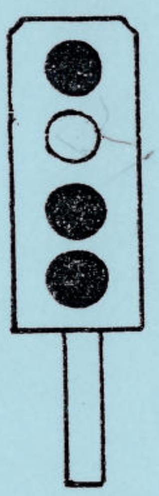
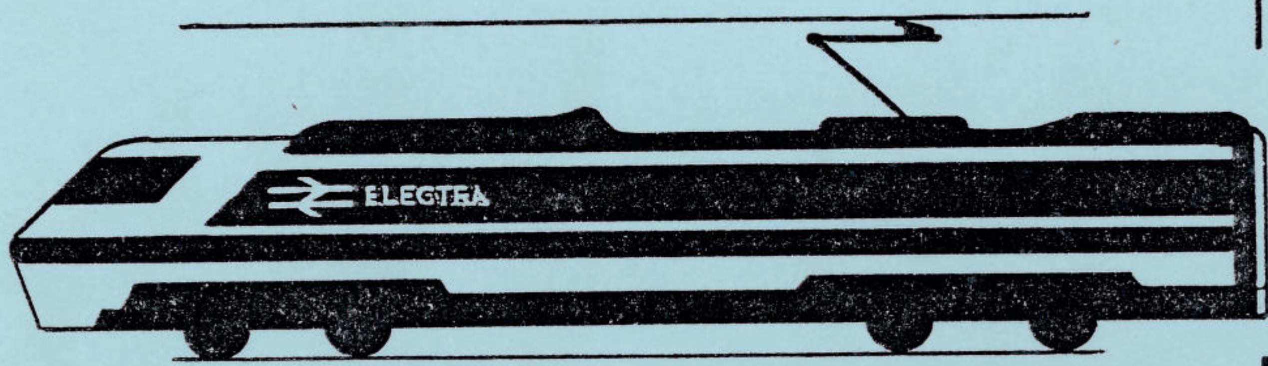
British Rail

Regional Signal
and
Telecommunications
Engineers Department





# ELECTRICAL PRINCIPLES 2.

Training School York
Eastern Region

# Contents

British Rail

**Course** E.P. 2.

**Section** One

**Content** Introduction.

**R.S. & T.E. Department**

**Training School** **York**

INTRODUCTION.

As you probably know, all of our power supplies, on British Rail, are A.C. There are many good reasons for this choice of electrical power transmission.

Alternating current voltages can be increased or decreased easily and without much power loss.

This is particulrly important in the transmission of electrical power. Very often large amounts of power must be transmitted and this is best achieved by using high voltages.

At the power station the voltage is "stepped up" by transformers to very high voltages and sent over the transmission lines to the various points that power is required.

At the point at which power is required, it is "stepped down" to the various voltages required by using further transformers.

To obtain the different values of voltages using D.C. power supplies, would need complicated and inefficient devices.

In communications alternating currents are the very nature of the speech, music and other signals which need to be transmitted. The techniques used in communications are, therefore, based on alternating current theory.

British Rail

**Course** E.P. 2.

**Section** Two.

**Content** Revision of Ohms Law.
Electrical Units.
Unit Multiples and Sub-Multiples.

R.S. & T.E. Department

Training School York

## ELECTRICAL UNITS

| Quantity | Unit | Symbol |
|---|---|---|
| Voltage | Volt | V |
| Resistance | Ohm | Ω |
| Capacitance | Farad | F |
| Inductance | Henry | H |
| Frequency | Herz | Hz |
| Power | Watt | W |
| Current | Ampere | A |
| Time | Second | s |

## UNIT MULTIPLES AND SUBMULTIPLES

| Prefix | Symbol | Factor by which unit is multiplied | Example |
|---|---|---|---|
| Giga | G | $10^9$ = 1000,000,000 | Gigahertz (GHz) |
| Mega | M | $10^6$ = 1000,000 | Megawatt (MW) |
| Kilo | K | $10^3$ = 1000 | Kilometre (Km) |
| Milli | m | $10^{-3}$ = 0.001 | millihenry (mH) |
| Micro | $\mu$ | $10^{-6}$ = 0.000001 | microsecond ($\mu$s) |
| Nano | n | $10^{-9}$ = 0.000000001 | nanosecond (ns) |
| Pico | p | $10^{-12}$ = 0.000000000001 | picofarad (pF) |

British Rail

Course E.P. 2.

Section Three.

Content Waveforms.

R.S. & T.E. Department

Training School York

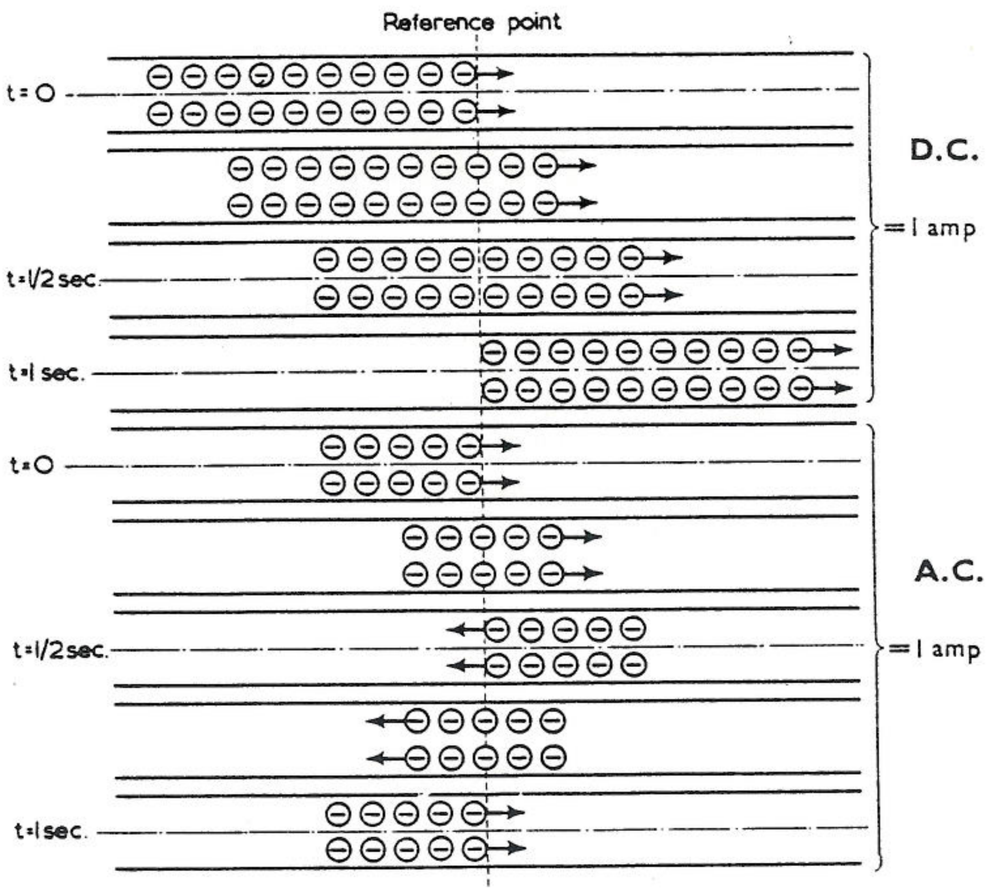
ALTERNATING CURRENT.

Alternating current (A.C.) is the flow of electrons back and forth in a wire at regular intervals, going first in one direction and then in the other.

Direct current (D.C.) flows only in one direction and that the current is measured by the number of electrons passing a point in one second. This is known as a coulomb. ($6{\cdot}26 \times 10^{18}$) or (6·26 million, million, million).

If half a coulomb of electrons moves in one direction past a point in half a second, then reverses direction and moves past the same point in the opposite direction during the next half second, a total of one coulomb of electrons passes the point in one second. This is one ampere of A.C.

