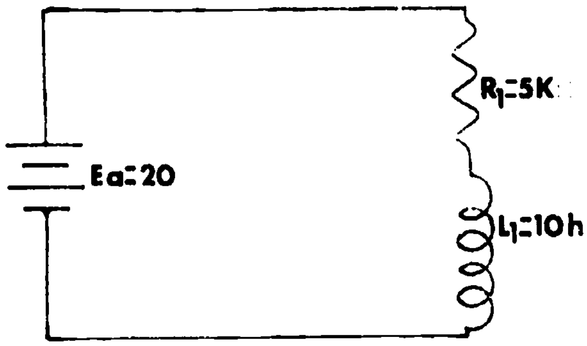
(0.2 sec or 200 msec)

13. Refer to the previous diagram. What is the time between T3 and T4?

- -

(200 msec)

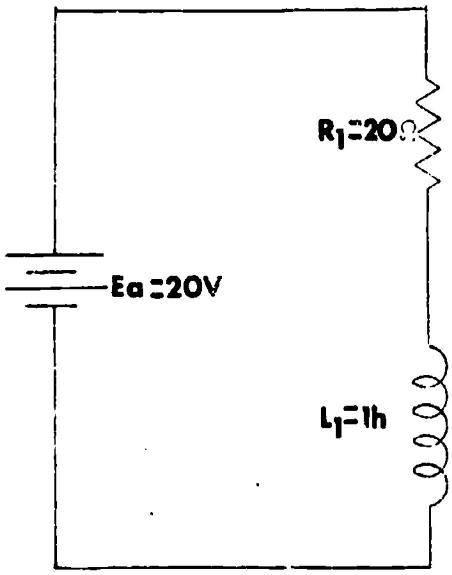
14. Solve for <u>TC</u>.



TC ______________

(2 msec)

15. Solve for <u>TC</u>.

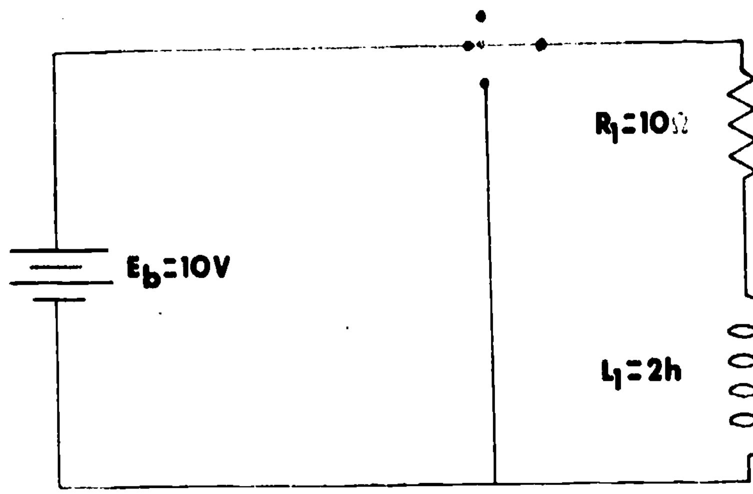


TC ______________

(.05 sec or 50 msec)

16. After a DC LR circuit has been energized for a period of time, the resistor will be the only component limiting current flow.

After the below circuit current has stabilized, what is I_T?



(1 amp)

17. Current flow will increase by 63.2% of its maximum during one time constant. What would be the value of current at T1 if the circuit of frame 16 were energized at T0? ________

$(I_{T1} = 63.2\%$ of I

$I_{T1} = 0.632 \quad 1a$

$I_{T1} = 0.632a)$

18. The increase in current during the second time period will be 63.2% of the current change remaining from T1 to total current. What would be the increase in current from T1 to T2? ________

$(I_T - I\ @\ T1) \times 63.2\% =$
$(1a - 0.632a) \times 0.632 =$
$(0.368) \times 0.632 = 0.233a$

19. Adding the current flowing at T1 to the increase in current during T1 to T2, we can find the amount at T2.

The current flowing at T2 will be ________________.

(0.632 + 0.233a = 0.865a)

20. Determine the current increase during the time between T2 and T3.

____

(I_T = I @ T2) x 63.2% =
(1a - .865) x 63.2% =
(0.135 x 63.2% = 0.085a)

21. The current flowing at T3 is ________________.

(0.085a + 0.865a = 0.95 amp)

22. Determine the current flowing at T4. ________________

(0.98 amp)

23. Current flowing at T5: ________________

(1a)

24. Current is, for all practical purposes, maximum after five time constants.

After five time constants, what percentage of current flow will be assumed to flow in the circuit? ________________

(100%)

25. A much simpler method to determine the current at any time constant is to learn the percentage values for each of the time constants.

What is the percentage increase of current during the first TC?

____ a. 86.5%
____ b. 63.2%
____ c. 98%
____ d. 100%

- -

(b) 63.2%

26. During two time constants, the current increased to 0.865a.

The percentage of current increase in the first two time periods is:

____ a. 86.5%.
____ b. 63.2%.
____ c. 98%.
____ d. 100%.

- -

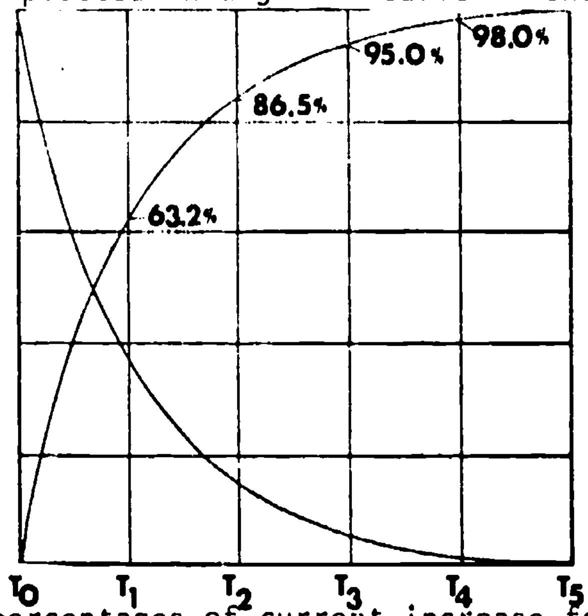
(a) 86.5%

27. What is the percentage of current increase during the four time constants from T0 to T4 ____________; during the five time constants from T0 to T5? ____________

- -

(98%; 100%)

28. These percentage values remain the same for any LR circuit. These values can be plotted on a growth curve as shown below.



Fill in the percentages of current increase for the times below.

T2 ______
T4 ______

(86.5%; 98%)

29. The decay curve is also assigned percentage values which are determined by subtracting the growth curve percentages, at the time in question, from 100%.

For example:

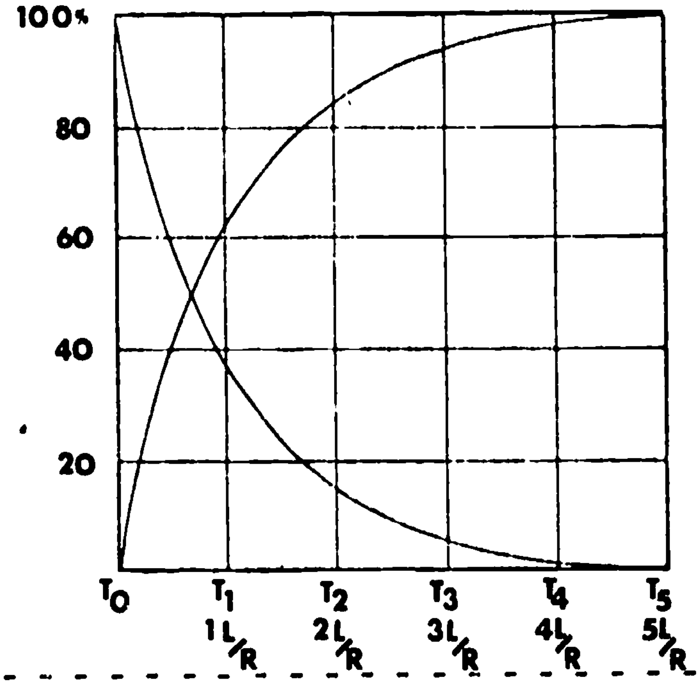
At T1 the decay percentage would be 100% - 63.2% = 36.8%

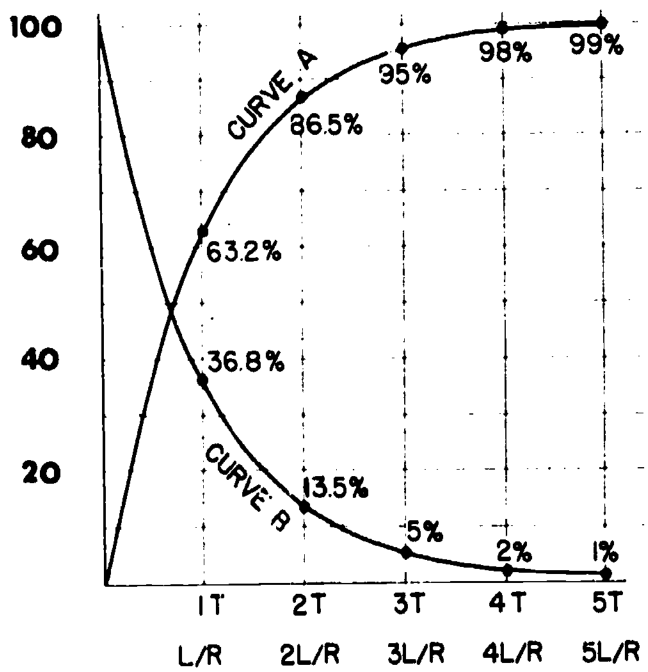
What is the percentage value of the decay curve at T3? ______

(5%)

30. A graph which is labeled with percentage values on the growth and decay curves is known as a Universal Time Constant Chart.

Label the Universal Time Constant Chart below.





31. List the percentages of maximum Ohm's Law value that current will reach at the end of:

a. T1. ______________
b. T2. ______________
c. T3. ______________
d. T4. ______________
e. T5. ______________

- -

(a. 63.2%; b. 86.5%; c. 95%; d. 98%; 3. 100%)

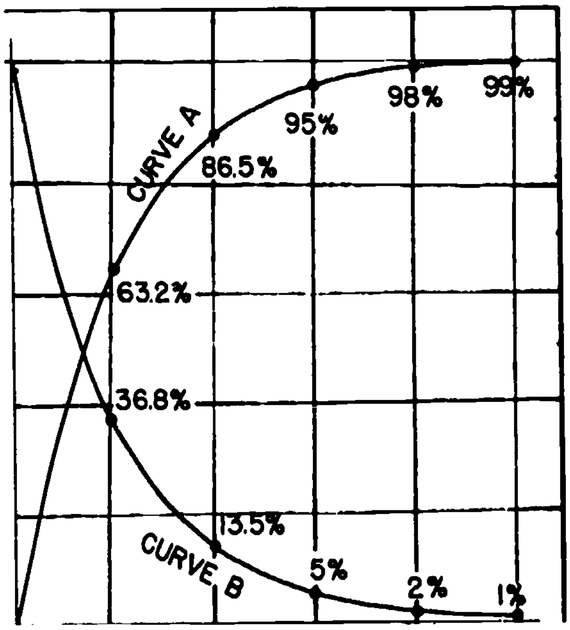
YOU MAY TAKE THE PROGRESS CHECK, OR YOU MAY STUDY ANY OF THE OTHER RESOURCES LISTED. IF YOU TAKE THE PROGRESS CHECK AND ANSWER ALL THE QUESTIONS CORRECTLY, GO TO THE NEXT LESSON. IF NOT, STUDY ANY METHOD OF INSTRUCTION YOU WISH UNTIL YOU CAN ANSWER ALL THE QUESTIONS CORRECTLY.

SUMMARY
LESSON II

LR Time Constant

We have seen that current rise or decay in a series DC LR circuit follows a certain general curve. We found that current requires five equal periods of time (time constants) to fully rise or decay. Each time constant is equal to the circuit inductance in henrys divided by the circuit resistance in ohms ($TC = \frac{L}{R}$).

The change in current during one time constant is always 63.2% of the difference between the final current value and the instantaneous current at the beginning of the time constant. The graph below shows the values of current vs. time constant for both rise (Curve A) and decay (Curve B). Memorize the percentages at each time constant.



AT THIS POINT, YOU MAY TAKE THE LESSON PROGRESS CHECK, OR YOU MAY STUDY THE LESSON NARRATIVE OR THE PROGRAMMED INSTRUCTION OR BOTH. IF YOU TAKE THE PROGRESS CHECK AND ANSWER ALL OF THE QUESTIONS CORRECTLY, GO TO THE NEXT LESSON. IF NOT, STUDY ANOTHER METHOD OF INSTRUCTION UNTIL YOU CAN ANSWER ALL THE QUESTIONS CORRECTLY.

NAVPERS 94558-9a

BASIC ELECTRICITY AND ELECTRONICS
INDIVIDUALIZED LEARNING SYSTEM

MODULE NINE
LESSON III

Using the Universal Time Constant Chart

Study Booklet

Bureau of Naval Personnel
January 1972

OVERVIEW
LESSON III

<u>Using the Universal Time Constant Chart</u>

In this lesson, you will study and learn about the following:

- the Universal Time Constant Chart
- practical applications for the chart
- variational analysis of LR time constants

BEFORE YOU START THIS LESSON, PREVIEW THE LIST OF STUDY RESOURCES ON THE NEXT PAGE.

LIST OF STUDY RESOURCES
LESSON III

Using the Universal Time Constant Chart

To learn the material in this lesson, you have the option of choosing, according to your experience and preferences, any or all of the following:

STUDY BOOKLET:

- Lesson Narrative
- Programmed Instruction
- Lesson Summary

ENRICHMENT MATERIAL:

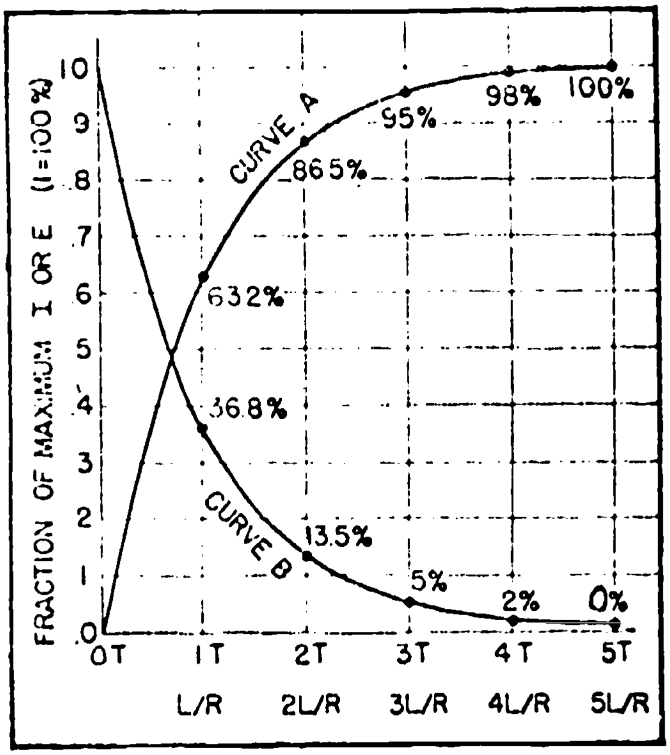
NAVPERS 93400A-1b "Basic Electricity, Alternating Current." Fundamentals of Electronics. Bureau of Naval Personnel. Washington, D.C.: U.S. Government Printing Office, 1965.

YOU MAY NOW STUDY ANY OR ALL OF THE RESOURCES LISTED ABOVE. YOU MAY TAKE THE PROGRESS CHECK AT ANY TIME.

NARRATIVE
LESSON III

Using the Universal Time Constant Chart

The Universal Time Constant Chart indicates the magnitude of voltage and current in a series LR circuit at any particular time constant during rise and decay. The curves give the percentage of maximum voltage or current at the end of each time period.



Curve A plots:

1. I on rise;
2. E_R on rise.

Curve B plots:

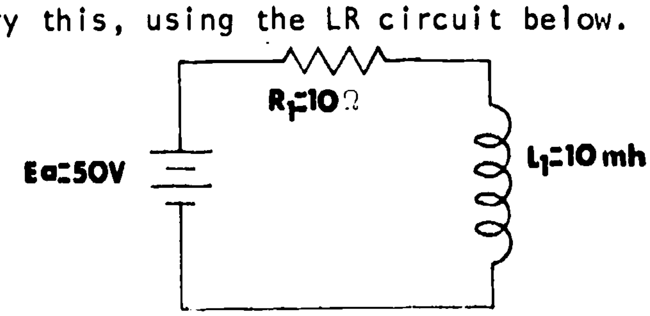
1. I on decay (with coil as source.)
2. E across coil (E_L).
3. E across resistor (E_R) on decay.
4. I on decay.
5. Decay of CEMF on the rise of I.

Practical Application of Chart

In advanced schools and courses, you may have to compute circuit quantities by using the Universal Time Constant Chart, particularly for applications to radio and other amplifying equipment.

To use the chart, you must first determine the maximum voltage or current for a given circuit and then multiply this maximum by the percentage at any particular time constant. In this manner, it is possible to determine quantities of current or voltage in a circuit at a given time constant.

Let's try this, using the LR circuit below.



We are going to solve for:

TC (time constant)
I @ (means after) 5 TC
E @ 5 TC
Maximum CEMF

Recall that the formula for finding the time constant is

$TC = \frac{L}{R}$.

Step 1

What is the time constant for the circuit on the preceding page? ____________________

$TC = \frac{L}{R}$

$TC = \frac{10\ mh}{10\ \Omega} = \frac{10 \times 10^{-3}}{10} = 1 \times 10^{-3}$ or 1 msec

TC = 1 msec

If one TC is 1 msec, about how long will it take for I to reach maximum? ______________

---

5 time constants x 1 msec = 5 msec

Step 2

Now we want to determine what current will be in the same circuit after five time constants.

What is the maximum Ohm's Law value of current in this circuit? ________________

$I = \frac{E}{R}$ $I = \frac{50\ v}{10\ \Omega} = 5\ a$

Step 3

What is the maximum voltage drop across the resistor?

____

In this series circuit, if E_a is 50v, maximum E_R will also be 50v.

Step 4

The maximum counter EMF occurs at the instant the circuit is energized and is equal to the applied voltage. Therefore, in this circuit maximum CEMF is 50v.

So far, we know this about the circuit:

TC = 1 ms

maximum I = 5 a

maximum E_R = 50 v

maximum CEMF = 50 v

Now, by using the Universal Time Constant Chart, we can find circuit values at the end of specific time constants. For example, we can:

Find I @ T2.

At T2, you know from memory that I will have reached 86.5% of its maximum. Therefore, by multiplying .865 x 5 a, you will find I @ T2 = 4.325 a.

When we find values in this manner, we round off figures for convenience. So, we say I @ T2 = 4.3 a.

For the same circuit, what is E_R @ T3? At T3, the voltage drop is 95% of E_{max}.

Figure E_R @ T3:

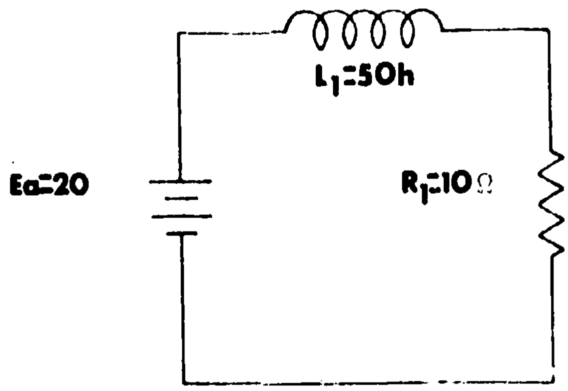
E_R @ T3 equals .95 x 50 v
E_R @ T3 = 47.5 v

Now find E_L at T1.

You know E_L is plotted on Curve B; therefore, to find the percentage of T1 at Curve B, subtract the percentage of T1 on curve A from 100%. 100% - 63.2% = 36.8%. Now multiply .368 x maximum voltage. .368 x 50 v = 18 v.

E_L at T1 = 18 v

Practice



In this circuit, observe that we have increased the value of L from the previous circuit. We can assume then that the time constant will be longer than it was in the other circuit.

Because there is more inductance in the circuit, it will take current longer to reach its maximum value.

1. Find TC in the above circuit. TC = ______________
2. Find maximum I. I = ______________
3. Find maximum E_R. E_R = ______________
4. Find maximum E_L. E_L = ______________

You should have determined that TC = 5 seconds, I = 2 a, E_R = 20 v, and E_L = 20 v.

Knowing that one time constant equals 5 seconds, if you were asked to find the value of a quantity after 15 seconds, what time constant line would indicate the percentage to use? ________________

You would find the percentage at T3. Each time constant is 5 seconds, so 15 seconds would be three time constants.

---

1. Find I at 15 sec. ____________
2. Find E_R at 15 sec. ____________
3. Find E_L at 20 sec. ____________

Your answers should be as follows:

I @ 15 sec. = 1.90 a
E_R @ 15 sec. = 19.0 v

NOTE: You can also calculate E_R by Ohm's Law after you know the amount of current:

$E = IR$ or $E = 1.9\text{ a} \times 10\ \Omega = 19\text{ v}$
E_L @ 20 sec. = .40 v

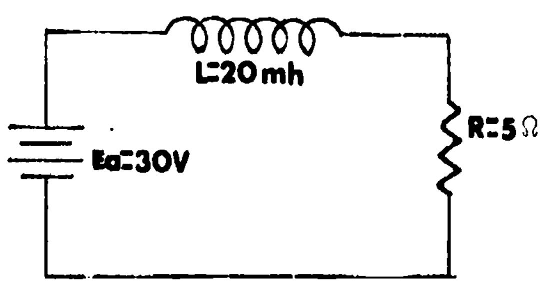
Find I at T5. ____________

Find E_L at T5. ____________

At T5, current will have reached its maximum value of 2 amps. At T5, counter EMF will have reached 0, as current will be steady. If there is no rate of change, there can be no CEMF.

---

1. Solve this circuit for:



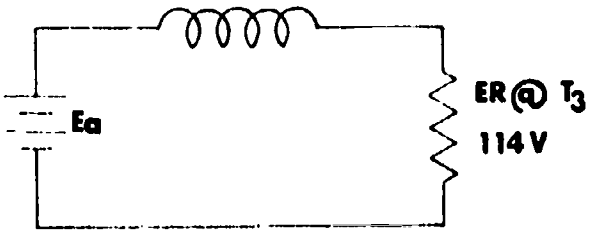
TC ________

E_R @ T2 ________

I @ T3 ________

E_L @ T1 ________

2. What is the value of E_a if the voltage drop across the resistor is 114 v at T3?



E_a = ___________

3. A coil with a DC resistance of 22 Ω is placed across a source; 0.1 second after the circuit is closed, the current has reached 63.2% of its final value. What is the L of the coil?

L = ___________

ANSWERS:

1. TC = 4 msec
   E_R @ T2 = 25.95 v or 26 v (rounded out)
   I_R @ T3 = 5.7 a
   E_L @ T1 = 11.04 v or 11 v

2. E_a = 120 v

3. L = 2.2 h

   To solve for L, you know that if current has reached 63.2% of maximum at 0.1 seconds, then the time constant is 0.1 seconds.

   $$TC = \frac{L}{R}$$

   $$0.1 \text{ sec.} = \frac{L}{22\Omega}$$

   To isolate L, multiply both sides of the quation by 22.

   $$2.2 = \frac{L \times \cancel{22}}{\cancel{22}}$$

   Therefore, L = 2.2 h

Variational Analysis

Consider what happens to the time constant if you:

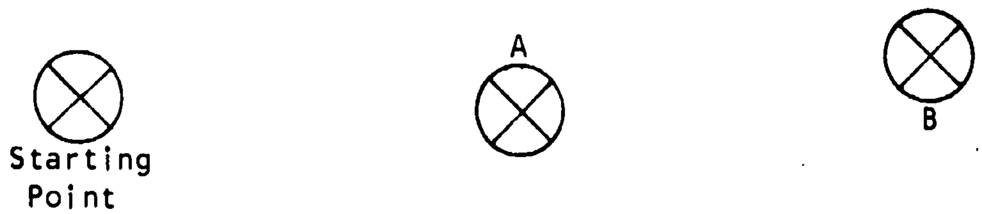
Increase circuit R. = TC $\downarrow$
Increase circuit L. = TC $\uparrow$
Decrease R. = TC $\uparrow$
Decrease L. = TC $\downarrow$

With the same value of L and R, what will happen to TC if the applied voltage is increased?

I hope you said nothing, because TC will vary only if you change L or R or both.

With the same value of L and R, if you increase E_a, current will increase. This increases the rate of change. Because current must reach a greater maximum in the same amount of time, it will have to rise faster.

As an example, imagine that you have to get to point A, and your dog has to get to point B in the same amount of time -- 2 seconds.



Because you both have the same amount of time, but your dog has a greater distance to cover, he will have to run to point B, but you can walk to point A.

Similarly, if E_a is increased, the maximum current will be greater, and current will have to rise faster to reach 63.2% of its maximum in the same length of time.

AT THIS POINT, YOU MAY TAKE THE PROGRESS CHECK OR YOU MAY STUDY ANY OF THE OTHER RESOURCES LISTED. IF YOU TAKE THE PROGRESS CHECK AND ANSWER ALL OF THE QUESTIONS CORRECTLY, GO TO THE NEXT LESSON. IF NOT, STUDY ANY METHOD OF INSTRUCTION YOU WISH UNTIL YOU CAN ANSWER ALL THE QUESTIONS CORRECTLY.

PROGRAMMED INSTRUCTION
LESSON III

Using the Universal Time Constant Chart

THIS PROGRAMMED SEQUENCE HAS NO TEST FRAMES.

1. Recall that the growth and decay curves, when used as a Universal Time Constant Chart, are labeled in:

   ____ a. percentages.
   ____ b. volts.
   ____ c. amps.

- -

(a) percentages

2. State the percentage values found on the growth curve of a Universal Time Constant Chart.

   a. T1 ____________ d. T4 ____________
   b. T2 ____________ e. T5 ____________
   c. T3 ____________

- -

(a. 63.2%; b. 86.5%; c. 95%; d. 98%; e. 100%)

3. State the percentage values found on the decay curve of a Universal Time Constant Chart.

   a. TC 1 ____________ d. TC 4 ____________
   b. TC 2 ____________ e. TC 5 ____________
   c. TC 3 ____________

- -

(a. 36.8%; b. 13.5%; c. 5%; d. 2%; e. 0%)

4. Current increase in a DC LR circuit is plotted on the:

____ a. growth curve.
____ b. decay curve.

(a) growth curve

5. Recall that the voltage drop across the resistor results from current flow in the circuit.

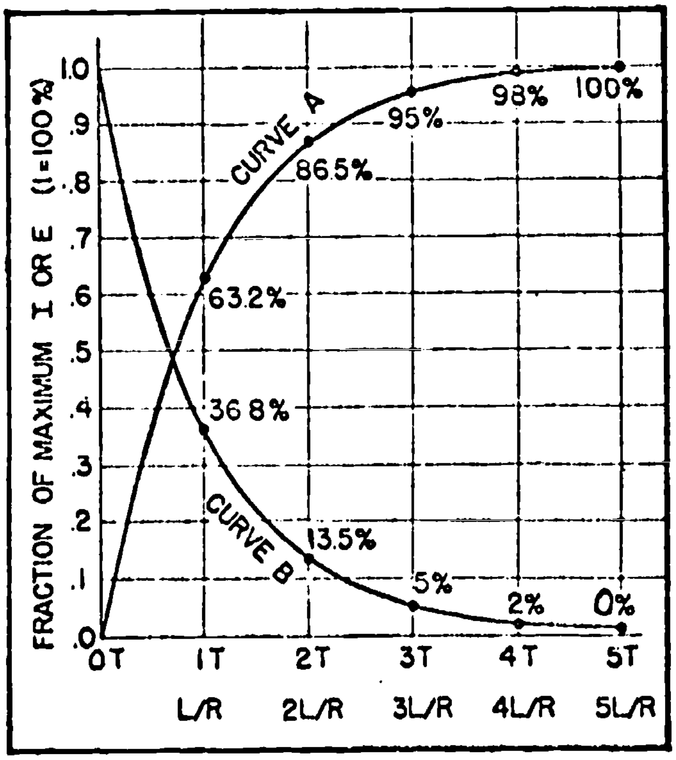
E_R, upon energizing a DC LR circuit, is plotted on the:

____ a. decay curve.
____ b. growth curve.

(b) growth curve

6. Curve A would be used to plot:

____ a. I on rise.
____ b. $\overline{I}$ on decay.
____ c. $\overline{E}_R$ on decay.
____ d. E_R on rise.



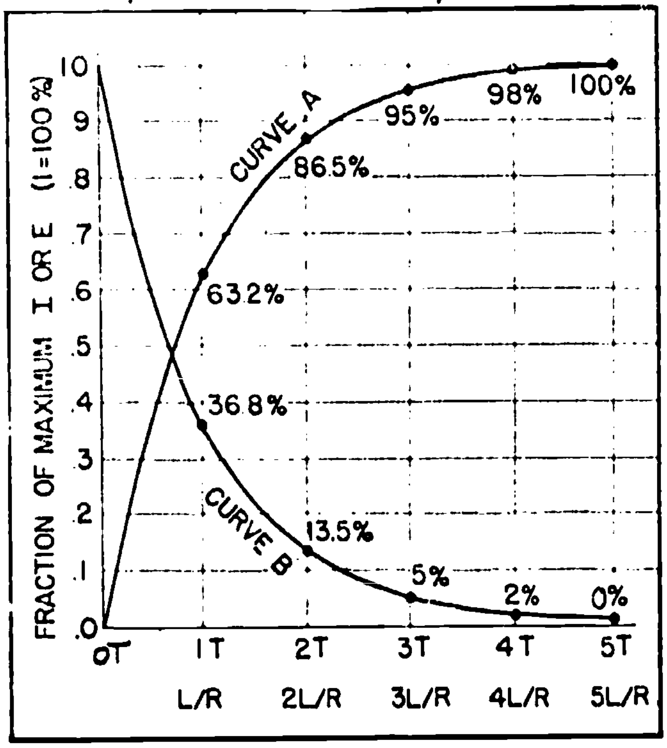
(a. I on rise; d. E_R on rise)

7. Upon de-energizing the circuit, current will decrease from maximum to zero.

Which curve would be used to plot current decay?

____ a. curve A

____ b. curve B



(b) curve B

8. E_R, upon de-energizing the circuit, will be plotted on curve ______. (Refer to preceding illustration.)

(B)

9. Due to the collapsing field, the CEMF will be maximum and be decreasing upon de-energizing the circuit.

Upon de-energizing the circuit, CEMF would be plotted on curve ____.

(B)

10. Match the circuit quantity to the curve upon which it would be illustrated when de-energizing the circuit.

____ a. E_L on decay	1.	Curve A
____ b. E_R on decay	2.	Curve B
____ c. $\underline{I}$ on decay		
____ d. CEMF on decay		

(a. 2; b. 2; c. 2; d. 2)

11. Match the lettered curves in the chart to the appropriate conditions.

____ 1. decay of CEMF

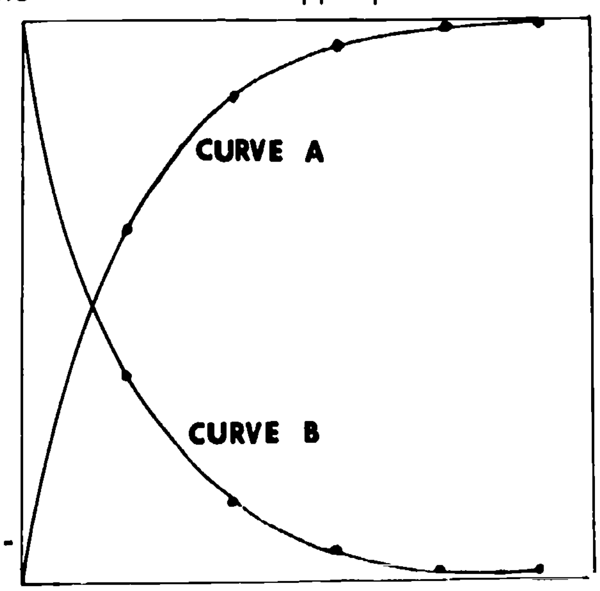
____ 2. E_L on decay

____ 3. E_R on decay

____ 4. $\underline{I}$ growth

____ 5. E_R growth

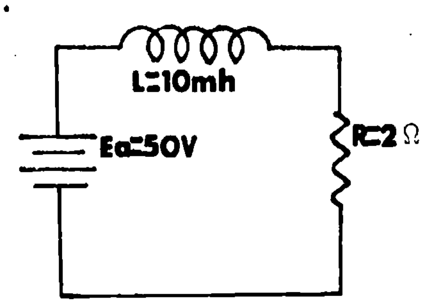
____ 6. I_T on decay



(1. b; 2. b; 3. b; 4. a; 5. a; 6. b)

12. Recall that the time constant of a circuit is found by the ratio of inductance to resistance.

Solve for TC. ____________



(TC = 5 milliseconds)

13. Recall that current is considered to reach maximum after five time constants.

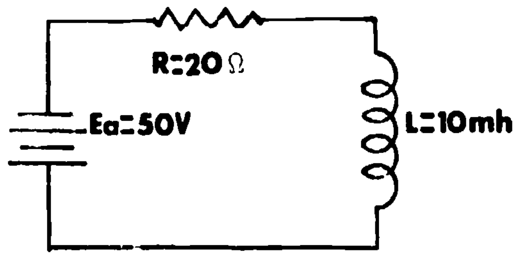
What would be the time required for current to reach its maximum value in the circuit of frame 12?

- -

(25 milliseconds)

14. Ohm's Law can be used to determine the maximum current flowing in a DC LR circuit.

Determine I after five time constants. ____________

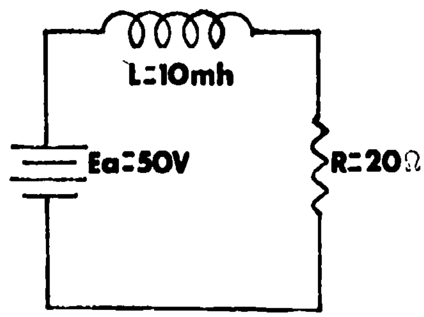


- -

(2.5 a)

15. Current flowing in a circuit at any time constant can be found by multiplying the percentage value for that time constant by I maximum.

Solve for I at T3. ____

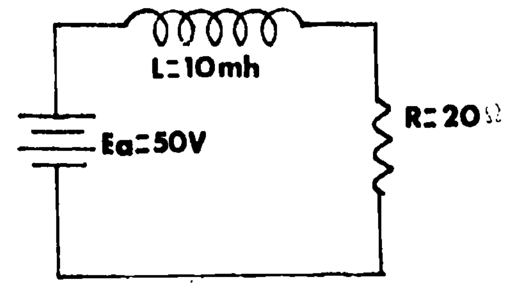


- -

(2.37 a)

16. To determine the voltage drop across the resistor (E_R) at a particular time, multiply the current flowing at that time by the value of resistance.

Solve for E_R @ T3. ____



(47.5 v)

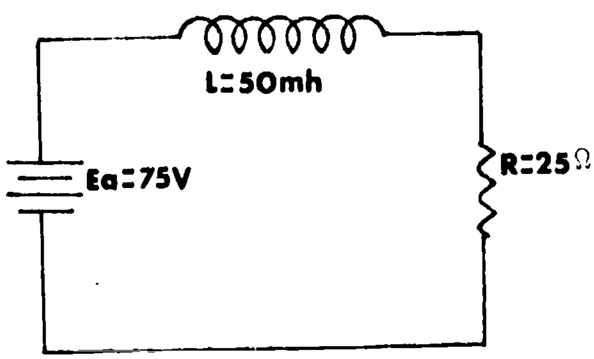
17. Recall that the sum of the voltage drops must equal the applied voltage. What would be the voltage drop across the coil (E_L) in frame 16 at T3?