## COMPARING DC and AC Current Flow IN A WIRE

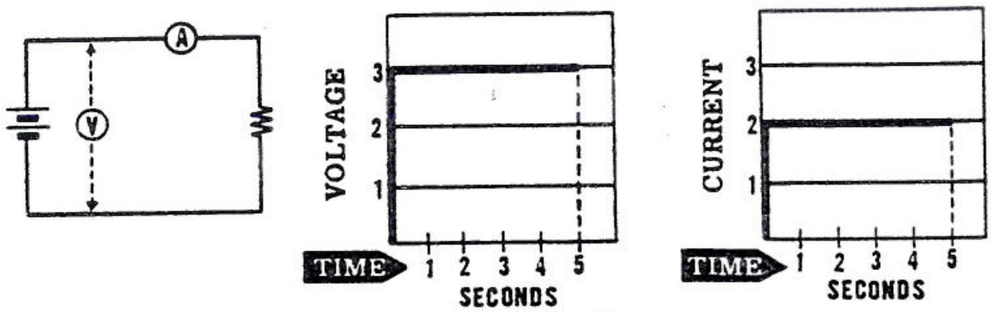


WAVEFORMS.

Waveforms are pictures showing how voltages and currents vary over a period of time.

The waveforms for direct current are straight lines; for neither the voltage or the current vary in a given circuit. If you connect a fixed resistance across a battery and take a measurement of voltage across, and current through, theresistor at regular intervals of time, you will find no change in their values. If you plot the value of V and A, each against time, you will obtain straight lines. These will be the waveforms of the voltage and current.

WAVEFORMS ARE PICTURES OF VOLTAGE OR CURRENT VARIATIONS

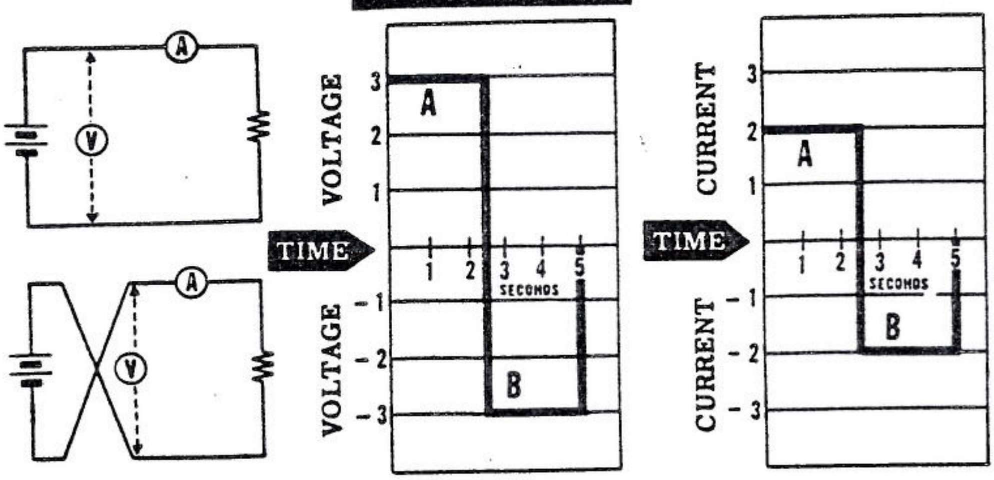



DC WAVEFORMS

If, with the same circuit, you reverse the battery connections at regular intervals, then the voltage across, and the current through, the resistor will also be reversed at regular intervals. This can be proved by using a centre-zero meter.

If you now plot the values of V and A once again, you will obtain readings which are alternately above and below the zero line. Join up the ends of these lines drawn to represent these readings, and you will obtain waveforms which show that the current and voltage are A.C. rather than D.C.; for the waveforms indicate clearly both the changing direction of the current flow and the reversal in the polarity of the voltage.

AC WAVEFORMS

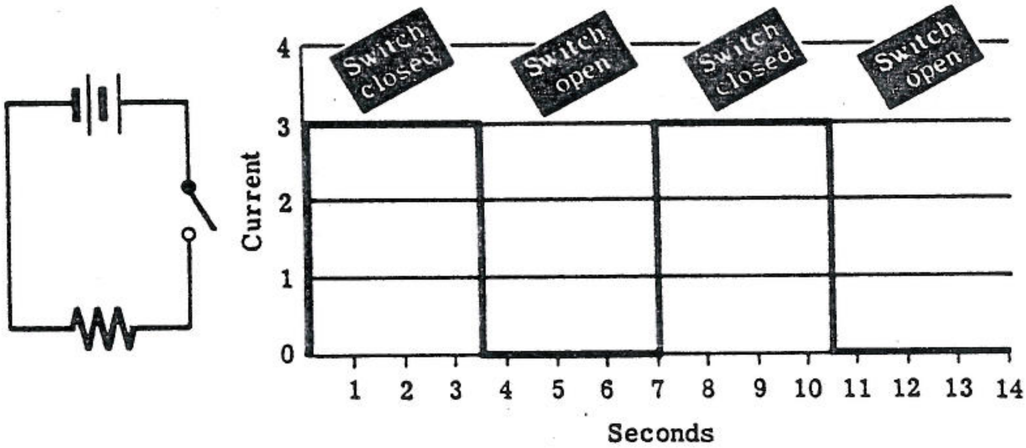


Another type of waveform is pulsating D.C., which represents variations in voltage and current flow without a change in the direction of current flow. This kind of waveform is found in the D.C. generator output which contains a ripple or variation caused by commutator action.

Battery waveforms do not have this variance unless the circuit itself is changed, e.g. by reversing the battery terminals to obtain an A.C. waveform.

If, in a circuit consisting of a resistor and a switch connected across a battery, you open and close the switch, causing the current to stop and start but not reverse direction, the circuit current is pulsating direct current. The waveforms for this pulsating current resemble A.C. waveforms, but do not go below zero since the current does not change direction.

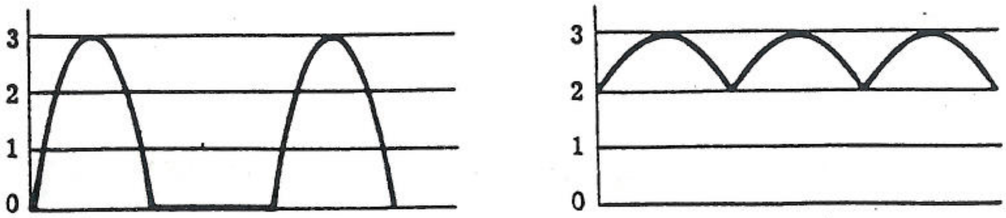
## PULSATING DC




Waveforms of voltage and current are not always made of straight lines connecting points. In most cases waveforms are curved, representing the gradual changes in voltage and current.

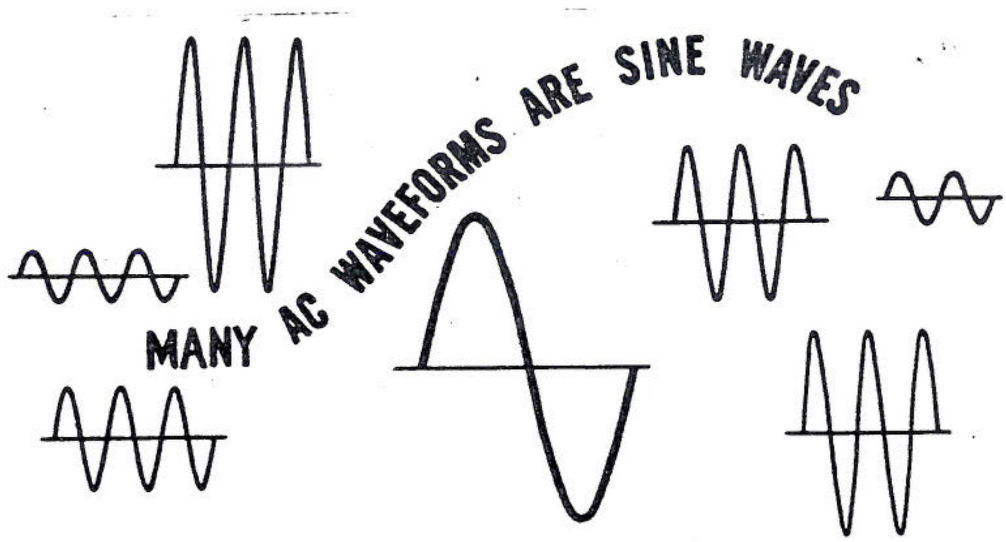
Pulsating direct current does not always vary between zero and a maximum value, but may vary over any range between these values. The waveforms of a D.C. generator is pulsating D.C., which does not fall to zero but which varies instead only slightly below the maximum value.