(2.5 v)

18. The CEMF at the third time constant would be ________ volts.

(2.5)

19. Solve for the following:



a. TC = ____

b. I @ T3 = ____

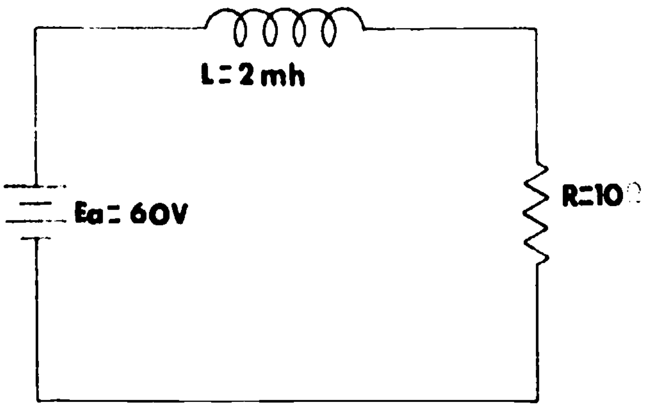
c. E_R @ T2 = ____

d. E_L @ T1 = ____

e. maximum CEMF= ____

(a. 2 msec; b. 2.85 a; c. 64.875 v; d. 27.6 v; e. 75 v)

20. Solve for quantities indicated.



a. TC = ________

b. I @ 5 TC = ________

c. I @ T1 = ________

d. E_R @ T3 = ________

e. maximum CEMF = ____

f. E_L @ T4 = ____ rise

(a. 0.2 msec; b. 6.00 a; c. 3.79 a; d. 57 v; e. 60v; f. 1.2 v)

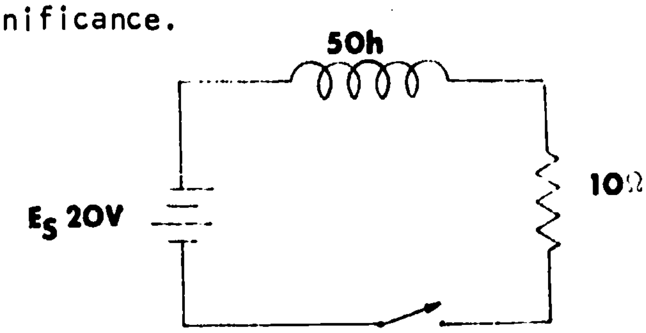
IF ANY OF YOUR ANSWERS IS INCORRECT, GO BACK AND TAKE THE PROGRAMMED SEQUENCE AGAIN.

IF YOUR ANSWERS ARE CORRECT, YOU MAY TAKE THE PROGRESS CHECK, OR YOU MAY STUDY ANY OF THE OTHER RESOURCES LISTED. IF YOU TAKE THE PROGRESS CHECK AND ANSWER ALL THE QUESTIONS CORRECTLY, GO TO THE NEXT LESSON. IF NOT, STUDY ANY METHOD OF INSTRUCTION YOU WISH UNTIL YOU CAN ANSWER ALL THE QUESTIONS CORRECTLY.

SUMMARY
LESSON III

Using the Universal Time Constant Chart

This is a practice lesson on the use of the Universal Time Constant Chart. Study the lesson, and make sure you fully understand its values and their significance.



What is the TC of the above circuit? What is I maximum? What current flows after 15 seconds? If you cannot solve this problem, go to the narrative or programmed units for more information and practice. Answers: TC = 5 sec, I_{MAX} = 2 a, I @ 15 sec = 1.9 a.

AT THIS POINT, YOU MAY TAKE THE LESSON PROGRESS CHECK, OR YOU MAY STUDY THE LESSON NARRATIVE OR THE PROGRAMMED INSTRUCTION OR BOTH. IF YOU TAKE THE PROGRESS CHECK AND ANSWER ALL OF THE QUESTIONS CORRECTLY, GO TO THE NEXT LESSON. IF NOT, STUDY ANOTHER METHOD OF INSTRUCTION UNTIL YOU CAN ANSWER ALL THE QUESTIONS CORRECTLY.

NAVPERS 94558-9a

BASIC ELECTRICITY AND ELECTRONICS

INDIVIDUALIZED LEARNING SYSTEM

MODULE NINE

LESSON IV

Inductive Reactance

Study Booklet

Bureau of Naval Personnel

January 1972

OVERVIEW

LESSON IV

Inductive Reactance

In this lesson you will study and learn about the following:

- how a coil reacts
- induction in AC circuits
- reactance
- formula for X_L
- how frequency affects X_L
- how inductance affects X_L
- solving problems for X_L

BEFORE YOU START THIS LESSON, PREVIEW THE LIST OF STUDY RESOURCES ON THE NEXT PAGE.

LIST OF STUDY RESOURCES
LESSON IV

Inductive Reactance

To learn the material in this lesson, you have the option of choosing, according to your experience and preferences, any or all of the following:

STUDY BOOKLET:

Lesson Narrative
Programmed Instruction
Lesson Summary

ENRICHMENT MATERIAL:

NAVPERS 93400A-1b "Basic Electricity, Direct Current." Fundamentals of Electronics. Bureau of Naval Personnel. Washington, D.C.: U.S. Government Printing Office, 1965.

AUDIO-VISUAL:

Super 8 - "Inductive Reactance."

YOU MAY NOW STUDY ANY OR ALL OF THE RESOURCES LISTED ABOVE. YOU MAY TAKE THE PROGRESS CHECK AT ANY TIME.

NARRATIVE
LESSON IV

Inductive Reactance

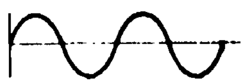
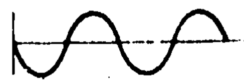
A Coil Reacts

A coil, you remember, produces a counter EMF when the current flow through it changes. We can say then, that a coil reacts to a current change.

Up to this point we have only examined what inductance does in a circuit with a DC source. We know that when we have a change in current, the coil reacts by producing a counter EMF. In a DC circuit we know that after about five time constants, current becomes maximum and stable. When there is no change, the inductor does not react; current remains at its steady value. There is no counter EMF in the circuit.

Induction in AC Circuits

Recall from previous lessons that AC is constantly changing - flowing first in one direction, then the other.

Whereas a DC waveform after current is maximum looks like a straight line ————, AC produces a continuous sine wave that shows the cycles like this:  or 

In an AC circuit, the inductor reacts constantly to the current fluctuations of the AC sine wave. When a coil reacts to changes in current, it sets up an opposition to current. We measure any opposition to current in ohms. The symbol Ω, then, does not always mean resistance. By a generalized definition, Ω is used to measure any opposition to current flow.

Reactance

The opposition that a coil sets up is called reactance. The symbol for any kind of reactance is X. When we are talking about the reactance of a coil, it is called inductive reactance. In order to distinguish inductive reactance from other kinds of reactance, the symbol for inductive reactance in an AC circuit is X_L (pronounced X sub L).

X_L is defined as the opposition a coil offers to alternating current.

Observe that both resistance and inductive reactance act as opposition to current. They are both measured in ohms, but we cannot call X_L a resistance. Recall that resistance is a physical property. X_L is not a physical property; CEMF causes X_L, and X_L can be changed by changing frequency or inductance, whereas resistance is a physical property and cannot be changed except by changing the load itself.

Remember, then, that X_L is an opposition; resistance is an opposition, and they are both measured in ohms.

Formula for X_L

To determine the amount of inductive reactance of any coil, we can use this formula:

$$X_L = 2\pi fL$$

Note: 2π (pronounced two pie) in this formula is a constant. It must be in the formula, and it always remains the same. The equivalent of 2π is always about 6.28, so that the formula can be rewritten:

$$X_L = (6.28) \times (f) \times (L)$$

f stands for the frequency of the applied voltage in hertz.

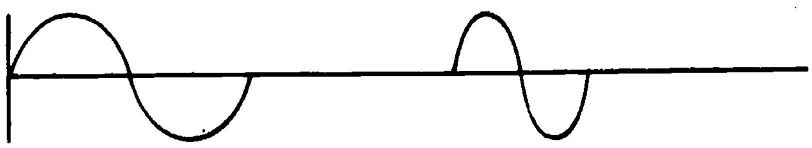
L, of course, stands for the inductance of the coil in henrys. Recall that a coil has an inductance of 1 henry if a CEMF of 1 volt is induced in the coil when current through the coil is changing at the rate of 1 ampere per second.

The opposition a coil offers to alternating current is measured in ohms and is called inductive reactance or X_L.

Frequency Affects X_L

Frequency of the applied voltage affects inductive reactance, because if frequency is increased the rate of change of current is increased.

Note these sine waves with different frequencies:



Increased f = Greater rate of change

Consequently, with the rate of change increased, the magnetic field cuts the coil faster. By Faraday's Law, the faster the field cuts the coil, the higher the EMF induced.

The higher the frequency, the more the coil reacts, the more CEMF produced. The higher the frequency, the more opposition the coil offers to AC current flow. The higher the frequency, the more X_L.

Inductance Affects X_L

If inductance is increased by changing any of the factors which affect inductance (number of turns, cross-section, or permeability) the magnetic field is increased. When the field strength is increased, there are more lines to cut the conductor and the CEMF induced increases.

A coil with high inductance reacts more than a coil with low inductance.

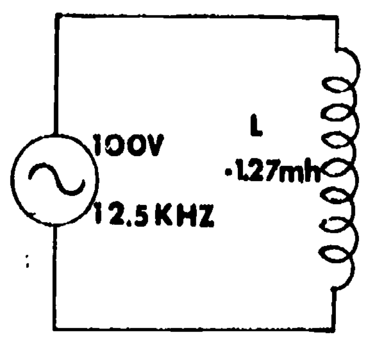
By increasing either frequency or inductance, opposition to AC current is increased.

$$X_L = 2\pi fL$$

What will happen to X_L if the applied voltage is increased?

Nothing, of course. Only L and f can increase or decrease X_L.

Solving Problems for X_L



Assume that in this circuit there is no resistance, only inductance. Notice that the frequency is 12.5 kilohertz per second and inductance is 1.27 millihenrys.

Solve for X_L.

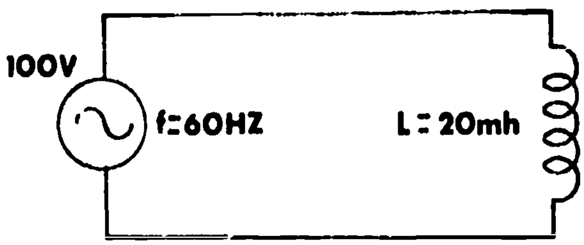
$$X_L = 2\pi fL$$
$$X_L = (6.28) \times (12.5 \times 10^3) \times (1.27 \times 10^{-3})$$

$$X_L = (6.28) \times (12.5) \times (1.27)$$
$$X_L = 99.695\ \Omega$$

or we can round this off and use this sign $\doteq$ which means approximately equals.

$$X_L \doteq 100\ \Omega$$

Solve for X_L in this circuit.



The problem should have been worked.

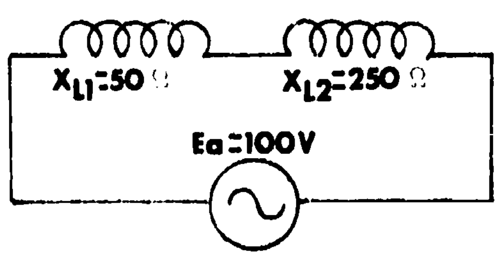
$X_L = 2\pi fL$	(State formula.)
$X_L = (6.28) \times (60) \times (2 \times 10^{-2})$	(Substitute known values.)
$X_L = 7.536\ \Omega$	(Compute by multiplying.)

You may round out the figures to:

$$X_L \doteq 7.5\ \Omega$$

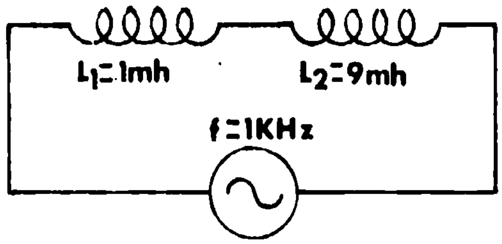
Because X_L is an opposition and can be measured in ohms, X_L in series and parallel circuits can be computed by applying the same rules you used for solving resistance.

Solve these problems.

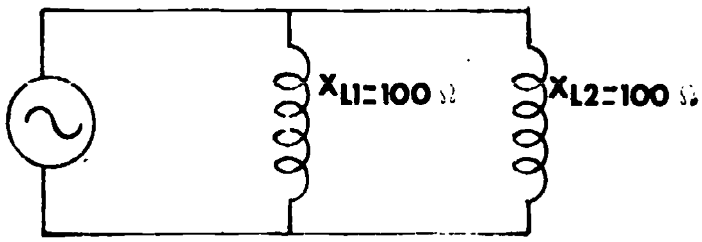
1. 

X_L = ________

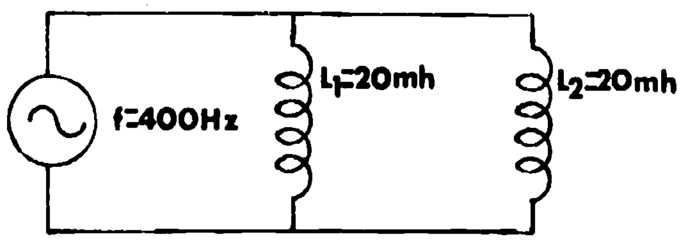
2. In circuit shown in problem 1, what will happen to voltage drops across the coils if frequency increases? ____________

3. 

X_L = ____________

4. 

X_L = ____________

5. 

X_L = ____________

6. In the above problems, if frequency is increased, what will happen to I_T?

(Check answers on next page)

Answers:

1. Total X_L = 300 Ω
2. Nothing. They will stay the same. The sum of the voltage drops equals the applied voltage, and increasing frequency does not increase E_a.
3. X_L = 62.8 Ω
4. X_L = 50 Ω
5. X_L = 25 Ω
6. I_T will decrease.

AT THIS POINT, YOU MAY TAKE THE PROGRESS CHECK, OR YOU MAY STUDY ANY OF THE OTHER RESOURCES LISTED. IF YOU TAKE THE PROGRESS CHECK AND ANSWER ALL OF THE QUESTIONS CORRECTLY, GO TO THE NEXT LESSON. IF NOT, STUDY ANY METHOD OF INSTRUCTION YOU WISH UNTIL YOU CAN ANSWER ALL THE QUESTIONS CORRECTLY.

PROGRAMMED INSTRUCTION
LESSON IV

Inductive Reactance

THIS PROGRAM SEQUENCE DOES NOT CONTAIN ANY TEST FRAMES.

1. Recall that an inductor reacts to a change in:

____ a. voltage.
____ b. current.

- -

(b) current

2. You have learned that an inductor opposes a change in current flow by an induced voltage called ________.

- -

(CEMF)

3. In a DC circuit, this CEMF affects the circuit only during the first __________ time constants after energizing or de-energizing the circuit.

- -

(five)

4. Because AC continuously changes in magnitude, the coil reacts in an AC circuit:

____ a. during the first five time constants only.
____ b. all of the time the circuit is energized.
____ c. only at the time the circuit is first energized.
____ d. only at the time the circuit is first de-energized.

- -

(b) all of the time the circuit is energized

5. Since a coil is said to react to AC, you might infer that this opposition is called:

____ a. reactance.
____ b. ohms.

- -

(a) reactance

6. The proper name for the opposition offered by an inductor is inductive reactance.

A coil offers ____________ ____________ to AC.

- -

(inductive reactance)

7. The symbol used for reactance is X.

The symbol for inductive reactance is:

____ a. X_C.

____ b. X_L.

____ c. R.

____ d. V.

- -

(b) X_L

8. Inductive reactance offers an opposition to current flow and the unit of opposition to current flow is the ohm.

Select the symbol for the unit of opposition offered by an inductor.

____ a. R.
____ b. X_L.
____ c. Ω.
____ d. V.

- -

(c) Ω

9. Opposition to current flow is measured in

____ a. henrys.
____ b. ohms.
____ c. resistance.

(b) ohms

10. Although the units of X_L are ohms, it cannot be measured by an ohmmeter because X_L reacts only to a change in current.

What type of meter could be used to measure X_L directly?

____ a. voltmeter
____ b. ammeter
____ c. ohmmeter
____ d. none of the above

(d) none of the above

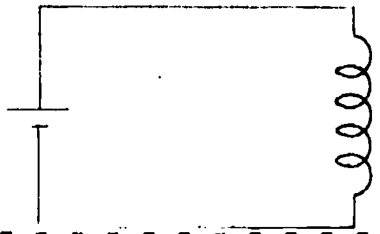
11. X_L is a factor limiting current in ____________ circuits only.

____ a. DC
____ b. AC

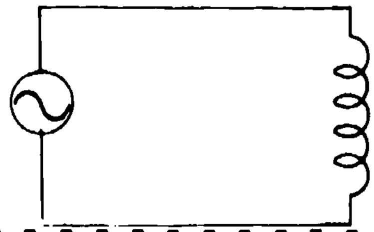
(b) AC

12. Check the circuit in which X_L would be significant.

____ a.



____ b.



(b)

13. The amount of X_L can be found if the inductance of the coil and the frequency of voltage applied to the circuit are known.

Which of the following must be known to determine X_L?

____ a. R
____ b. f
____ c. L
____ d. V
____ e. I

(b. f; c. L)

14. The constant 2π (pronounced <u>two pie</u>) is also required to determine X_L.

Select the correct formula for determining X_L.

____ a. $X_L = f x L$

____ b. $X_L = \frac{f x L}{3}$

____ c. $X_L = 2\pi fL$

(c) $X_L = 2\pi fL$

15. The numerical value of 2π is 6.28.

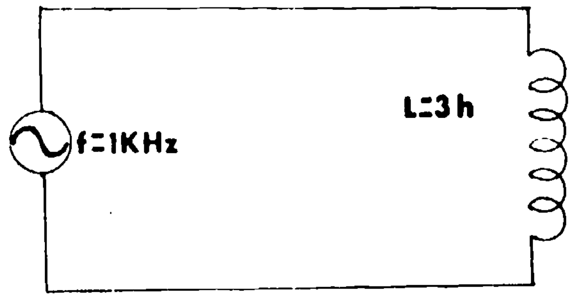
Write the equation for determining X_L using the numerical value for 2π. ________

($X_L = 6.28\ fL$)

16. What would be the value of X_L if the frequency were 60Hz and the inductance 100 mh? ________

(37.68Ω or 37.7Ω)

17. Find X_L.

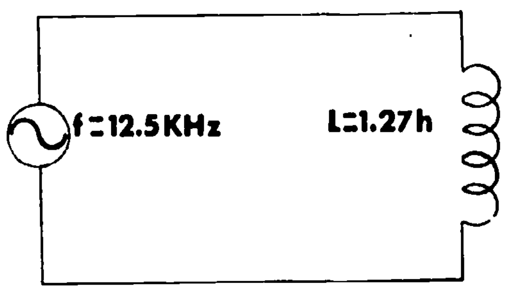


X_L = ________

(18840Ω)

18. Solve for X_L

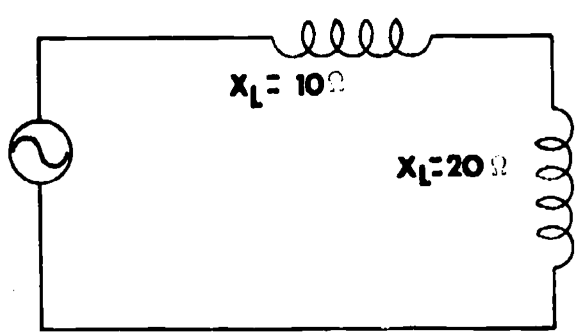
X_L = ________



(99.7KΩ)

19. To solve circuits containing more than one reactance in series, use the same rules you used for total opposition in series resistive circuits.

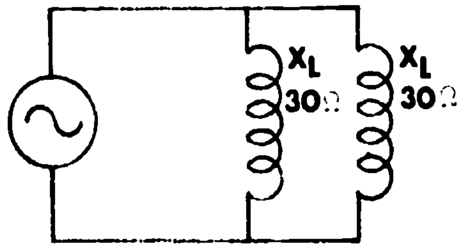
Solve for total X_L ________.



(30Ω)

20. The total opposition in a circuit containing parallel connected reactance is found just like total opposition in a parallel resistive circuit.

Solve for total X_L ____________

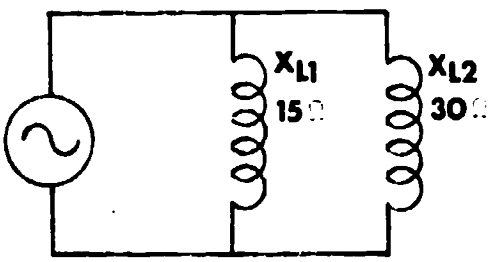


(15Ω)

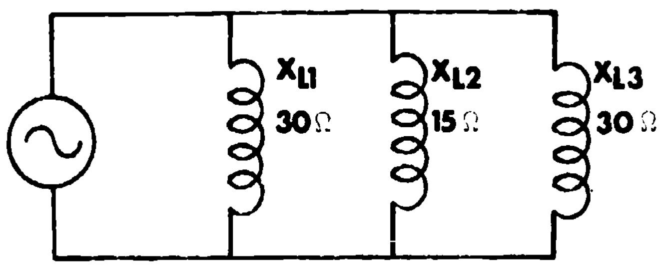
---

21. Solve for total X_L.

A.



B.



Total X_L ____________ Total X_L ____________

(A. 10Ω; B. 7.5Ω)

---

22. The X_L of a coil is directly proportional to the frequency.

Use arrows to show what happens to X_L if frequency is:

a. increased. ____________
b. decreased. ____________

(a. ↑; b. ↓)

23. The inductive reactance of an AC inductive circuit is:

____ a. inversely proportional to frequency.
____ b. directly proportional to frequency.

- -

(b) directly proportional to frequency

24. Inductance affects X_L:

____ a. directly
____ b. inversely

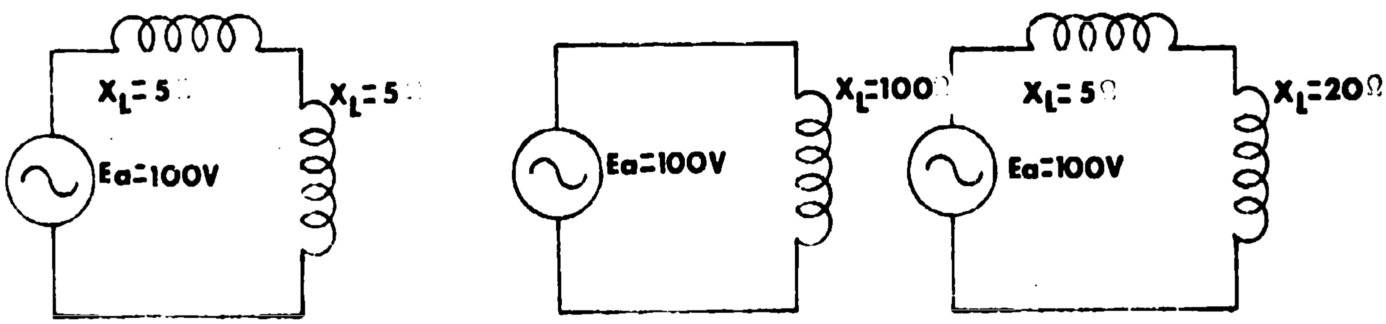
- -

(a) directly

25. In a purely inductive circuit, X_L limits the current flow.

Select the circuit having the most current flow.

____ a. ____ b. ____ c.



- -

(a)

26. If frequency were increased in the above problems, which circuit would have the largest current flow? ________

- -

(a)

27. An increase in frequency in a purely inductive circuit causes current flow to:

____ a. increase.
____ b. decrease.

(b) decrease

---

28. Complete by matching.

____ 1.	when L is constant, if f is increased X_L will ...	a.	increase
____ 2.	when f is constant, if L is decreased, X_L will ...	b.	decrease
____ 3.	if f is increased, L will ...	c.	not change
____ 4.	if X_L is decreased, current will...		

(1. a; 2. b; 3 c; 4.a)

IF ANY OF YOUR ANSWERS IS INCORRECT, GO BACK AND TAKE THE PROGRAMMED SEQUENCE AGAIN.

IF YOUR ANSWERS ARE CORRECT, YOU MAY TAKE THE PROGRESS CHECK, OR YOU MAY STUDY ANY OF THE OTHER RESOURCES LISTED. IF YOU TAKE THE PROGRESS CHECK AND ANSWER ALL THE QUESTIONS CORRECTLY, GO TO THE NEXT LESSON. IF NOT, STUDY ANY METHOD OF INSTRUCTION YOU WISH UNTIL YOU CAN ANSWER ALL THE QUESTIONS CORRECTLY.

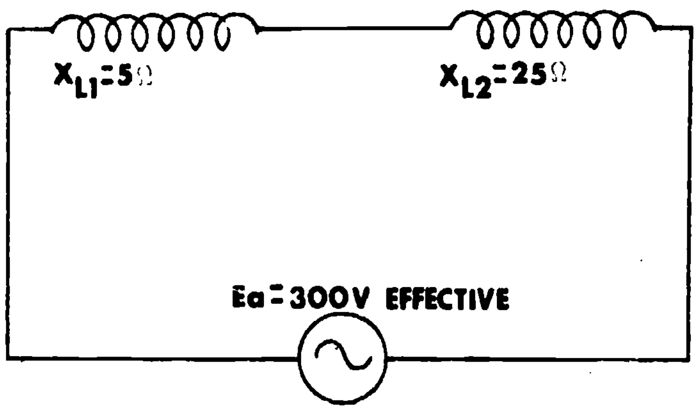
SUMMARY
LESSON IV

Inductive Reactance

In an AC circuit current through a coil is continuously changing. The coil reacts by producing a counter EMF which resembles an ohmic opposition, even though there is no resistance. The opposition that a coil sets up is called inductive reactance. The symbol for any kind of reactance is X, and that for a coil is X_L. Note that it is not a physical property like R, since X_L increases with increasing AC frequency (f).

Actually, $X_L = 2\pi fL$.
$= 6.28fL$

Given:



What is the effective value of the AC current flow.

Answer: 10 amps.

AT THIS POINT, YOU MAY TAKE THE LESSON PROGRESS CHECK, OR YOU MAY STUDY THE LESSON NARRATIVE OR THE PROGRAMMED INSTRUCTION OR BOTH. IF YOU TAKE THE PROGRESS CHECK AND ANSWER ALL OF THE QUESTIONS CORRECTLY, GO TO THE NEXT LESSON. IF NOT, SELECT ANOTHER METHOD OF INSTRUCTION UNTIL YOU CAN ANSWER ALL THE QUESTIONS CORRECTLY.

NAVPERS 94558-9a

BASIC ELECTRICITY AND ELECTRONICS
INDIVIDUALIZED LEARNING SYSTEM

MODULE NINE
LESSON V

Relationships in Inductive Circuits

Study Booklet

Bureau of Naval Personnel
January 1972

OVERVIEW

LESSON V

Relationships in Inductive Circuits

In this lesson you will study and learn about the following:

- -frequency and inductance
- -frequency and inductive reactance
- -X_L and Ohm's Law
- -power in purely inductive circuits

BEFORE YOU START THIS LESSON, PREVIEW THE LIST OF STUDY RESOURCES ON THE NEXT PAGE.

LIST OF STUDY RESOURCES
LESSON V

Relationships in Inductive Circuits

To learn the material in this lesson, you have the option of choosing, according to your experience and preferences, any or all of the following:

STUDY BOOKLET:

Lesson Narrative

Programmed Instruction

Lesson Summary

ENRICHMENT MATERIAL:

NAVPERS 93400A-1b "Basic Electricity, Alternating Currert." Fundamentals of Electronics. Bureau of Naval Personnel. Washington, D.C.: U.S. Government Printing Office, 1965.

YOU MAY NOW STUDY ANY OR ALL OF THE RESOURCES LISTED ABOVE. YOU MAY TAKE THE PROGRESS CHECK AT ANY TIME.

NARRATIVE
LESSON V

Relationships in Inductive Circuits

Frequency and Inductance

If we were to increase the frequency in an inductive circuit, what would happen to the inductance? ______

Answer: Nothing.

Recall that inductance is a physical property and can only be changed by physically changing some property of the inductor, such as adding an iron core to a coil. In other words, if an inductor in a circuit has an inductance of 2 h, and if the frequency of the applied voltage is changed, the inductor still has an inductance of 2 h.

Frequency and Inductive Reactance

If you change the frequency of the voltage applied to a circuit, inductive reactance (X_L) of the coil changes. The rate of change of current either increases or decreases with frequency, and the inductor's reaction is directly proportional to the rate of change of cu rent flow.

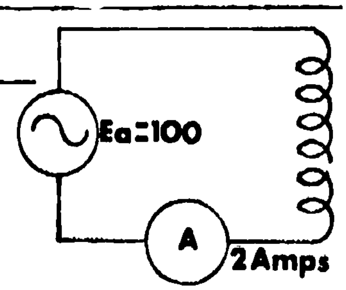
X_L and Ohm's Law

In a purely inductive circuit, we can solve for quantities by substituting X_L for R in Ohm's Law.

$$I = \frac{E_a}{X_L} \qquad E_a = I \cdot X_L$$

$$X_L = \frac{E_a}{I}$$

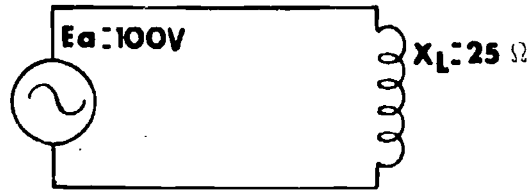
In this circuit what is X_L? ____________



By Ohm's Law $R = \frac{E}{I}$ or $X_L = \frac{E_a}{I}$,

we have $X_L = \frac{100v}{2a}$ or $X_L = 50\Omega$

In this circuit what is I? ____________

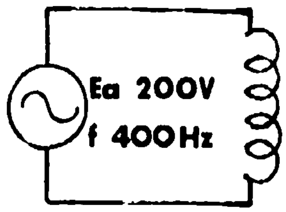


By Ohm's Law $I = \frac{E}{R}$ or $I = \frac{E_a}{X_L}$,

we have $I = \frac{100v}{25\Omega}$ or $I = 4a$

Practice Problems: (Round off answers)

1\.



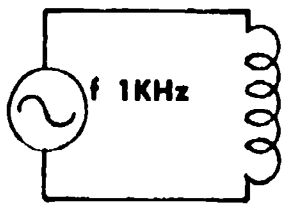
$L = 10mh$

X_L = ____________

I_T = ____________

E_L = ____________

2\.



$X_L = 628\Omega$

L = ____________

3. What will happen to I if frequency is constant and L increases? ____________

4. What will happen to I if L is constant and f decreases? ____________

5. What will happen to X_L if the applied voltage decreases? ____________

6. What will happen to I if E_a decreases ? ____________

Answers:

1. $X_L = 25\Omega$

   $I_T = 8a$

   $E_L = 200v$

2. $L = 0.1h$ or $100mh$

3. decrease

4. increase

5. nothing

6. decrease

Power in Purely Inductive Circuits

You recall we learned previously that we have true power dissipation only in circuits containing resistance; therefore there is no true power in a purely inductive circuit. True power is designated P_t and can be found by the formula $P_t = I^2R$. True power is measured in watts.

Apparent Power

Because the power in a purely inductive circuit is never consumed, we call this power apparent power. It is the power which apparently is available in the circuit. In a purely inductive circuit, there is no resistance; therefore, there can be no power consumption. Apparent power is designated P_a and measured in volt amperes (va).

Looking now at a purely inductive circuit, because there is no resistive load, the apparent power is not consumed.

---

1. P_t is measured in ________________, abbreviated ________________.
2. P_a is measured in ________________, abbreviated ________________.

---

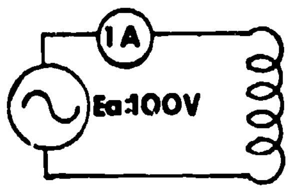
1. watts, W   2. volt amperes; va

Reactive Power

If an inductive circuit does not consume power, then what happens to the power in the circuit? Answer: Returns to the source. If an AC source is supplying 50 volts to a purely inductive circuit, and current in the circuit is 2 amps, we can say that the apparent power (P_a) is 50 x 2 or 100 va (volt amps). This apparent power is received by the inductor which stores the 100 va in its electromagnetic field. Because the coil cannot consume the power, it stores it during part of the applied voltage cycle.

Then on part of the cycle, the inductor's magnetic field collapses sending the power back to the source. The power that is stored by the inductor and sent back to the source is called reactive power or P_x.

source puts out 100 va



coil stores 100 vars

Reactive power (P_x) is measured in vars. Vars stands for volt amps reactive.

Reactive power is equal to apparent power in a purely inductive AC circuit.

Summary

P_t - True Power = watts (w); consumed by resistance.
P_a - Apparent Power = volt amperes (va); consumed in a purely resistive circuit; stored in a purely inductive circuit.
P_x - Reactive Power = vars; reactive power alternates between the generator and the load and is never dissipated.

In purely resistive circuit, $P_a = P_t$.

In purely inductive circuit, $P_a = P_x$.

---

1. Which formula would you use to find apparent power in any circuit? ________

2. Which formula would you use to find true power? ________

Answers:

1. $P = EI$ or $P_a = EI$
2. $P_t = I^2R$

AT THIS POINT, YOU MAY TAKE THE PROGRESS CHECK, OR YOU MAY STUDY ANY OF THE OTHER RESOURCES LISTED. IF YOU TAKE THE PROGRESS CHECK AND ANSWER ALL OF THE QUESTIONS CORRECTLY, GO TO THE NEXT LESSON. IF NOT, STUDY ANY METHOD OF INSTRUCTION YOU WISH UNTIL YOU CAN ANSWER ALL THE QUESTIONS CORRECTLY.

PROGRAMMED INSTRUCTION
LESSON V

Relationships in Inductive Circuits

THIS PROGRAMMED SEQUENCE HAS NO TEST FRAMES.

1. Recall from a previous lesson that inductance is a physical property.

   What effect would increasing frequency have on the inductance of a circuit?

   ____ a. increase
   ____ b. decrease
   ____ c. remain the same
   ____ d. unknown

(c) remain the same

2. Inductive reactance, unlike inductance, is directly affected by frequency change.

   Increasing circuit frequency causes inductive reactance (X_L) to:

   ____ a. decrease.
   ____ b. remain the same.
   ____ c. increase.

(c) increase

3. An inductor is a reactive component and is affected by changes in circuit frequency.

If the voltage applied to an inductive circuit is doubled:

____ a. X_L will decrease; I will double.
____ b. X_L will remain constant; I will double.
____ c. X_L will increase; I will decrease by half.
____ d. X_L will remain constant; I will decrease by half.

(b) X_L will remain constant; I will double

---

4. X_L is an opposition to AC current just as resistance is.

Check the true statement.

____ a. X_L and R are identical in that both offer maximum opposition in a DC circuit.
____ b. X_L and R both offer opposition to current, but X_L affects only AC circuits.
____ c. X_L and R both offer a constant opposition regardless of circuit frequency changes.
____ d. X_L will increase as R decreases.

(b) X_L and R both offer opposition to current, but X_L affects only AC circuits

---

5. Inductive reactance is directly proportional to applied frequency.

Since circuit current is determined by circuit opposition and the value of applied voltage, when applied voltage is held constant, increasing frequency will:

____ a. have no effect on I.
____ b. decrease inductance and increase I.
____ c. increase X_L and decrease I.
____ d. decrease X_L and decrease I.

(c) increase X_L and decrease I

---

6. Inductive reactance (X_L) is an opposition as is resistance; its unit of opposition is measured in ohms (Ω).

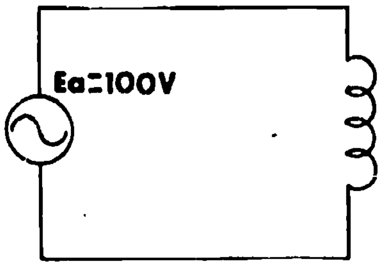
X_L is comparable to R in that it can be substituted for R in any Ohm's Law formula.

Match the corresponding forms of Ohm's Law.

____ 1. $I = \frac{E}{R}$	a. $P = I^2 \cdot X_L$
____ 2. $E = I \cdot R$	b. $E = I \cdot X_L$
____ 3. $P = I^2 \cdot R$	c. $I = \frac{E}{X_L}$
____ 4. $E = \sqrt{P \cdot R}$	d. $E = \sqrt{P \cdot X_L}$

(1. c; 2. b; 3. a; 4. d)

7. Solve for current in the circuit below.



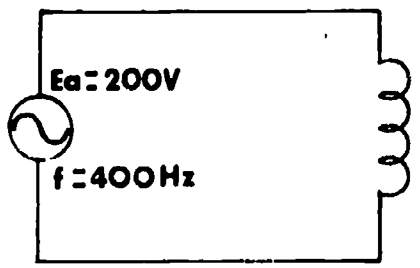
$X_L = 50\Omega$

$I =$ ____________

(2 a)

8. Inductance may be given instead of inductive reactance. In such cases, L must be converted into X_L.

Use the formula $X_L = 2\pi fL$, and solve for X_L in the below circuit.



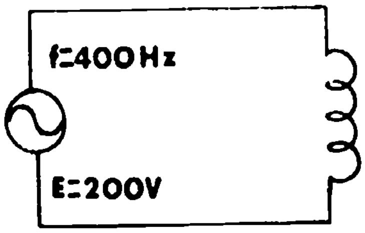
L = 750 mh

$X_L =$ ____________

(1,884)

9. If a circuit is purely inductive, you may substitute X_L for R in Ohm's Law to find that current.

Solve for circuit current in the below circuit.