## OTHER WAVEFORMS OF PULSATING DC.....



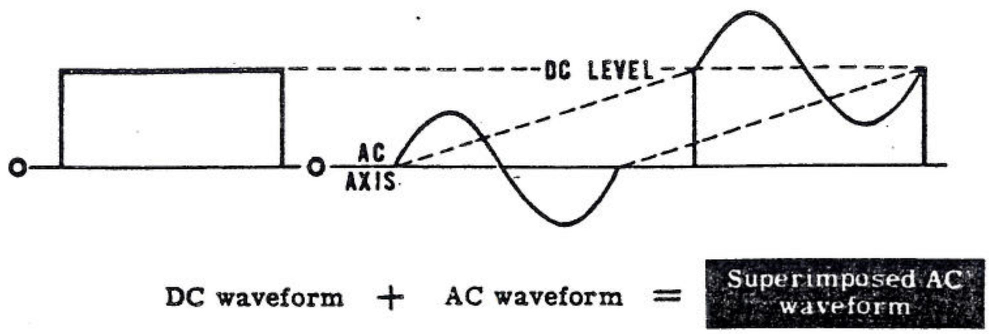
The waveforms of most alternating currents are curved to represent gradual changes in voltage and current, first increasing then decreasing in value for each direction of current flow.

Most alternating current you will use has a waveform represented by a sine curve, which you will find out about later. While alternating currents and voltages do not always have waveforms which are exact sine curves, they are normally assumed to have a sine waveform unless otherwise stated.




When direct current and alternating current voltages are both present in the same circuit, the resulting voltage waveform is a combination of the two voltages. the A.C. wave is added to the D.C. wave, with the value of the D.C. voltage becoming the axis from which the A.C. wave moves in either direction. Thus the D.C. voltage value replaces the zero value as the A.C. waveform axis.

The resulting waveform is neither pure D.C. nor A.C. It is called "Superimposed A.C." meaning that the A.C. wave is added to, or placed over the D.C. wave.



British Rail

**Course** E.P. 2.

**Section** Four.

**Content**

Alternating Current Cycles.

Frequency.

Elementary Generator Construction.

Maximum and Peak to Peak Values of a Sine Wave.

R.M.S. Values of a Sine Wave.

**R.S. & T.E. Department**

**Training School** **York**

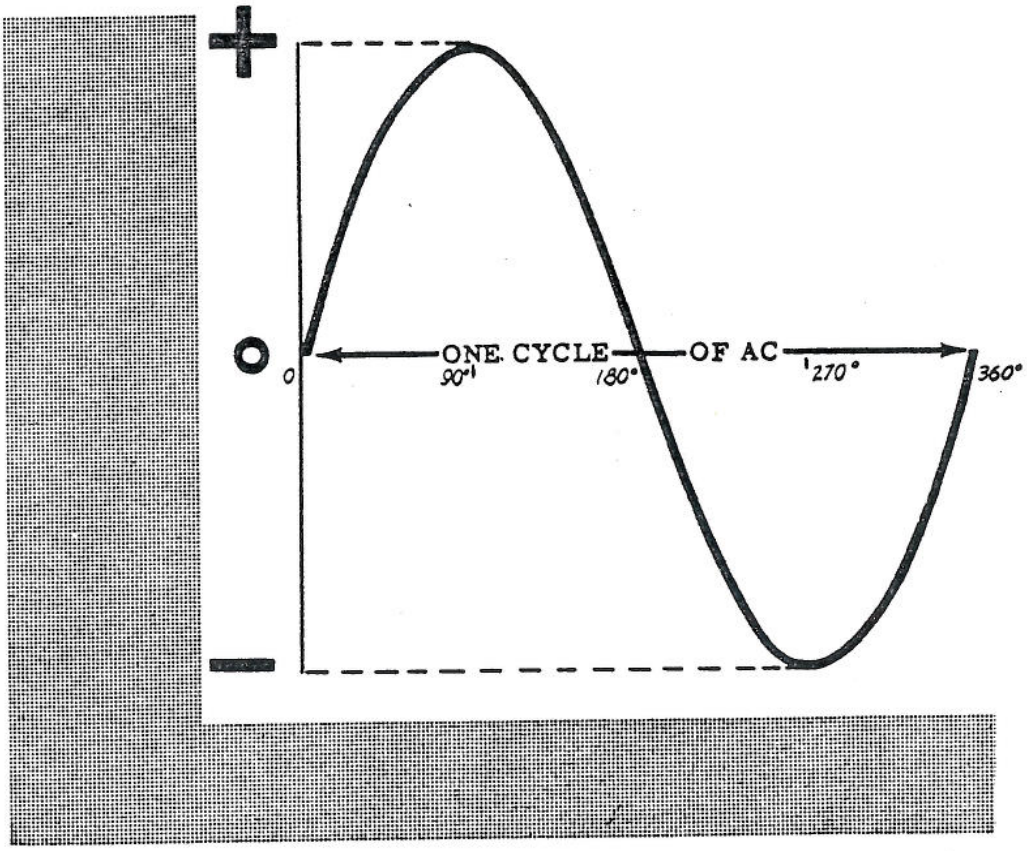
ALTERNATING CURRENT CYCLES.

When a waveform of an A.C. voltage or current passes through a complete set of positive and negative values, it completes a "Cycle."

A.C. current first rises to a maximum and falls to zero in one direction then rises and falls to zero in the opposite direction. This completes a cycle of A.C. current, and thecycle repeats itself as long as the current flows.

So A.C. voltage first rises to a maximum and falls to zero in one polarity, then rises to a maximum and falls to zero in the opposite polarity to complete a cycle. Every complete set of both positive and negative values of either voltage or current forms a cycle.

A CYCLE IS A COMPLETE SET OF POSITIVE AND NEGATIVE VALUES




It will be seen on future pages how the voltage and current cycles are produced from an A.C. generator.

FREQUENCY.

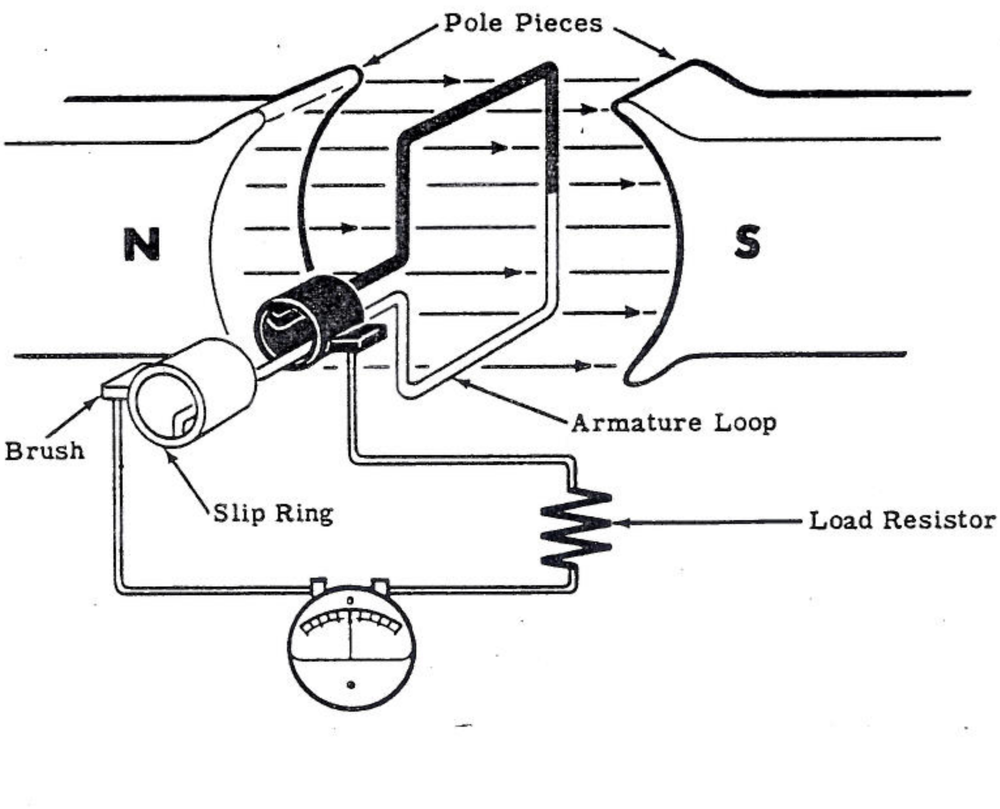
Frequency is the amount of cycles completed in 1 second (cycles per second) or as is more common Hertz (Hz.)

ELEMENTARY GENERATOR CONSTRUCTION.

When a wire moves in a magnetic field, electricity is produced within the wire. An elementary generator consists of a loop of wire placed so that it can be rotated in a uniform magnetic field to produce electricity in the loop. If sliding contacts are used to connect the loop to an external circuit, a current will flow round the external circuit and the loop.

The pole pieces are the north and south poles of the magnet which supplies the magnetic field. The loop of wire which rotates through the field is called the "Armature." The ends of the armature are connected to rings called "Slip rings," which rotate with the armature. Current collectors, which are called brushes, ride up against the slip rings to pick up the electricity generated in the armature, and carry it to the external circuit.

## THE ELEMENTARY GENERATOR




In the description that follows, visualise the loop rotating through the magnetic field. As the sides of the loop cut through the magnetic lines of force, they generate an E.M.F. which causes current to flow to the external circuitry.

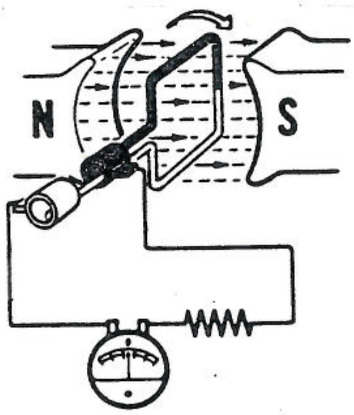
Assume that the armature loop is rotating in a clockwise direction, and and that it is in position 'A' (zero degrees).

In position 'A' the conductors of the loop are moving parallel to the magnetis field.

If a conductor is moving parallel to a magnetic field, it does not cut through any lines of force and no E.M.F. can be generated in the conductor.

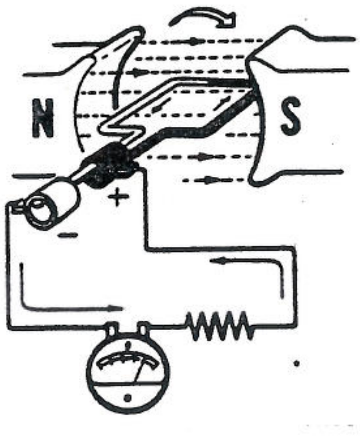
This applies to the conductors of the loop at the instant they go to position 'A'. - No E.M.F. is generated in them and, therefore, no current flows through the circuit. The ammeter is zero.

Position 'A'




As the loop rotates from positio 'A' to position 'B' the conductors are cutting through more and more lines of force, until at 90 degrees they are cutting through a maximum number of lines of force.

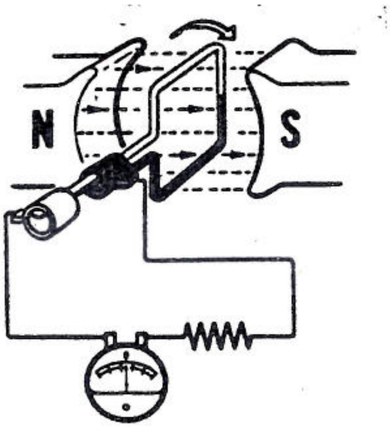
Position 'B'




Between zero and 90 degrees the E.M.F. generated in the conductors builds up to a maximum.
Note that as the black conductor cuts down through the field, the white conductor cuts up through the field.

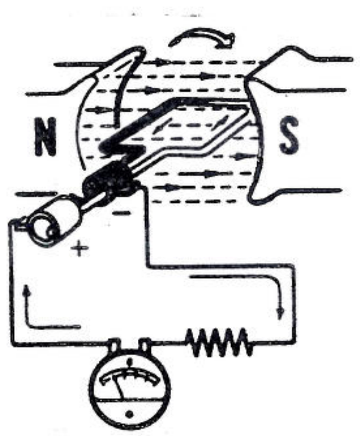
As the loop continues rotating from position 'B' (90 degrees) to position 'C' (180 degrees), the conductors which are cutting through a maximum number of lines of force at position 'B' cut through fewer lines of force, until, at position 'C' they are moving parallel to the magnetic field and no longer cut through any lines of force. The generated E.M.F., therefore, will decrease whilst the loop moves from 90 degrees to 180 degrees in the same manner as it increased from zero to 90 degrees, the currnt flow will similarly follow the voltage variations.

Position 'C'



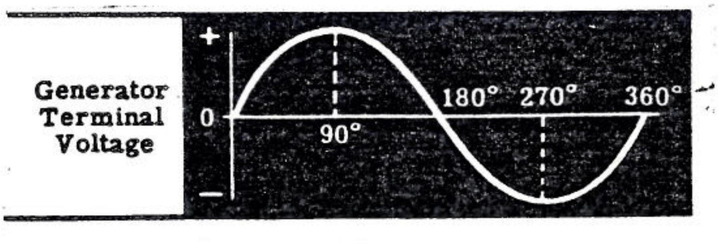

From position 'C' the loop continues to rotate to position 'D' (270 degrees). It should be noted that the black conductor is now beginning to cut up through the lines of force, opposite to that from positions 'A' to 'B'. Because the conductor is travelling through the lines of force in the opposite direction, the E.M.F. generated in the conductors will also be reversed in polarity. A similar effect, of course, is caused in the white conductor. The generator terminal voltage will be the same as it was from 'A' to 'C', except for its reversed polarity.

Position 'D'




The generated E.M.F. is said to be 'Induced' into the loop by the relative motion of the conductors and the magnetic field.

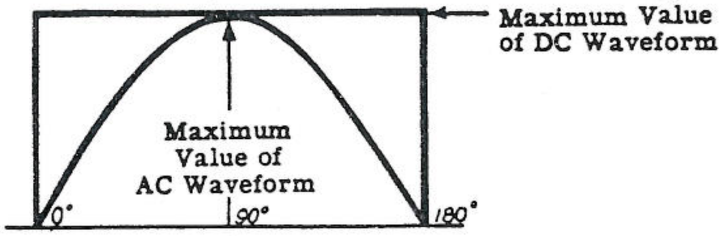
The voltage output waveform for the complete revolution of the loop is shown below.



MAXIMUM AND PEAK - TO - PEAK VALUES OF A SINE WAVE.