X_L = 1,884

I_T = ________

- -

(106 ma)

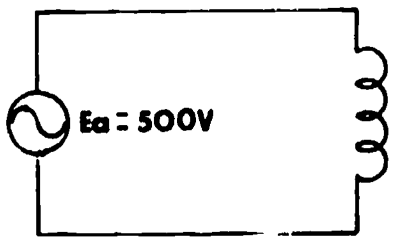
10. In the circuit of frame 9, what would happen to I if frequency were increased? ________

- -

(decrease)

11. Ohm's Law may be transposed to find individual quantities in reactive circuits.

Solve for X_L in the below circuit.



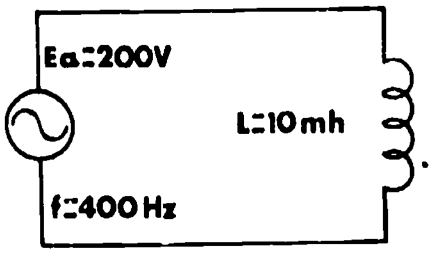
I = 0.25 amps

X_L = ________

- -

(2,000)

12. Using what you have learned, solve the following circuit for:



a. X_L = ______

b. I_T = ______

c. E_L = ______

- -

(a. 25Ω; b. 8a; c. 200v)

13. In the preceding problem, if frequency were increased, how would the following be affected?

a. X_L ____________________

b. I_T ____________________

c. E_L ____________________

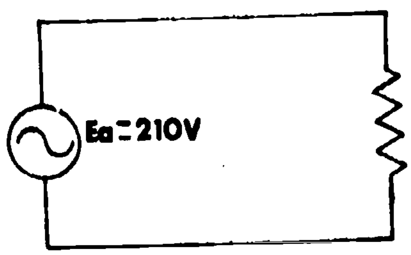
- -

(a. increase; b. decrease; c. remains the same)

14. Recall that the formulas used to solve for power in a resistive circuit are:

$$P = I^2R \qquad P = EI$$

What is the value of power in the below circuit?



R = 500Ω

P = ______

- -

(88.2 watts)

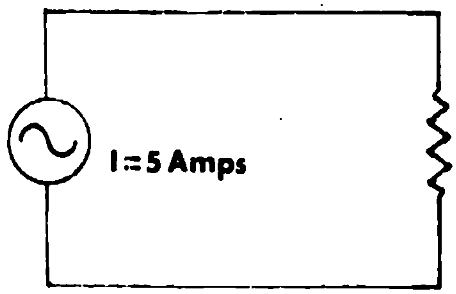
15. In a resistive circuit, power is a measure of how much electrical energy is being converted into heat energy.

Can the watts of energy in a resistive circuit be reclaimed or is this energy lost once it's been dissipated as heat?

____ a. It can be reclaimed.
____ b. It is lost.

(b) It is lost

16. Since power is the conversion of energy from one form to another, how many watts would be converted to heat in the circuit shown below?



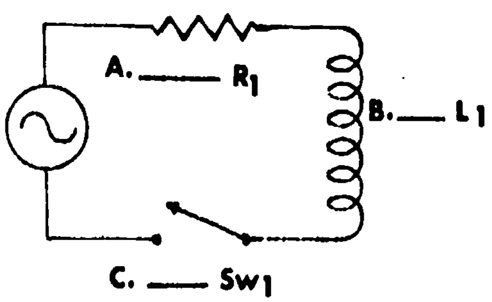
R = 250Ω

P = ________

(6,250 watts)

17. Remember, true power (P_t) is dissipated only in a resistive circuit.

In the below circuit which components dissipate true power?



(A)

18. The unit of true power is the ________________.

(watt)

19. True power is the amount of energy that is:

____ a. destroyed.
____ b. generated.
____ c. converted.
____ d. stored.

(c) converted

20. An inductor does not dissipate power; electrical energy is stored in the magnetic field around the inductor instead.

Power in an inductive circuit is:

____ a. dissipated as a magnetic field.
____ b. consumed as heat.
____ c. stored in a magnetic field.
____ d. determined by the core material of the inductor.

(c) stored in a magnetic field

21. As current increases through an inductor, the magnetic field strength increases.

As the current flow decreases through the inductor, the magnetic field:

____ a. remains the same.
____ b. decreases and cuts the coil.
____ c. increases to a higher value.
____ d. (none of the above)

(b) decreases and cuts the coil

22. Energy contained in the expanded magnetic field is returned to the circuit when the field collapses.

What is the true power dissipated by an inductor if the energy contained in the field is returned to the circuit?

____ a. No true power is dissipated.
____ b. Maximum true power is dissipated.
____ c. True power is one-fourth maximum power.
____ d. True power is four times maximum power.

(a) No true power is dissipated

23. Since an inductive circuit returns energy (power) to the circuit, it does not expend true power.

Which of the components below will not dissipate true power?

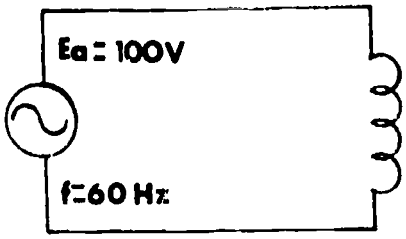
____ a.

____ b.

(a)

24. Using the power formula $P_X = EI$, the reactive power of an inductive circuit can be found.

Compute the reactive power (P_X) of the circuit below.



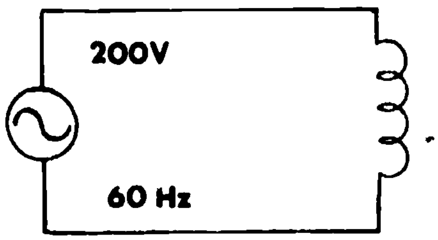
L = 50mh $P_X =$ ________

- -

(530 vars)

25. Reactive power is so named because the reactive component appears to consume the energy in building up its magnetic field.

Determine the value of P_X of the circuit below using the formula $P_X = I^2X_L$.



$X_L = 50\Omega$

- -

(800 vars)

26. Reactive power is measured in volt amps reactive or vars. Select the proper statement describing reactive power.

____ a. power consumed in a purely resistive circuit, measured in volt amps

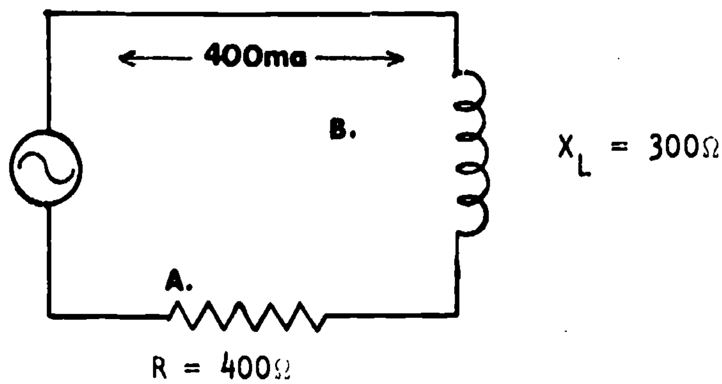
____ b. power consumed in a purely inductive circuit, measured in watts

____ c. power stored in a purely resistive circuit, measured in volt amps resistive

____ d. power stored in an inductive field, measured in volt amps reactive.

(d) power stored in an inductive field, measured in volt amps reactive

27. Since all power used to build a magnetic field is returned to the circuit as the current decreases, no true power is dissipated in an inductor.



a. Which component dissipates the true power, A or B?

____

Use the formulas $P = I^2R$ and $P = I^2X_L$ to solve for

b. true power ________________

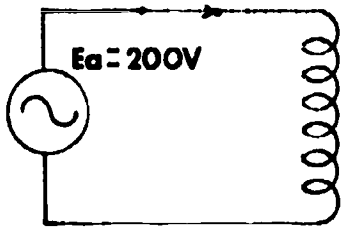
c. reactive power ________________

(a. A; b. 64w; c. 48 vars)

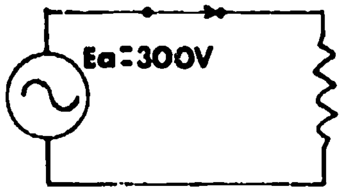
28. Match the descriptive statement to the corresponding circuit.

____ a. Only true power is found in this circuit.

____ b. Reactive power is found in this circuit.

1. 

$X_L = 50\Omega$

2. 

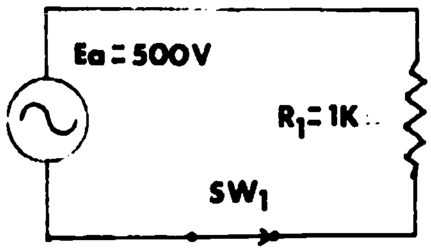
$R = 500\Omega$

- -

(a. 2; b. 1)

29. Let's talk about apparent power. Apparent power is the power which a source appears to supply to a circuit in a purely resistive circuit. Apparent power (P_a) is always equal to the circuit true power, for all the power is converted to heat in the resistor.

Solve for P_a and P_t in the circuit below.



P_a = ________

P_t = ________

- -

(P_a = 250va; P_t = 250w)

30. P_a is equal to P_t in the preceding circuit because:

____ a. in a purely resistive circuit all power consumed is stored in a magnetic field.

____ b. P_a always equals P_t in a purely resistive circuit.

____ c. power across the resistor is returned to the circuit.

- -

(b) P_a always equals P_t in a purely resistive circuit.

31. In a circuit containing only inductance, apparent power (P_a) is equal to reactive power (P_x).

Write a formula which may be used to solve for P_a and P_x in an inductive circuit. ___________

($P = EI$ or $P = I^2X_L$)

IF ANY OF YOUR ANSWERS ARE <u>INCORRECT</u>, GO BACK AND TAKE THE PROGRAMMED SEQUENCE AGAIN.

IF YOUR ANSWERS ARE CORRECT, YOU MAY TAKE THE PROGRESS CHECK, OR YOU MAY STUDY ANY OF THE OTHER RESOURCES LISTED. IF YOU TAKE THE PROGRESS CHECK AND ANSWER ALL THE QUESTIONS CORRECTLY, GO TO THE NEXT LESSON. IF NOT, STUDY ANY METHOD OF INSTRUCTION YOU WISH UNTIL YOU CAN ANSWER ALL THE QUESTIONS CORRECTLY.

SUMMARY
LESSON V

Relationships in Inductive Circuits

The relationships of current, voltage and inductive reactance follow Ohm's Law in the form $I = \frac{E}{X_L}$. This equation is used in the same way as in purely resistive circuits, so you should have no difficulty with it.

The power relationship in a reactive circuit differs from power in a resistive circuit. Previously you learned that true power (P_t) is dissipated only in a resistance. True power can always be found from the equation $P_t = I^2R$ and is measured in watts. In a purely inductive circuit there is no resistance and, therefore, no true power. In the reactive circuit power appears to be dissipated, for there is a voltage applied and a resulting current flow. This apparent power (P_a) is equal to the product of E and I and is measured in volt amperes (va).

The power in a purely inductive circuit is stored in the magnetic field surrounding the coil during part of the cycle, and then returned to the source when the field collapses during the remainder of the cycle. Because this action occurs only when there is reactance in a circuit, it is called reactive power (P_x). P_x is measured in reactive volt amperes, abbreviated vars.

AT THIS POINT, YOU MAY TAKE THE LESSON PROGRESS CHECK, OR YOU MAY STUDY THE LESSON NARRATIVE OR THE PROGRAMMED INSTRUCTION OR BOTH. IF YOU TAKE THE PROGRESS CHECK AND ANSWER ALL OF THE QUESTIONS CORRECTLY, GO TO THE NEXT LESSON. IF NOT, STUDY ANOTHER METHOD OF INSTRUCTION UNTIL YOU CAN ANSWER ALL THE QUESTIONS CORRECTLY.

NAVPERS 94558-9a

BASIC ELECTRICITY AND ELECTRONICS
INDIVIDUALIZED LEARNING SYSTEM

MODULE NINE

LESSON VI

Phase Relationships in Inductive AC Circuits

Study Booklet

Bureau of Naval Personnel
January 1972

OVERVIEW

LESSON VI

Phase Relationships in Inductive AC Circuits

In this lesson, you will study and learn about the following:

- understanding vectors
- rotating vectors
- phase
- voltage
- current
- phase lag

BEFORE YOU START THIS LESSON, PREVIEW THE LIST OF STUDY RESOURCES ON THE NEXT PAGE.

LIST OF STUDY RESOURCES
LESSON VI

Phase Relationships in Inductive AC Circuits

To learn the material in this lesson, you have the option of choosing, according to your experience and preferences, any or all of the following:

STUDY BOOKLET:

- Lesson Narrative
- Programmed Instruction
- Experiment
- Lesson Summary

ENRICHMENT MATERIAL:

NAVPERS 93400A-1B "Basic Electricity, Alternating Current." Fundamentals of Electronics. Bureau of Naval Personnel. Washington, D.C.: U.S. Government Printing Office, 1965.

NAVPERS 10086B "Basic Electricity." Bureau of Naval Personnel. Washington, D.C.: U.S. Government Printing Office, 1969.

AUDIO-VISUAL:

Sound/Slide Presentation - "Inductive Phase Relations."

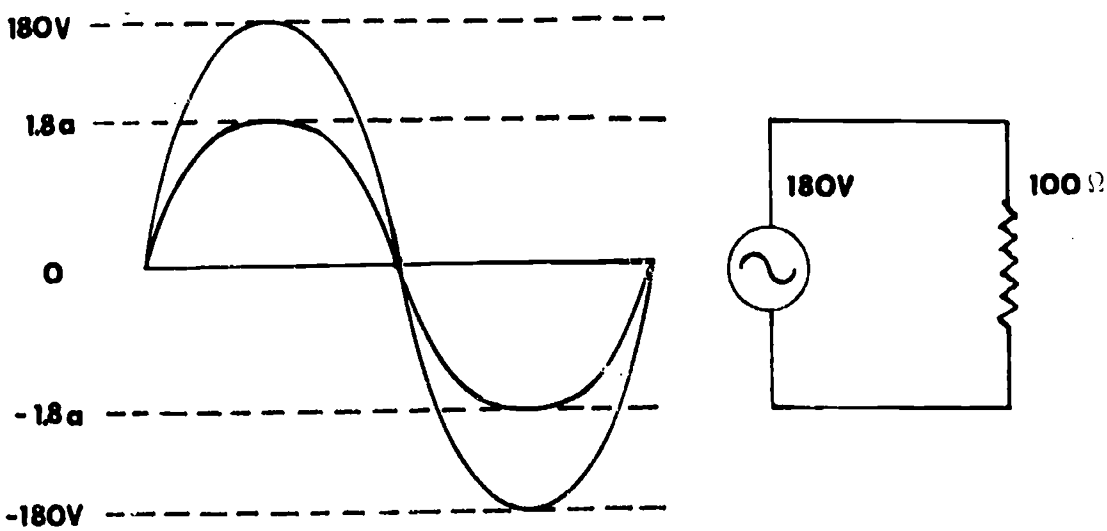
YOU MAY NOW STUDY ANY OR ALL OF THE RESOURCES LISTED ABOVE. YOU MAY TAKE THE PROGRESS CHECK AT ANY TIME.

NARRATIVE
LESSON VI

Phase Relationships in Inductive AC Circuits

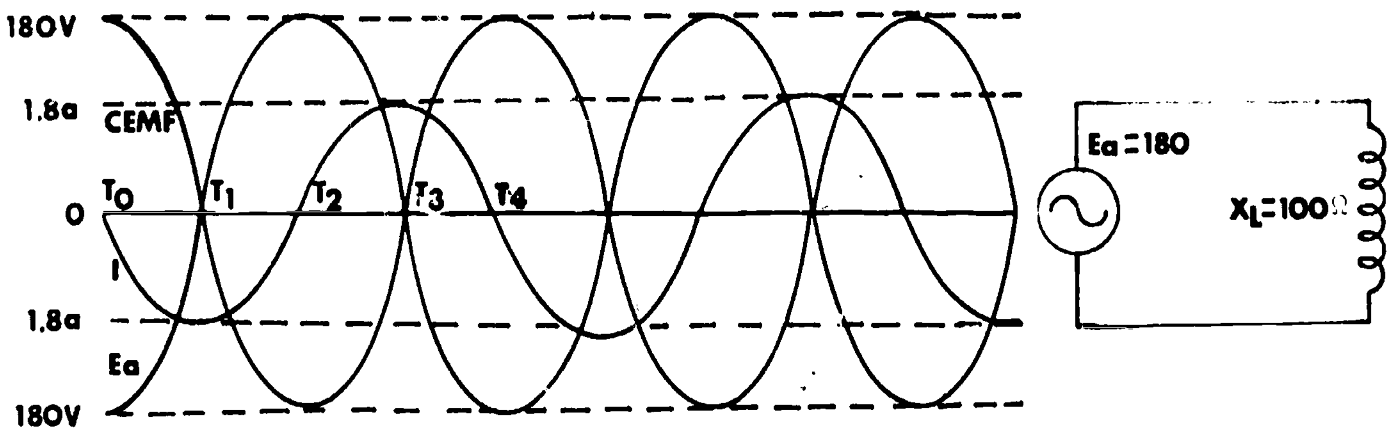
In a circuit containing only inductance, the CEMF induced in the coil limits the current by opposing the source voltage as explained in the last lesson. This CEMF also causes current to shift in phase from the source voltage. This phase shift means that the voltage and current sine waves do not vary in the same direction at the same time throughout a cycle.

Let's take a closer lock at phase. In a purely resistive AC circuit there is opposition to current flow but no phase shift; that is, current and voltage always change in the same direction at the same time through each cycle. A graph of the instantaneous values of voltage and current in this resistive circuit looks like this:



These values can be plotted using $i = \frac{e}{R}$ (remember little i and little e are instantaneous values.) In this graph, voltage and current are zero at the same instant, rise in the positive direction together, reach their maximum at the same instant, etc., through the entire cycle. This is yet another way of saying that the voltage and current are in phase.

In the inductive circuit, the action of the induced CEMF delays the change in current with respect to the change in voltage so that there is a phase difference between the voltage and current. Here is a graph of the instantaneous values of source voltage, current, and CEMF, and a schematic of the circuit which produces it.



The phase relationships shown on the graph above are explained in the following paragraphs.