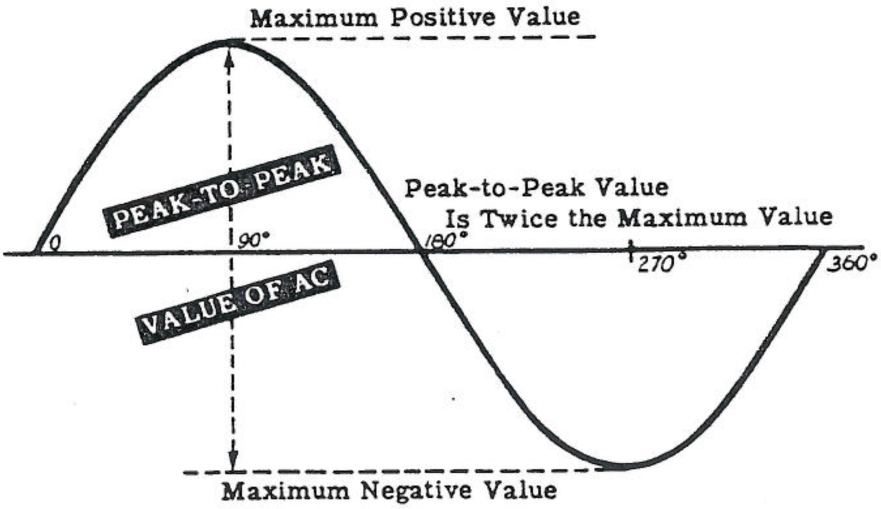
When comparing a half cycle of A.C. to that of the waveform of D.C. for the same period of time, it will be noted that the D.C waveform is at a maximum for the total length of time that current flows. The A.C. half cycle is only at maximum for a fraction of the time. It is only at this point the D.C. and A.C. values are equal.

## COMPARISON of DC and AC WAVEFORMS




In every complete cycle of A.C. there are two maximum or peak values, one for the positive half cycle and one for the negative half cycle. The difference between the peak positive and the peak negative values is called the peak - to - peak value of a sine wave. This value is twice the maximum or peak value of the sine wave, and is sometimes used for measurement of A.C. voltages.

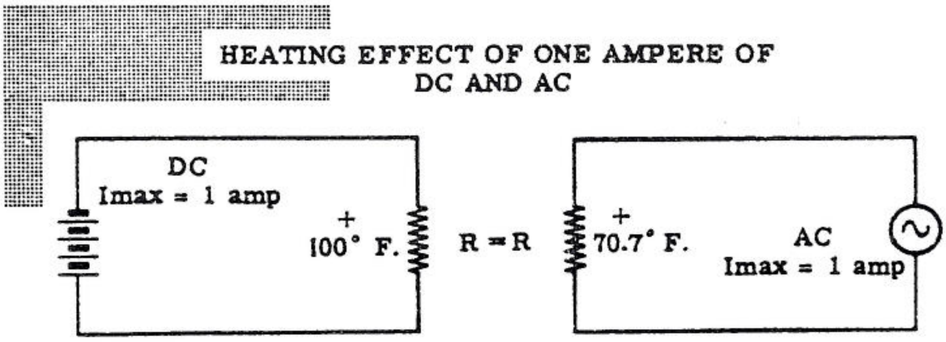
Usually, however, A.C. voltages and currents are expressed in r.m.s. (a term you will find out about later), rather than in peak - to - peak values.



## R.M.S. VALUE OF A SINE WAVE.

If a direct current flows through a resistance, the resulting energy converted into heat equals $I^2R$, or $E^2/R$ in watts. An alternating current with a maximum value of 1 ampere is not however, expected to produce as much heat as a direct current of 1 ampere, as alternating current does not maintain a constant value.

The rate at which heat is produced in a resistance forms a convenient basis for establishing an effective value of alternating current, and is known as the "heating effect" method. If a direct current of 1 ampere is passed through a resistor and raises its temperature by 100° F, an an alternating current of peak value 1 ampere and of sinusoidal waveform would raise the temperature of a similar resistor by only 70·7° F. If you compare the heating effect of these two currents, you get a means of establishing the effective value of the alternating current.




You can see that the alternating current is only 0·707 as effective as a direct current equal in value to the A.C peak value. In other words:

$$I_{eff} = 0 \cdot 707 I_{max}$$

An alternating current is said to have an effective value of 1 ampere when if will produce heat in a given resistance at the same rate as does 1 ampere of direct current. The peak value of such an alternating current would be 1·414 amperes.

The name more usually given to the effective value of an A.C. current is "r.m.s. value." Therefore,

$$I_{r.m.s.} = 0 \cdot 707 I_{max}$$

or

$$I_{r.m.s.} = I_{max}/\sqrt{2}$$

To calculate ;

Peak- to -Peak to r.m.s. ...........~~Divide by 2 x 0·707~~ THEN P to P x·707 / 2

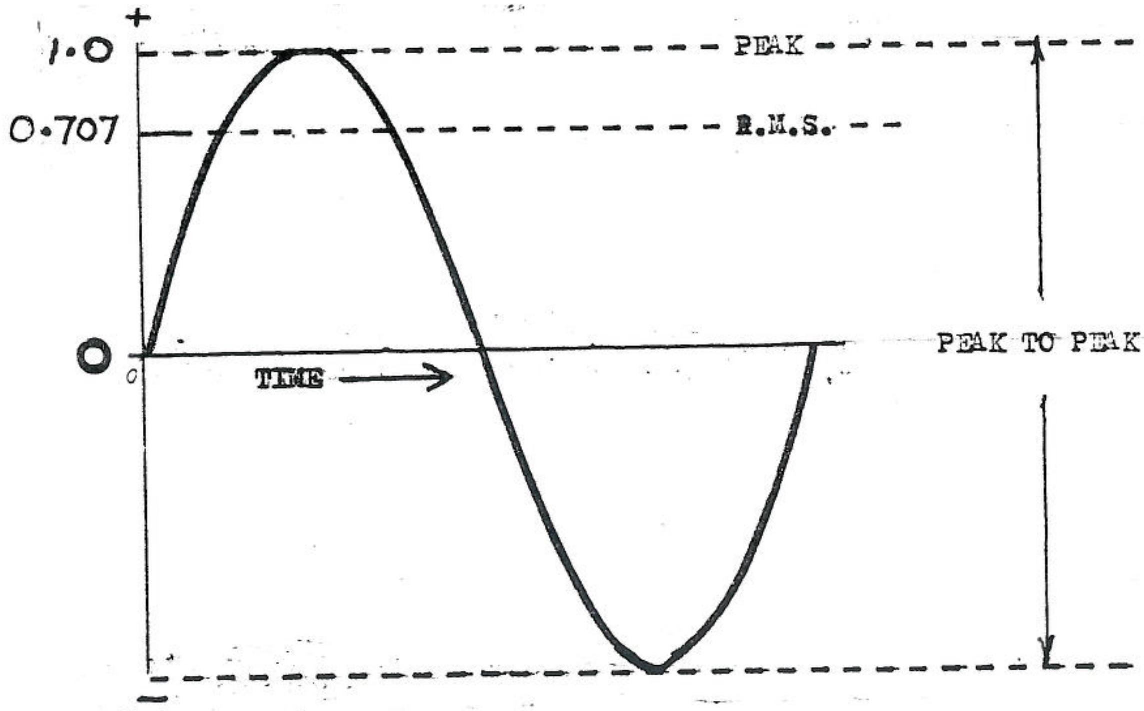
Peak to r.m.s. ....................Multiply by 0·707

r.m.s. to Peak ....................Multiply by 1·414

r.m.s. to Peak-to- Peak ...........Multiply by 2·828

WHEN A,C, VALUE IS SPECIFIED, IT IS ALWAYS THE R.M.S. VALUE THAT IS MEANT, UNLESS OTHERWISE STATED.

ALL METERS READ R.M.S. (UNLESS OTHERWISE STATED)



British Rail

Course E.P. 2.

Section Five.

Content Wavelengths.

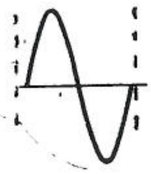
R.S. & T. E. Department

Training School York

## WAVELENGTHS.

A wavelength is the distance from the commencement of an A.C. cycle to its completion, measured in meters. The length of a wave is determined by the frequency at which it is being transmitted.

1 Wavelength



Measured in meters

Fundamentally, there is no difference between signals produced electro-magnetiacally, (e.g. radio or radar), and light waves, except that light waves are much shorter and therefore have a much higher frequency.

When all types of electromagnetic radiation are arranged in order of their wavelength, the result is called the elctromagnetic spectrum.

A table showing the electromagnetic spectrum is shown overleaf.

Notice how broad this range is: from long electrical oscillators with wavelengths measuring thousands of kilometers to cosmic rays with wave-lengths in trillionths of a meter.

(Human speech for example has a frequency range of between 300 Hz and 3·4 KHz.)

Like other electromagnetic waves, light travels through free space (that is, a vacuum) at the fantastic speed of 300,000,000 ($3 \times 10^8$) meters per second. Light travelling in the atmostphere moves slightly slower than this, but the figure of $3 \times 10^8$ m/s is still sufficiently accurate.

For transmission in free space and in the atmosphere, the speed of light is the same for all wavelengths; however, in other materials, such as water and glass, different wavelengths travel at different speeds. Regardless of the wavelength, when light travels through such materials, its speed is noticeably reduced.
The symbol for wavelength is:- $\lambda$

## CALCULATION OF WAVELENGTH.

$$\text{WAVELENGTH} = \frac{\text{Speed of light}}{\text{cycles per second}} \quad \text{or} \quad \frac{\text{300,000,000 meters per second}}{\text{Frequency (In Hz.)}}$$

e.g. To find the wavelength of 1,000,000 Hz.

$$\text{Wavelength } (\lambda) = \frac{300{,}000{,}000}{1{,}000{,}000} = 300 \text{ meters.}$$

This calculation may also be expressed as follows:-

$$\text{Wavelength } (\lambda) = \frac{300}{1} = 300 \text{ meters.}$$

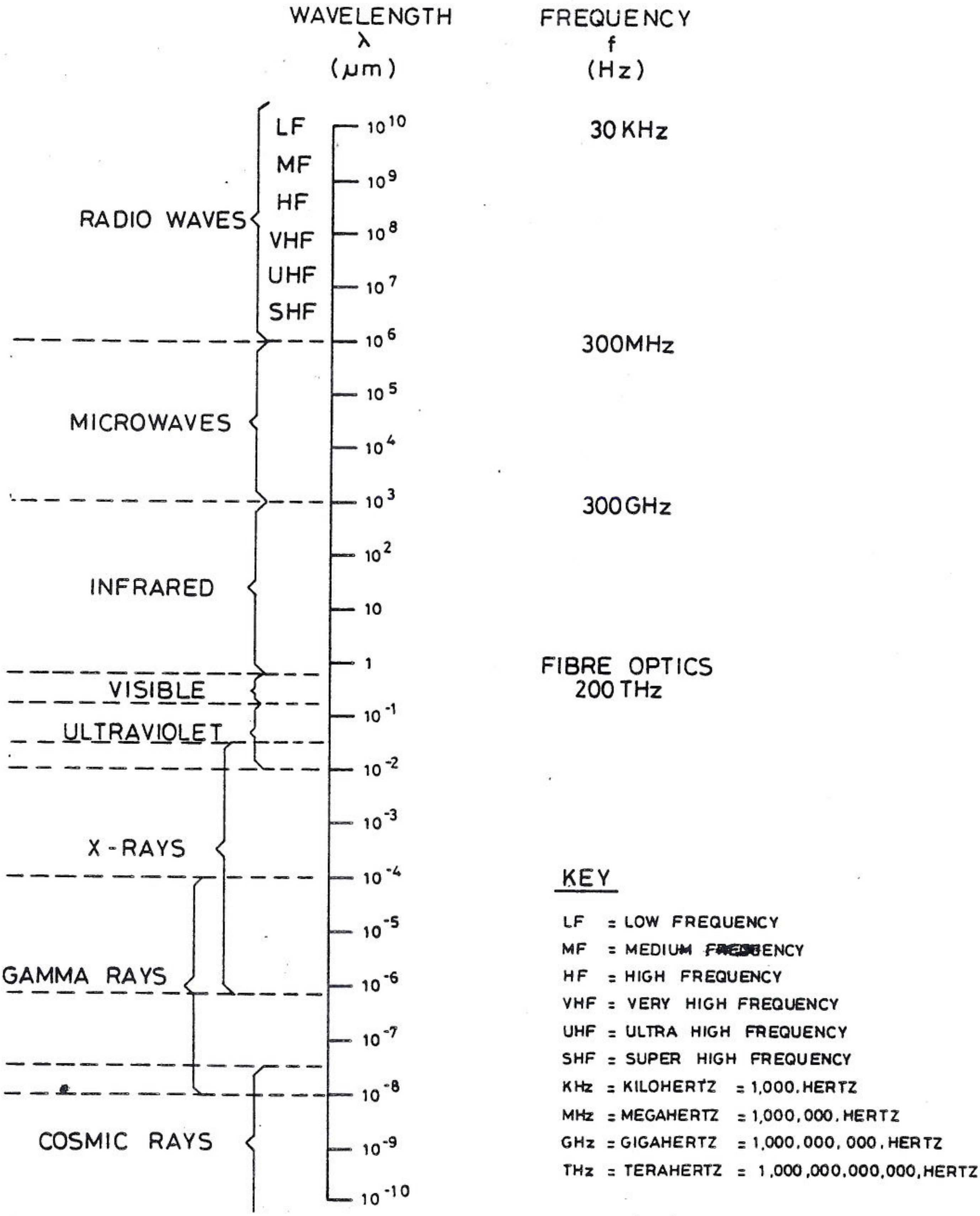
## PERIODIC TIME.

(Time taken for one complete cycle).

$$\text{Periodic Time} = \frac{\text{1 second}}{\text{Frequency}}$$

e.g. To find periodic time for 1 KHz.

$$\frac{\text{1 Second}}{1000} = \cdot 001 \text{ Second}$$ ( 1 Thousandth of 1 second)




ELECTROMAGNETIC SPECTRUM

British Rail

Course E.P. 2.

Section SIX.

Content Inductance.
Inductance Symbols.
Inductive Time Constant.
Inductive Reactance.
Inductance in Series and Parellel.