Assume the circuit is energized at t0 with E_a at its maximum negative value. Current will immediately attempt to increase producing a rapidly expanding magnetic field. The movement of this field through the wires of the coil causes a large CEMF which opposes and limits the current flow, preventing it from rising too rapidly. From t0 to t1, the current flow increases, changing at a rate which always keeps the CEMF exactly equal in value but opposite in direction to the applied voltage. At t1, the applied voltage is zero, the change in current is zero, the magnetic field is fully expanded and constant, and the CEMF is therefore zero. The magnetic field now contains all the energy supplied to the circuit from t0 to t1.

Between t1 and t2, the collapse of the magnetic field maintains current flow in the same direction, and the rate of change of current induces a CEMF which will again exactly balance the applied voltage. At t2, E_a and CEMF are at maximum values, the magnetic field is fully collapsed, and current is zero. At this point all the energy stored in the magnetic field has been returned to the circuit.

At t2, the applied voltage forces current to flow in the opposite direction, the change in current (and magnetic field) causes CEMF to build up again. The current is limited until, at t3, E_a and CEMF are zero and current is a steady maximum value. Once again, energy is stored in the expanded magnetic field, and the polarity of the field is reversed as compared to the field at time t1.

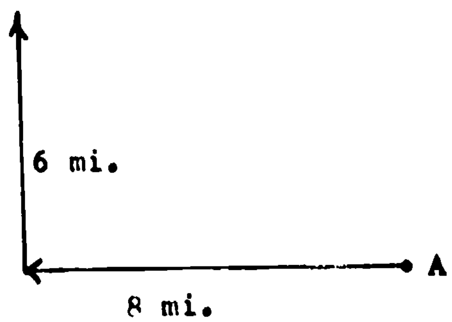
Commencing at t3, the magnetic field again collapses, and the resulting CEMF sustains a decaying current in the inductor. At t4, the magnetic field is fully collapsed, current is zero (but changing at its greatest rate) and E_a and CEMF are maximum, equal, and opposing each other.

This brings us back to the same conditions as those at t0 when we energized the circuit, and this cycle will continue until the circuit is de-energized.

One point which may help you better understand this action is the balance between the applied voltage and the CEMF. To help see why these two quantities are always exactly balanced, consider what would happen if one became greater than the other. If one exceeds the other, a change in current (and in the magnetic field) would have to take place. Such a change would produce a change in the CEMF to oppose the change in current. Study the graph to see how this would affect the values. You will find in every case the changing current will bring the induced voltage in the coil to the exact value needed to just balance the applied voltage.

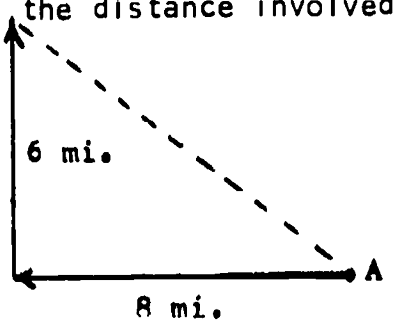
Phase shift or phase difference is usually measured in degrees of rotation, and the graph of E_a, I, and CEMF is repeated here with the time base marked in electrical degrees rather than units of time.

Vectors are useful tools for representing AC quantities. A vector is a line that shows both direction and magnitude. Let's look at an example: ⟶ This line with the arrowhead is a vector. The length of the line represents the magnitude and the arrowhead indicates a direction. This vector is shown in the standard vector position. One way vectors can be used is to find total distance from a starting point. If you traveled eight miles west from point A then six miles north, you could represent your travels with vectors like these:

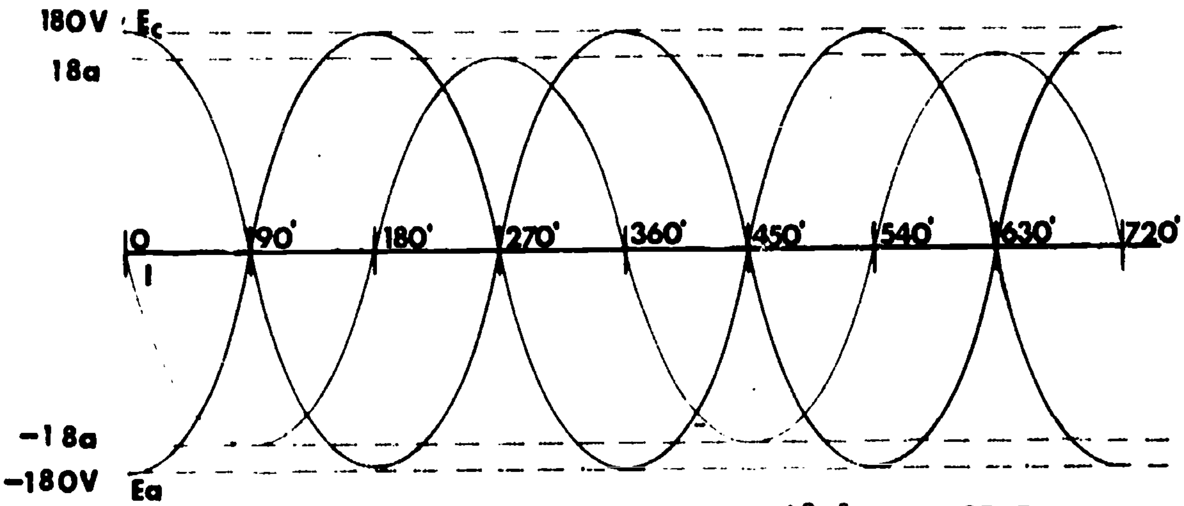


The length of the lines indicate distance; the arrows, direction. Although you have traveled a total of 14 miles, you obviously are not 14 miles from point A. You know that you are more than eight but less than 14 miles from point A, but you cannot figure the distance by just adding the two numbers.

By drawing a line directly from point A to the final point, however, you can measure off the distance involved.



This distance can be computed using the pythagorean theorem, for the two vectors form two sides of a right triangle. In this case, the total distance between the two points is: $\sqrt{8^2 + 6^2} = \sqrt{100} = 10$ miles. We can find the distance this way, but we cannot use this theorem to find the direction, so the computed answer is not a vector.

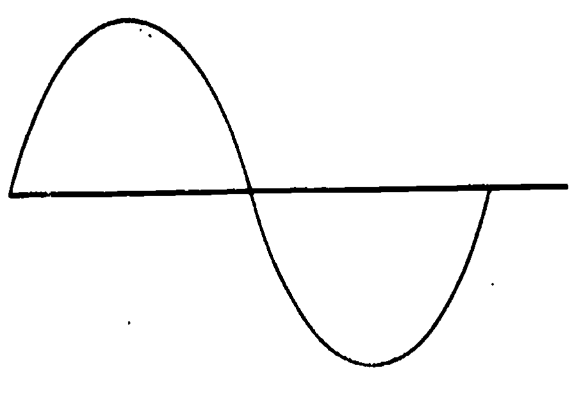


Examine the graph, and notice that at 180°, the CEMF starts through the same variations in the same directions that E_a did at 0°. For this reason, we say that the phase difference between E_a and CEMF is 180° or that E_a and CEMF are 180° out of phase. Looking again at the graph, you can see that E_a and I are 90° out of phase.

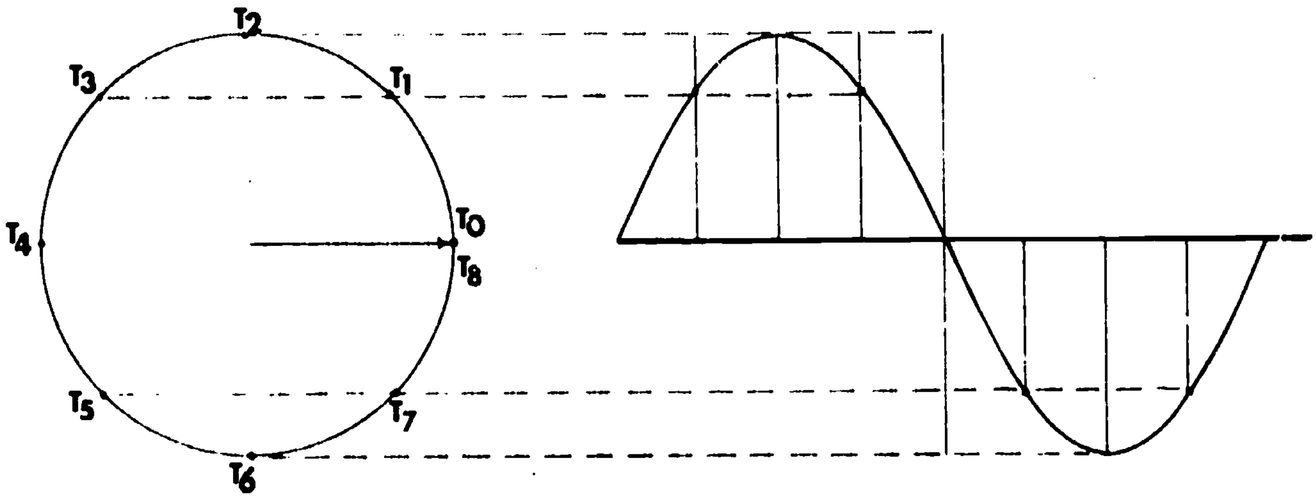
Current repeats all the changes of E_a 90° later on the graph, so we say that current lags source voltage in this circuit. This could also be expressed as "E_a leads I," depending on how you look at the situation. As you will see later, the two ways of seeing the phase shift can be helpful.

Because the applied voltage and CEMF are directly opposite each other, neither is said to lead or lag the other.

In electricity, vectors can be used to simplify AC calculations. For example, the output of an alternator is a voltage sine wave of 115 VAC. Its time-base graph looks like this:

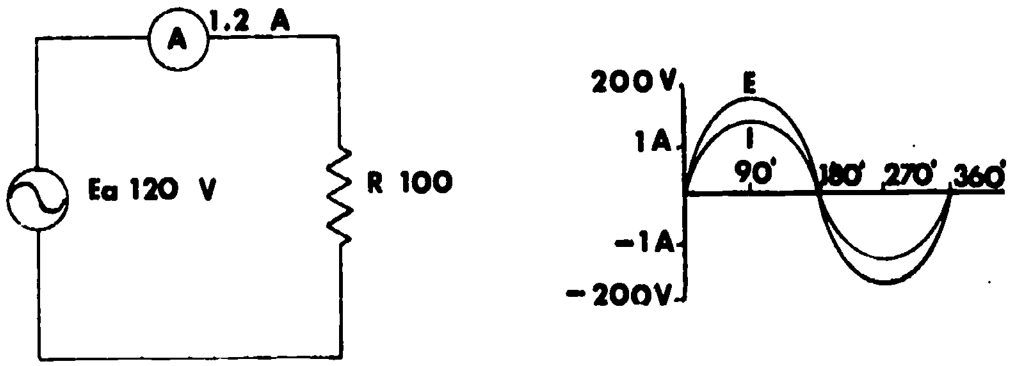


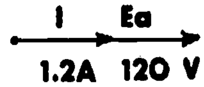
If you represent the rotating armature of the alternator by a rotating vector, a graph of the vertical distance from the vector point to its reference (<u>t0</u> in the sketch below) would also produce a sine curve.



Since the vector in its rotation produces the sine wave, the vector can represent the sine wave. For convenience in figuring, the length of the vector usually represents the effective value of the sine wave. Vector notation uses several other standard practices to help technicians talk more easily about AC. One of these is that the reference (zero) point for a vector is always pointing horizontally to the right as at <u>t0</u> in the sketch above. Counterclockwise rotation is the normal or positive rotation for a vector, and clockwise rotation is considered negative. The angle between the vector's position and the reference position is also positive for counterclockwise rotation and negative for clockwise movement. This angle is very important, and we will be discussing it much more in later modules. The name of the sine wave is based on this angle, for the sine of the angle is proportional to the instantaneous value of voltage or current.

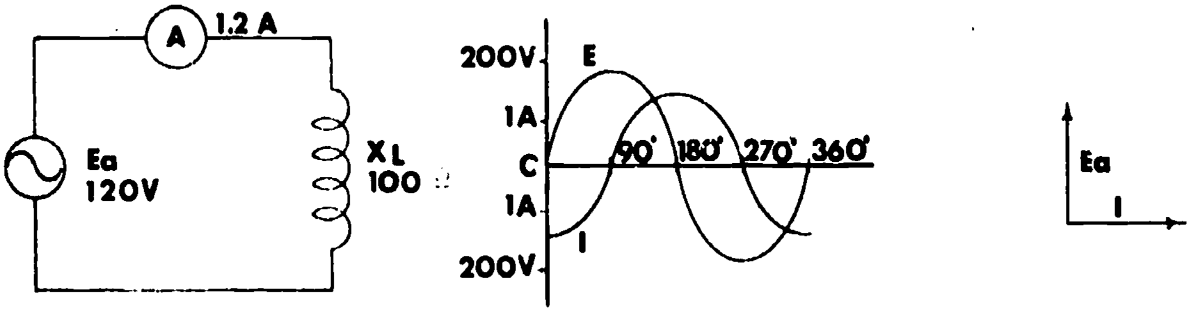
Here is an AC circuit, the time base graph of current and voltage in the circuit, and the vector diagram for voltage and current.



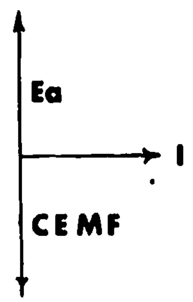


The voltage and current in this circuit are <u>in phase</u>, so the vectors point in the same direction.

In an inductive circuit, voltages and currents are no longer in phase and the circuit, graph, and vector diagrams are like this:



If CEMF is included in the vector diagram, this results:



A way to help you remember the voltage leads current in an inductive circuit is to remember the name <u>ELI</u>.

	(Inductance)	
E	L	I
voltage	leads	current

The vector diagrams are obviously much easier to draw than the sine curves, and, if you understand them, they show exactly the same things. In later modules, you will find other ways in which they can help you simplify working with AC.

AT THIS POINT, YOU MAY TAKE THE PROGRESS CHECK, OR YOU MAY STUDY ANY OF THE OTHER RESOURCES LISTED. IF YOU TAKE THE PROGRESS CHECK AND ANSWER ALL OF THE QUESTIONS CORRECTLY, DO THE EXPERIMENT WHICH BEGINS ON PAGE 127. YOU MAY TAKE THE MODULE TEST UPON COMPLETION OF THE EXPERIMENT. IF YOU DID NOT ANSWER ALL THE QUESTIONS CORRECTLY, STUDY ANY METHOD OF INSTRUCTION YOU WISH UNTIL YOU CAN ANSWER ALL THE QUESTIONS CORRECTLY.

PROGRAMMED INSTRUCTION
LESSON VI

Phase Relationships in Inductive AC Circuits

THIS PROGRAMMED SEQUENCE HAS NO TEST FRAMES.

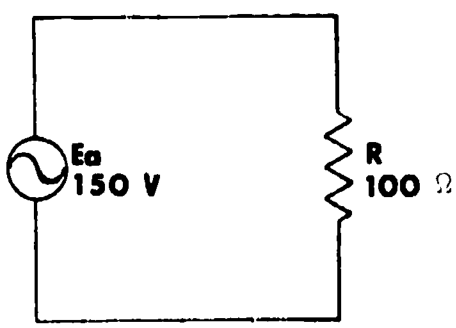
1. In a resistive AC circuit, the current flow through the resistor and the voltage drop across it increases and decreases in direct relation to one another.

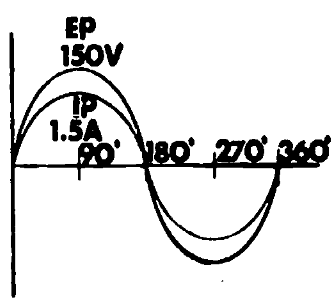
When current flow through a resistor is at peak value E_R would be:

____ a. minimum
____ b. maximum
____ c. minimum, but opposite in polarity
____ d. maximum, but opposite in polarity

(b) maximum

2. By dividing the base line into electrical degrees and plotting the sine waves of resistive voltage and current, it can be seen that both values go through their maximum and minimum points at the same instant of time and in the same direction. Because of this, they are said to be in phase.





The voltage and current in the above diagrams are in phase and reach their peak values at ________ and __________ degrees, their minimum values at __________, __________ and _________ degrees.

(90°; 270°; 0°; 180°; 360°)

3. When one value increases and decreases in direct proportion to another value, the two are said to be ____________.

(in phase)

---

4. The term phase as used with electrical values refers to the difference or lack of difference in time, or electrical degrees which exists between corresponding points on two or more waveforms. For example the positive peak values of in phase waveforms would occur at the same instant of time, but for out of phase quantities the positive peak values would occur at ____________ times.

(different)

---

5. The phase relationship and magnitude of electrical values, such as voltage and current are often represented by vectors. A vector is a line the length of which represents the magnitude of the value and the direction it is drawn represents the phase.

Voltage and current in a resistive circuit are in phase, the vectors representing these values would be drawn in the ________ direction.

(same) (Note: Although voltage and current do not have a direction in the three dimensional sense, phase and direction can be used interchangeably when discussing electrical values and vectors.

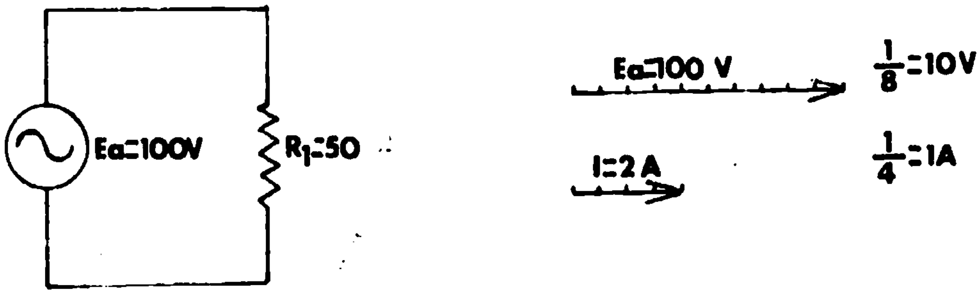
---

6. A vector can be used to represent the ______________ and ______________ of an electrical value.

(magnitude, phase or direction)

---

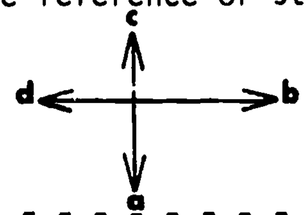
7. To represent the magnitude of a value, the vector is drawn to scale. For example, the voltage and current for the circuit shown is drawn as indicated.



(Go to next frame.)

8. To represent the phase relationship between values by using vectors, one value must be chosen as a reference to which the other values may be compared. In the vector diagram the value used as the reference is placed on the horizontal line drawn to the right of the zero point.