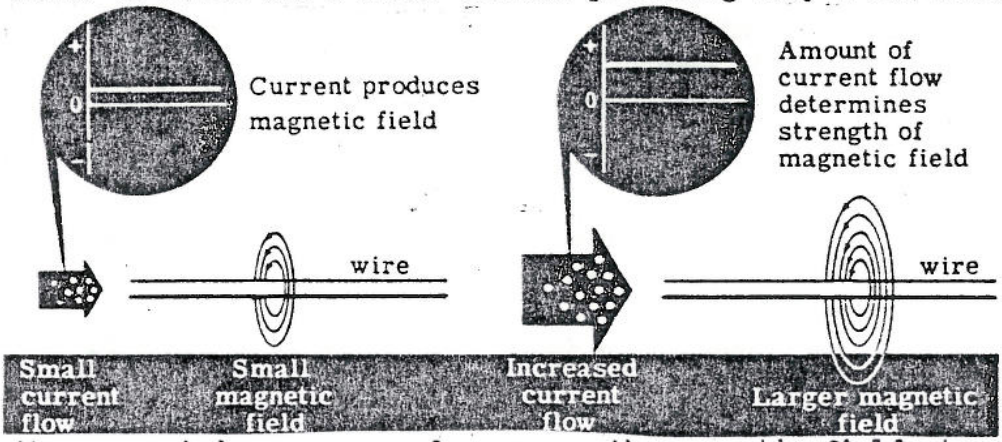
R.S. & T.E. Department

Training School York

## INDUCTANCE.

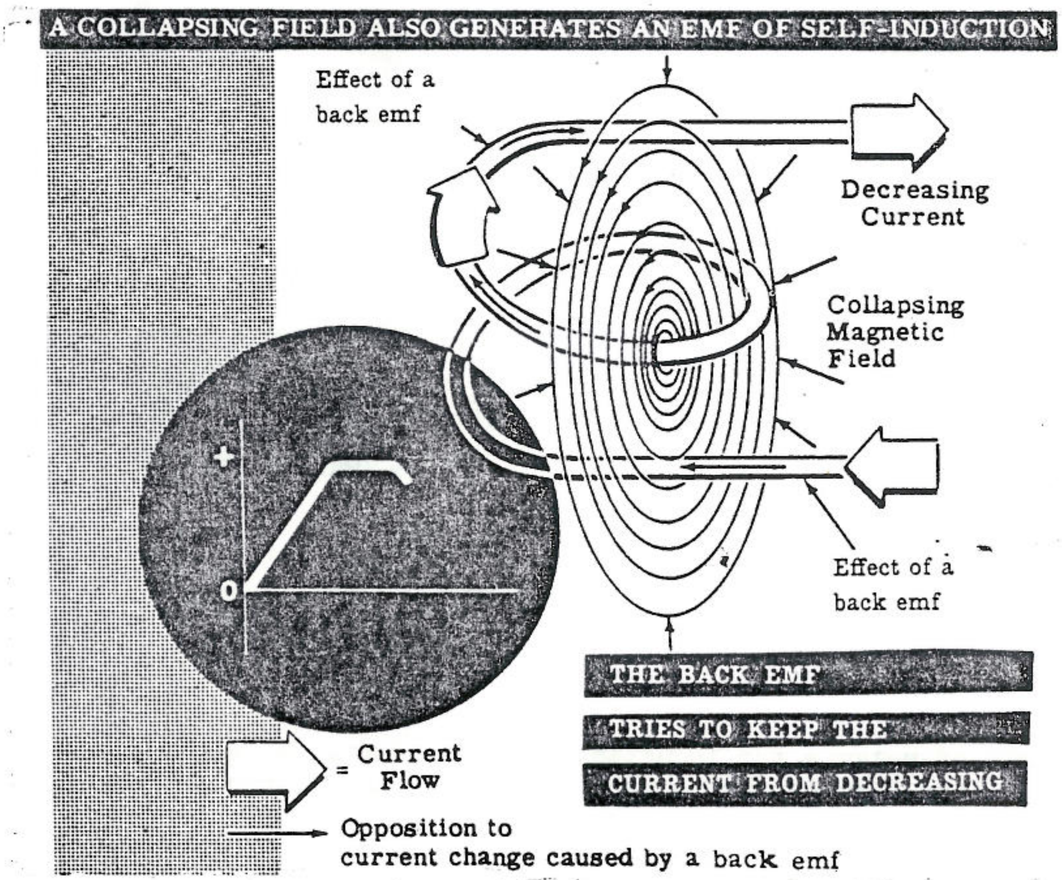
When current in an electrical circuit changes, the circuit opposes the change. The property of the circuit which opposes the change is called "Inductance."

An electric current always produces a magnetic field. The lines of force in this field encircle the conductor which carries the current, forming concentric circles around the conductor. The strength of the magnetic field depends on the amount of current flow, with a large current producing many lines of force and a small current producing only a few lines of force.




When the current increases or decreases, the magnetic field strength increases or decreases in the same direction. As the field strength, the lines of force increase and expand outwards from the centre of the conductor. Similarly, when the field strength decreases the lines of force contract towards the centre of the conductor.

This expansion and contraction of the magnetic field as the current varies causes an E.M.F. of self-inductance, or back E.M.F. which opposes any further change of current.



INDUCTANCE SYMBOLS.

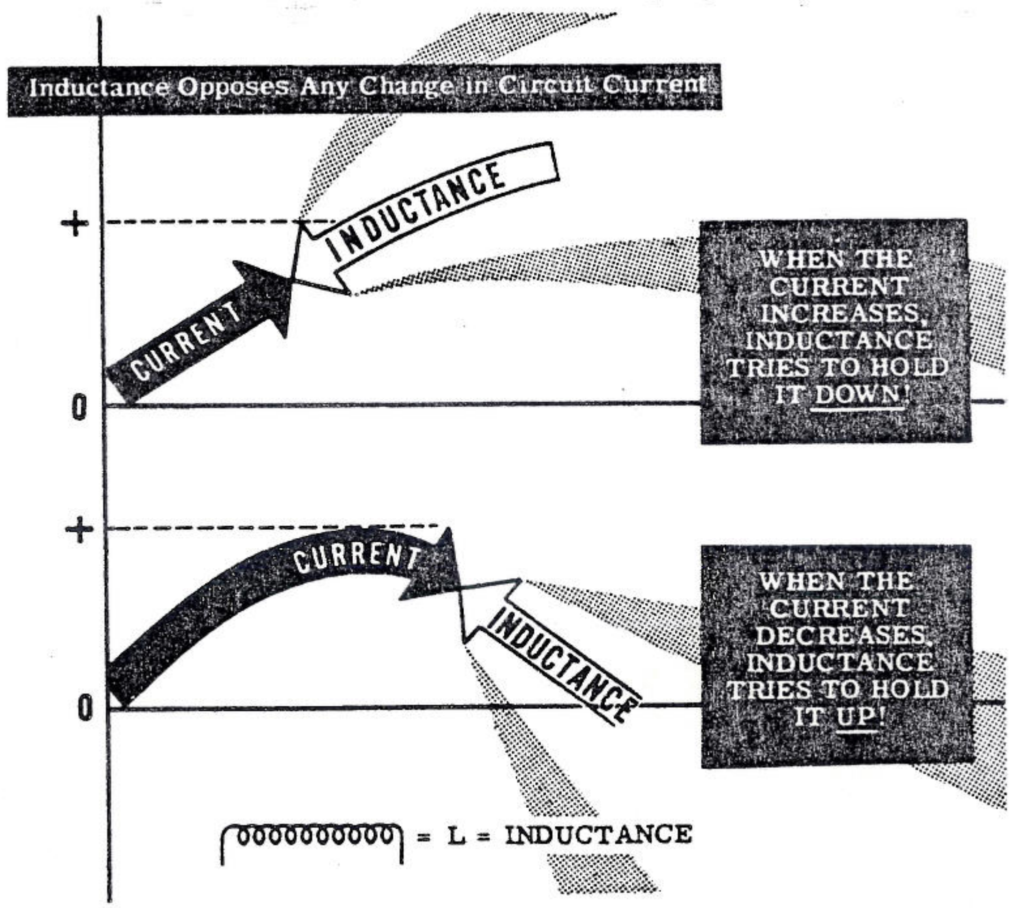
Although you cannot see inductance, it is present in every electrical circuit, and has an effect on the circuit whenever the circuit current changes.

In electrical formulas the letter L is used as a symbol to designate inductance. Because a coil of wire has more inductance than a straight length of the same wire, the coil is called an "inductor".

Since direct current is normally constant in value except when the power is turned on and off to start and stop the current flow, inductance affects D.C. current flow at these times, and usually has very little effect on the operation of the circuit. Alternating current, however, is continuously changing, so that the circuit inductance affects A.C. current flow at all times.

Although every circuit has some inductance, the value of the inductance depends on the physical construction of the circuit, and on the electrcal devices used in it.

In some circuits the inductance is so small that its effect is negligable, even when the current flowing is A.C.