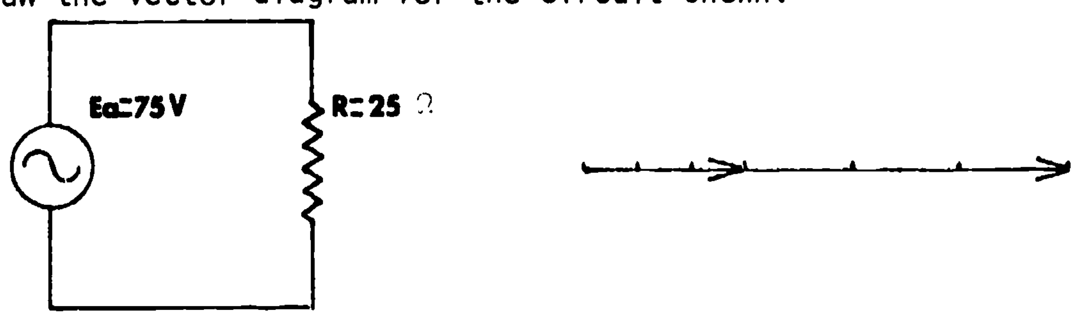
Which vector is in the reference or standard position? ________



(b)

9. Since voltage and current are in phase with one another in a resistive circuit both are drawn in the standard position. Refering to the example in frame 7.

Draw the vector diagram for the circuit shown.



(E = 75v (1/2" = 25v) (The choice of scale is an individual choice)
I = 3a (1/4" = 1a)

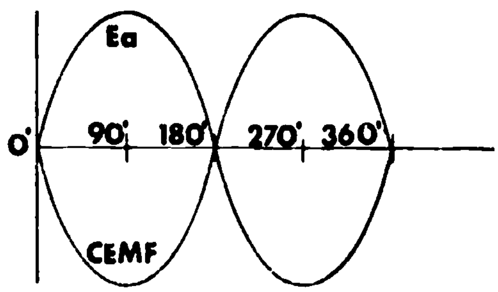
10. In an inductive circuit the electrical values are no longer in phase; there will now be a displacement in both time and electrical degrees between voltage and current. The displacement is referred to as a phase difference or phase shift.

A difference in phase means that the values in question will not reach their maximum and minimum values at the same ________ going in the same __________.

(time; direction)

---

11. To explain this phase shift, first consider the relationship between the applied voltage and the self-induced voltage (CEMF). Counter EMF by definition opposes the applied voltage. This effect is comparable to two forces pulling or pushing in opposite directions. This relationship is called a 180° phase shift and is represented like this:

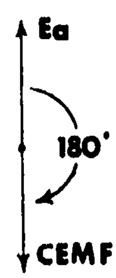


Although the two values do go through their maximum and minimum values at the same time, they are going in ______________.

(opposite directions)

---

12. The 180° phase difference can be represented either by sine waves as in frame 11 or by vectors like this:



In each case, the values can be seen to be ______________ each other. opposing/aiding

---

(opposing)

---

13. When CEMF is at its maximum positive value, the applied voltage is at its ________________ value.

- -

(maximum negative)

14. To be in phase the values must go through their maximum and minimum values at the ____________ time and in the __________ direction.

Values that are 180° out of phase will go through their maximum and minimum values at the ___________ time in __________ direction.

- -

(same; same; same; opposite)

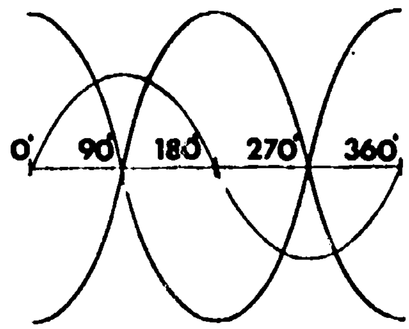
15. Draw the vector diagrams for two values that are in phase and two that are 180° out of phase.

(Assume all magnitudes are equal)

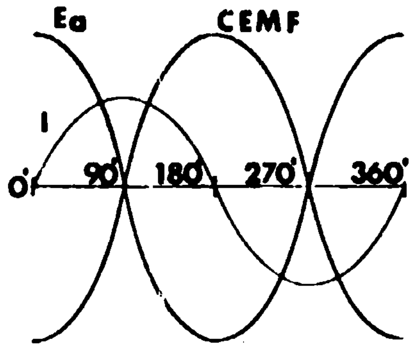
- -

16. Current in an inductive circuit is 90° displaced from both applied voltage and CEMF. To simplify, E_a reaches its positive peak 90° before current reaches its positive peak and current is 90° ahead of CEMF.

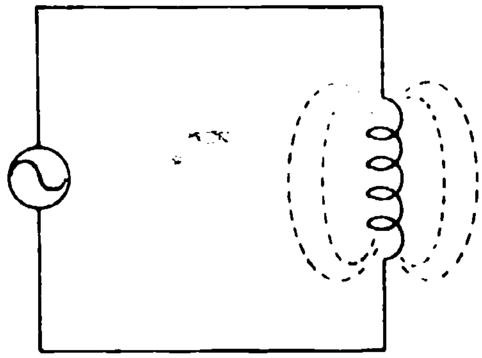
Label E_a, I, CEMF:

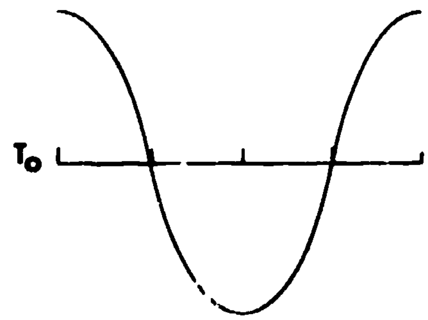


- -



17. The 90° phase shift between inductive voltage and current is due to the CEMF caused by the changing magnetic field around the coil





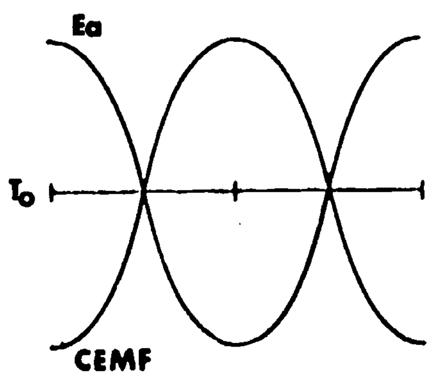
At t0 the applied voltage is at its maximum value. This will cause circuit current to try to increase from 0 to some value. At this instant of time even though current is zero it is experiencing its greatest rate of change.

At t0 current is changing at its greatest rate, which causes the magnetic field to change at its ____________ rate.
fastest/slowest

- -

(fastest)

18.



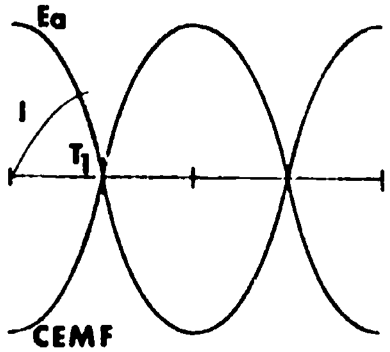
At this instant of time (t0) the rapidly changing magnetic field causes maximum self induced voltage. The CEMF, by opposing the applied voltage, also opposes the increase in current.

At t0 the CEMF is ____________ to the applied voltage and ____________ in polarity.

- -

(equal; opposite)

19. As current increases in value from 0, at t0, the rate of change is continuously decreasing this in turn causes CEMF to decrease.



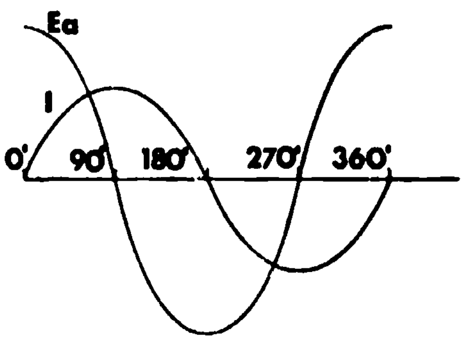
At tl the current sine wave has completed 90° and has reached its maximum value. The rate of change of current at this instant is zero and CEMF has decreased to zero.

CEMF is _______________ when the rate of change of current is greatest and _______________ when the rate of change is smallest.

(maximum; minimum) (Note: The terms t0, tl, etc., are merely used to indicate a point. There is no comparison between these designations and the time constants discussed previously.)

---

20. The phase relationship between voltage and current in an inductive circuit can now be visualized as:



From this illustration you can see that E_a is at its maximum positive value ____________________ degrees before current reaches its maximum positive value.

(90°)

21. This voltage and current relationship can be stated as voltage leads current by 90° or as current lags voltage by 90° depending on which value is used as a reference.

In an inductive circuit when voltage is maximum current is ________ and when current is maximum voltage is ________.

(minimum; minimum)

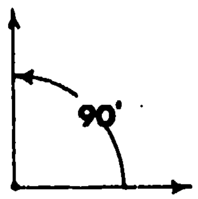
22. The angle by which voltage leads current is designated the circuit phase angle and is represented by the greek letter Θ (theta).

For a purely inductive circuit Θ = ________

(90°)

23. To represent the phase difference between voltage and current by using vectors, one value is selected as the reference value and is plotted in the standard position. The other value is then drawn in respect to the reference.

By convention, a value that is moved counterclockwise from the reference is said to have a positive phase angle (leading angle).

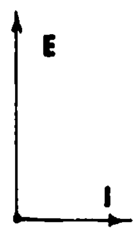


A value that is moved clockwise from the reference is said to have a negative phase angle (lagging angle).

(Go to next frame.)

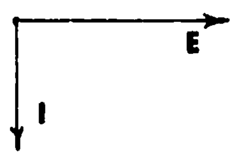
24. Using current as the reference, draw a vector diagram showing the phase relationship between voltage and current in an inductive circuit.

- -



25. Using voltage as the reference draw the vector diagram for an inductive circuit.

- -



26. As shown in the two preceding frames the phase relationship between voltage and current in an inductive circuit can be given as: Voltage ___________ current by 90° or as current __________ voltage by 90°.

- -

(leads; lags)

27. A convenient way of remembering the phase relationship between voltage and current in an inductive circuit is by remembering the name ELI.

Voltage	Lead	Current
E	L	I

Inductance

GO TO THE NEXT PAGE AND PERFORM THE EXPERIMENT.

EXPERIMENT

The Oscilloscope and the Signal Generator

Introduction

The oscilloscope is a testing device which displays voltage variations with respect to time. It traces a graph of instantaneous voltages such as the waveforms you have seen produced by alternators and generators. Used properly, a good oscilloscope can measure the frequency, phase difference, amplitude, and shape of any periodic waveform. (A periodic waveform is one which has the same shape and size through each cycle.) An oscilloscope is one of the most versatile test instruments available to you.

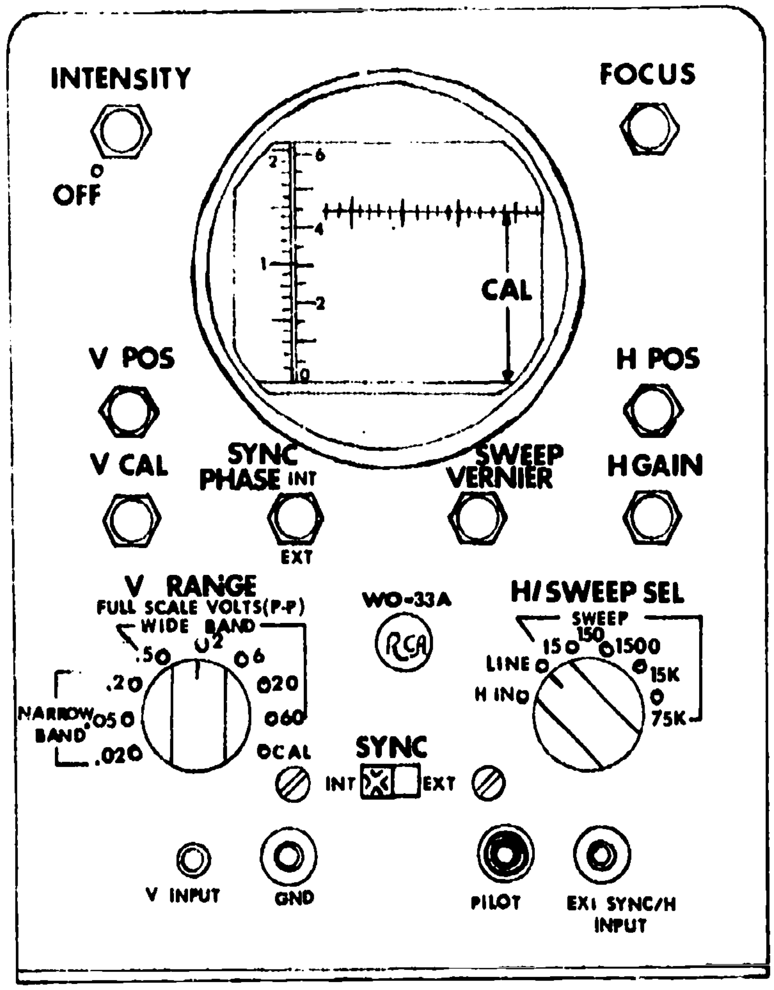
The oscilloscope you will use is an RCA Model WO-33A Oscilloscope, a portable, three-inch screen unit. Because it uses extremely high voltages in some of its circuits, do not attempt to remove it from its case. Handle the oscilloscope with care, for it is delicate, and the cathode ray tube can implode, throwing pieces of glass around with great force.

Get an oscilloscope and a signal generator from the materials center. Using the scope diagram, the scope, and the following directions, become familiar with the scope, its controls, and the function of each control.

Oscilloscope Controls

The front panel controls of the oscilloscope vary the size of the signal display, the position of the pattern on the screen, the brightness of the display, the sharpness of the trace, and the rate of the time base. You are going to use the "scope" to observe how the waveforms in your power supply change as AC is converted to DC.

The diagram shown at the top of the next page shows the oscilloscope and the controls that you will be concerned with. Look at the controls on the illustration and locate each corresponding control on the oscilloscope you are using. With no test leads connected to the scope, plug in its power cord and turn the intensity control (upper left corner of scope) clockwise until a distinct snap is felt and heard. When the scope is energized the red pilot light on the lower front of the scope will be lighted. Wait a few minutes, then continue to turn the intensity control until a sharp clear line is traced on the scope face. Caution, over intensity will damage the face of the picture tube so do not get the trace too bright. If after turning the scope on and waiting several minutes, adjusting the intensity

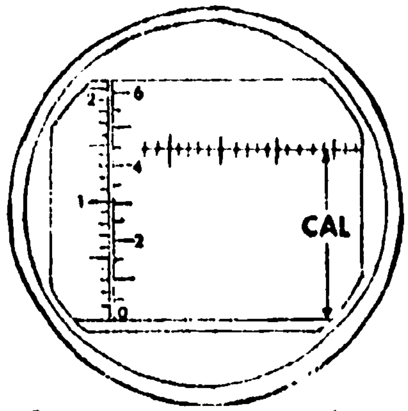


control does not show a trace on the scope, vary the setting of the vertical positioning control (V POS) and the horizontal positioning control (H POS). (The vertical positioning control is located directly below the intensity control on the left side. The H POS is located directly to right of the V POS control and below the Focus control.) This should move the trace across the screen. The V POS control, as its name implies, controls the location of the trace in a vertical plane on the scope face. The H POS, determines the horizontal location of the trace.

Using the V POS and H POS controls, adjust the trace to the center of the picture tube, just to the right of and level with the numeral "1" imprinted on the scope face.

The "focus" control mentioned above is located in the upper right hand corner of the scope. Adjust it for a distinct trace.

At this point the screen should look like this:



On the right side of the scope and directly below the H POS control is the horizontal gain control (H GAIN). Its purpose is to adjust the horizontal length of the image. Adjust the H GAIN until the left end of the trace is just to the right of the graduated inner vertical line.

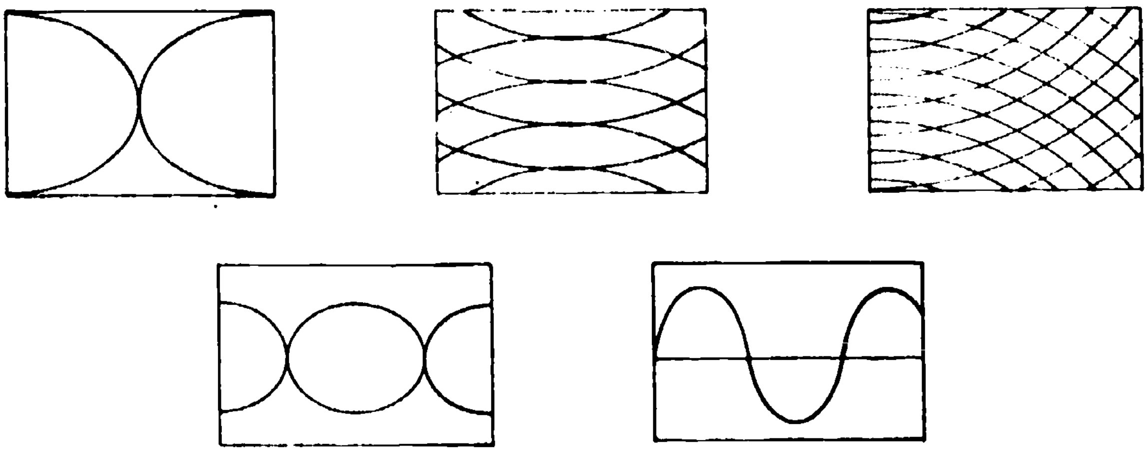
Directly below the screen is the SYNC/PHASE control (left of center) and the (SWEEP VERNIER) control (right of center). Both of these work in conjunction with the internal amplifier of the scope. The SYNC/PHASE control synchronizes an externally applied signal so that it is in phase with the output of the internal amplifier. The SWEEP VERNIER control is used for fine adjustment when synchronizing the horizontal sweep of the signal to stop the side to side movement of the trace. With no input to the scope, the 2 controls, will have little or no effect on the trace. Place both controls to a mid range setting.

Locate the voltage range (V RANGE) control which is the large rotary switch located on the lower left front of the scope. Its function is to control the vertical magnitude of the input signal. The smaller the input signal the further counterclockwise the V RANGE control is rotated. The larger the signal the further clockwise rotation.

Turn the V RANGE switch to the "cal" position. This position provides an internal input signal for adjustment of the scope.

In the "cal" position you should have various designs on the scope. The (H/SWEEP) selector determines the frequency of the trace sweep (that is how many times per second the trace goes from left to right

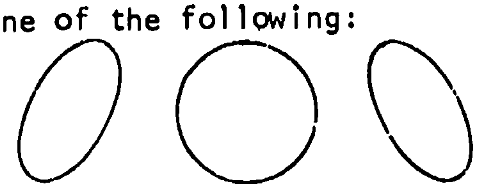
on the screen). Turn it to the "15" position. You may have any one of the following patterns on the scope.



Turn the H SWEEP control through the remainder of the sweep positions, and observe the results. You can see as the sweep frequency increases the image becomes smaller, more compact. Now return the "H SWEEP" to the 15 position. If the image is continually moving across the screen use the SYNC/PHASE control and the SWEEP VERNIER control to synchronize and stop the image.

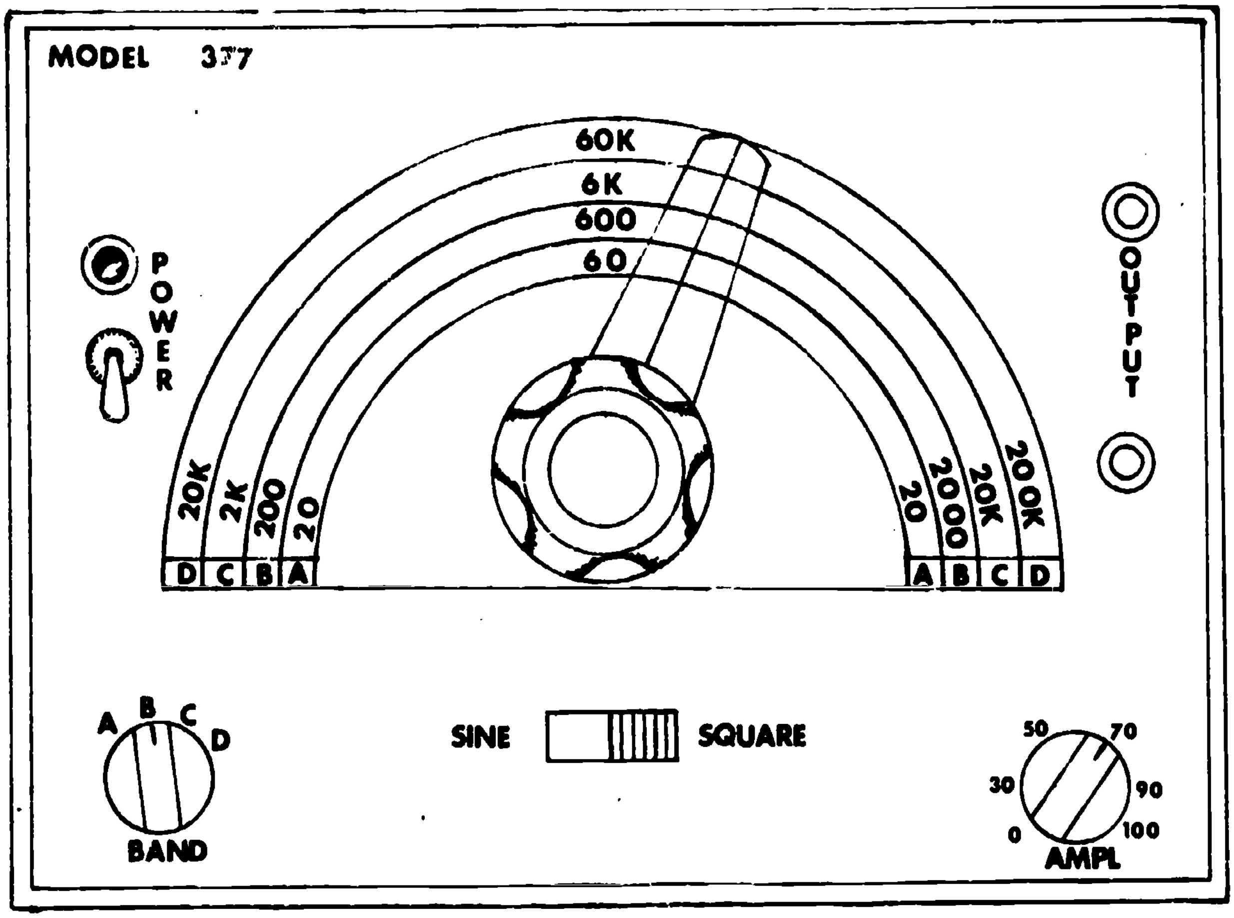
The SYNC control (a sliding toggle switch) is used to select the signal applied to the horizontal circuit of the scope. It has an internal and external position, move it from its present position and use the SWEEP VERNIER to again stop the image.

Now turn the H/SWEEP switch to the "line" position. You should have a picture like one of the following:



Turn the intensity fully counterclockwise and leave the scope on.

Let's look at the Model 377 Signal Generator.



The front panel of the signal generator contains five controls and two jacks. The power switch (upper left front) is turned on at this time to allow the signal generator ample warm up time.

This piece of equipment is capable of generating either sine

 or square  wave signals. Its

range is 20 hz to 200 khz. Looking at the drawing you will find the power switch on the upper left, directly below the indicator lamp. On the lower left you find the band switch, its function is to select which range of frequencies you wish to use: Band A is 20 to 200 hz, Band B is 200 to 2000 hz, and so on. Right in the center is the fine frequency tuning control. This control is used in conjunction with the band switch to select the desired output frequency. For example: If the band switch is in the D position, the fine frequency tuner is used to select any frequency between 20 khz to 2000 khz.

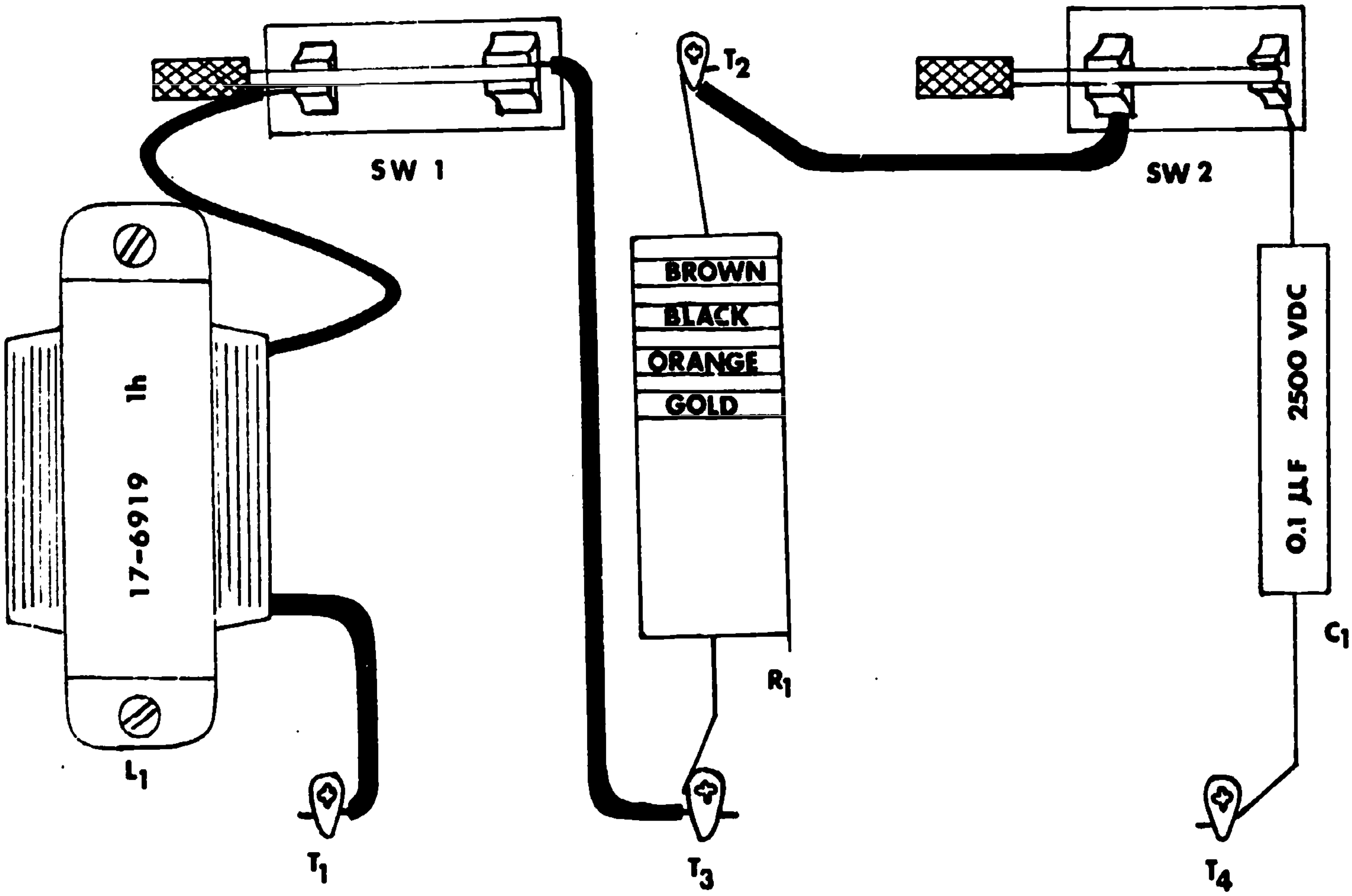
Directly below the fine frequency tuner is the sine/square wave selector switch. As its name implies its position will determine

what type of output signal is available from the 2 output jacks that are located on the upper right half of signal generator.

Located in the lower right corner, the "amplitude" control, adjust magnitude of the signal output. A clockwise rotation increases the amplitude of the output signal.

Now that you have been briefed on the test equipment, the controls and their functions, let's move on to the actual experiment.

SERIES RLC CIRCUIT



From your equipment select the vector board with an inductor, resistor and capacitor connected in series. With the WO-33A Scope, the Model 377 Signal Generator, the pictorial drawing of the circuit, and necessary test leads; connect the equipment as directed below:

1. Using a set of test leads, connect the "output" of the signal generator to terminals T1 and T2 of the vector board.

2. Close SW1, this puts the inductor and resistor in series. (Leave SW2 open.)

3. Using a black lead, connect a jumper from signal generator upper output terminal to "EXT SYNC/H INPUT" on the scope.

4. Connect the gray test lead to "V INPUT" on the scope.

5. From the test lead on scope (using jumpers) connect the black lead to T3 on the vector board.

6. Using the red test lead (jumper) as a probe connect one end to the short blue lead on the scope test lead head.

7. Plug in the scope and signal generator, insure both are turned on.

8. Signal generator indicating power on, pilot lamps should be glowing red.

9. On scope set SYNC switch to EXT.

10. Set V RANGE to 60.

11. Set H/SWEEP SELECTOR to 150.

12. Adjust intensity for clear distinct pattern, caution, over intensity can burn scope face.

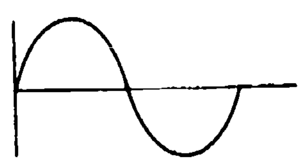
13. On signal generator set "band" to "range B."

14. Set waveform to SINE.

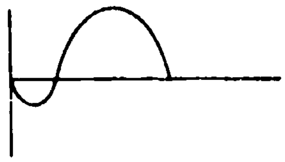
15. Set amplitude to maximum range (100).

16. Hold red test lead from scope, on terminal T2, adjust signal generator frequency selector to around 1500 Hz on range scale.

17. Using scope control SYNC/PHASE adjust for scope pattern like this:



18. Move red test probe to terminal T1, without changing any adjustments. We will have a pattern on our scope like this



slightly indicating a phase shift of something less than 90°.

By adjusting the SYNC/PHASE control you can adjust for a trace that is exactly 180° from the trace found on T2. We <u>do not</u> have a phase shift of 180°.

Feel free to change any control settings, on either piece of test equipment. You have some strange sights in store.

When you have finished experimenting with the equipment disconnect all leads and secure all test equipment.

YOU MAY NOW TAKE THE PROGRESS CHECK, OR YOU MAY STUDY ANY OF THE OTHER RESOURCES LISTED. IF YOU TAKE THE PROGRESS CHECK AND ANSWER ALL THE QUESTIONS CORRECTLY, YOU HAVE MASTERED THE MATERIAL AND ARE READY TO TAKE THE MODULE TEST. SEE YOUR LEARNING SUPERVISOR.

IF YOU DECIDE NOT TO TAKE THE PROGRESS CHECK AT THIS TIME, OR IF YOU MISSED ONE OR MORE QUESTIONS, STUDY ANY METHOD OF INSTRUCTION YOU WISH UNTIL YOU HAVE ANSWERED ALL THE PROGRESS CHECK QUESTIONS CORRECTLY.

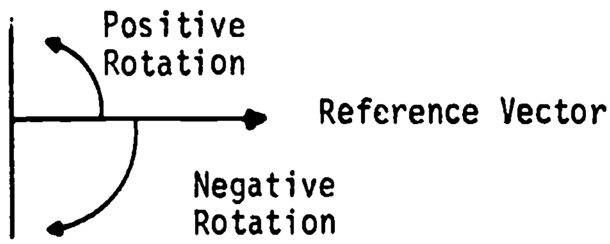
THEN SEE YOUR LEARNING SUPERVISOR AND ASK TO TAKE THE MODULE TEST.

SUMMARY
LESSON VI

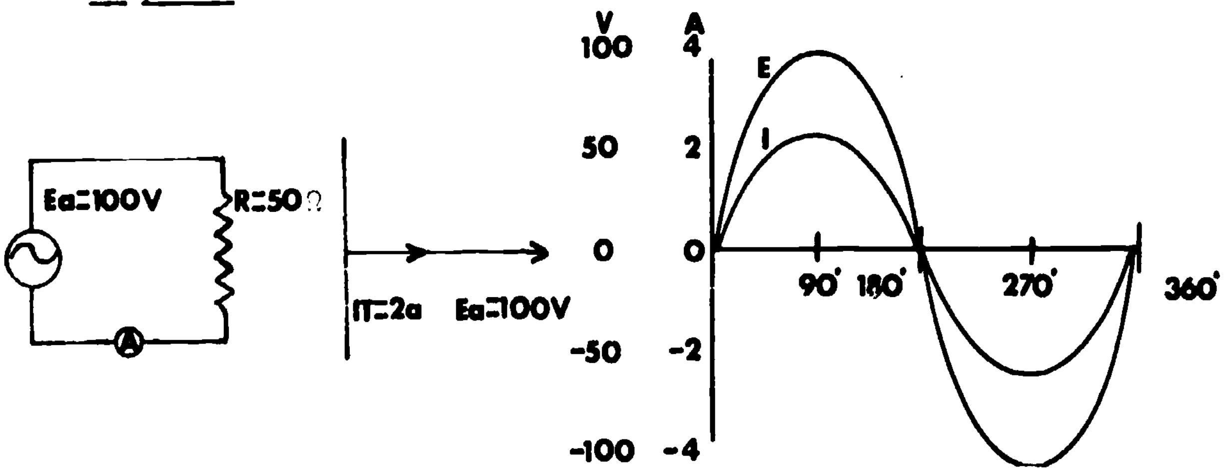
Phase Relationships in Inductive AC Circuits

Vectors are used to help explain and solve phase relationships in AC circuits. If the magnitude of the vector represents the maximum (peak) value of voltage or current, the sine function of the rotating polar vector will produce the sine wave you have seen frequently. This means that it is possible to represent the sine wave by the vector alone.

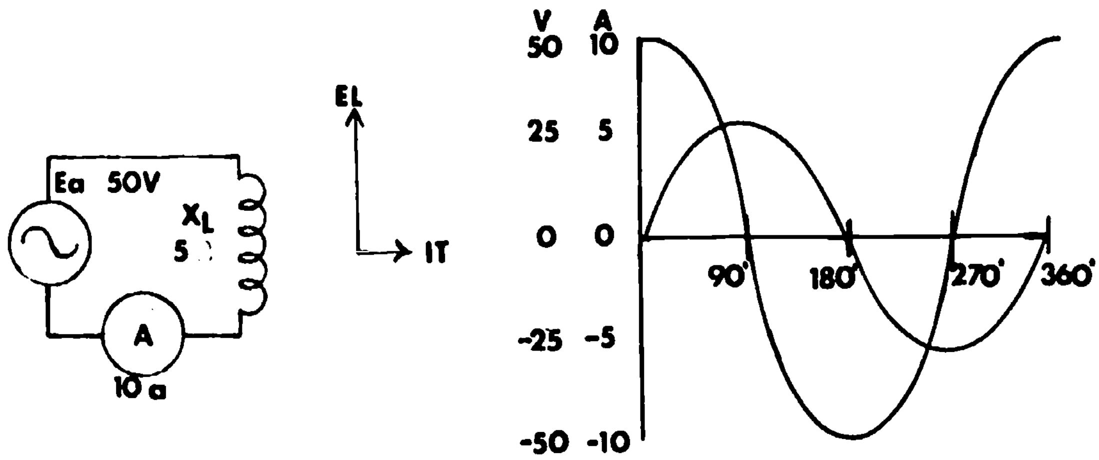
Phase relations between voltages or currents of the same frequency can be represented by polar vectors separated by the appropriate angles. By common usage, the reference vector is always shown in the standard position (see diagram below), and normal rotation is counterclockwise. Rotation in a clockwise direction is considered negative. See the diagram below:



A very common use for vectors is to present the phase and amplitude relationships of voltage and current in an AC circuit. When the load in a circuit is purely resistive, the voltage and current are <u>in phase</u> and the vector and sine wave graphs are as shown here:



In a purely inductive circuit, the CEMF induced in the coil delays the current, causing it to lag the applied voltage by 90° as illustrated at the top of the next page.



A memory aid to help you remember that voltage lleads current in an inductive circuit is the name <u>ELI</u>:

<u>E</u> (voltage) <u>L</u> (inductance) <u>I</u> (current) and

<u>E</u> leads (comes before) current.

AT THIS POINT, YOU MAY TAKE THE LESSON PROGRESS CHECK, OR YOU MAY STUDY THE LESSON NARRATIVE OR THE PROGRAMMED INSTRUCTION OR BOTH. IF YOU TAKE THE PROGRESS CHECK AND ANSWER ALL THE QUESTIONS CORRECTLY, DO THE EXPERIMENT WHICH BEGINS ON PAGE 127. YOU MAY TAKE THE MODULE TEST UPON COMPLETION OF THE EXPERIMENT. IF YOU DID NOT ANSWER ALL THE QUESTIONS CORRECTLY, STUDY ANY METHOD OF INSTRUCTION YOU WISH UNTIL YOU CAN ANSWER ALL THE QUESTIONS CORRECTLY.