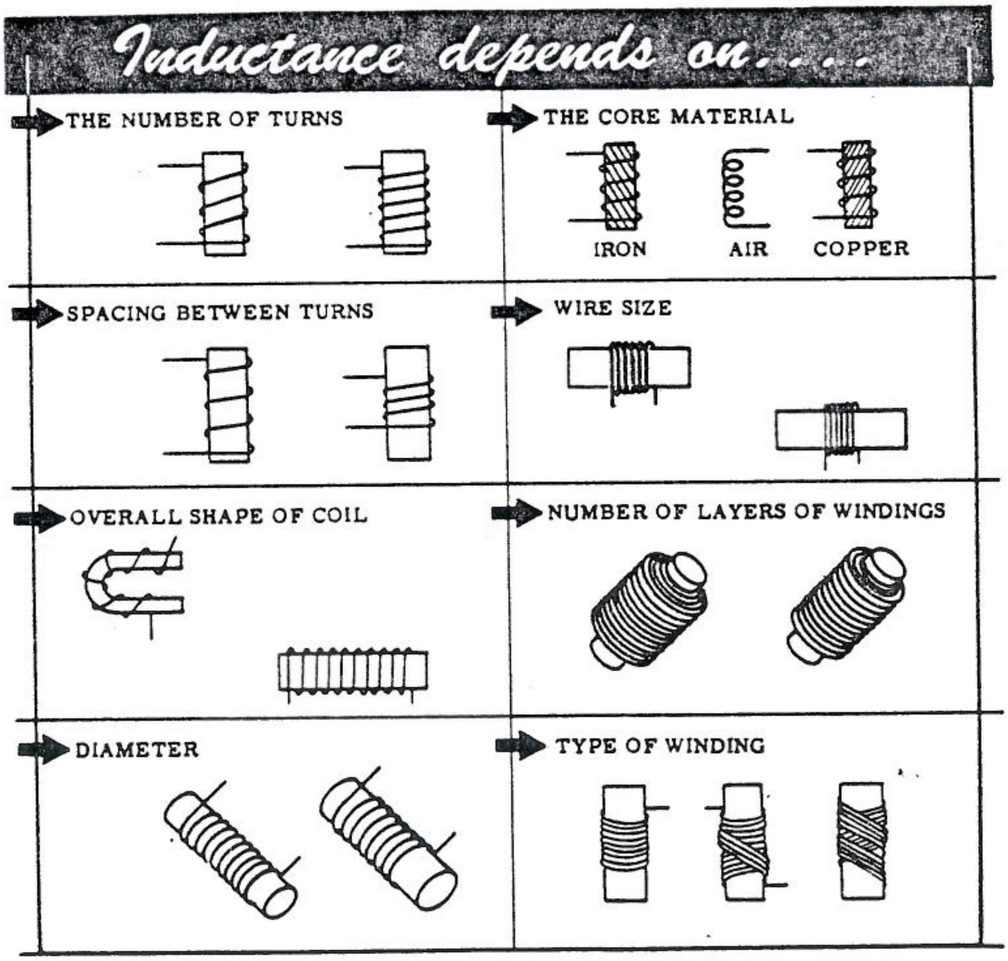



The basic unit of measure for inductance is the henry. For quantities of inductance smaller than one henry, the millihenry and microhenry are used.

A circuit has an inductance of one henry when the back E.M.F. induced in it is one volt when the current changes at a rate of one ampere per second.

Inductance can only be measured with special instruments and depends entirely on the physical construction of the circuit. Some of the factors most important in determining the amount of inductance of a coil are; the number of turns, the spacing between turns, coil diameter, kind of material around and inside the coil, the wire size, number of layers of wire, type of coil winding and the overall shape of the coil. Wire size does not affect the inductance directly, but does determine the number of windings that can be used in a given space.

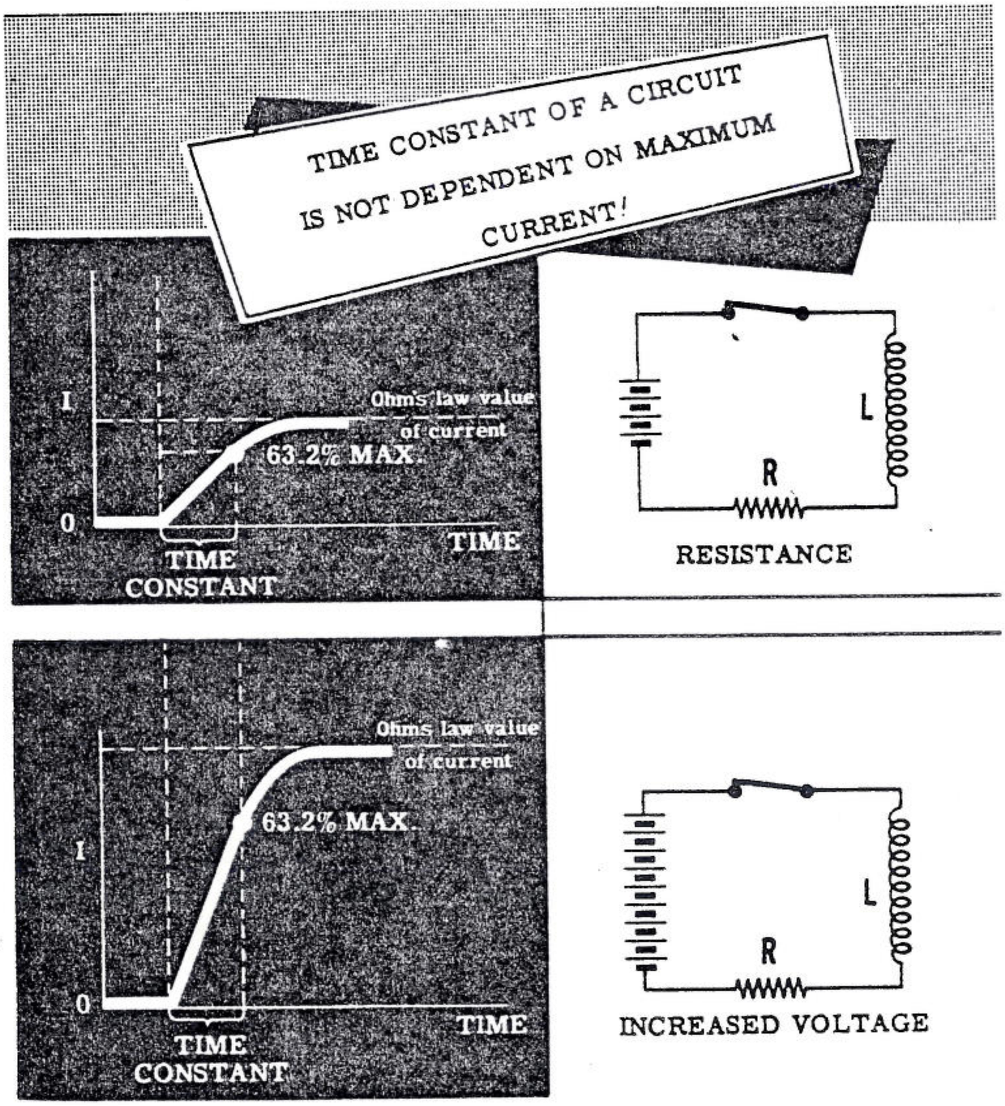
All these factors are variable, and no single formula can be given to find inductance. Many differently constructed coils could have an inductance of one henry, and each would have the same effect on the circuit.



The time constant of a given inductive circuit is always the same for both the build-up and the decay of the current. If the maximum current value differs, the curve may rise at a different rate; but it will reach its maximum in the same amount of time, and the general shape of the curve will be the same.

Thus, if a greater voltage is used, the maximum current will increase; but the time required to reach the maximum will be unchanged.

Every inductive circuit has resistance, since the wire used in a coil always has resistance. Thus a perfect inductance — an inductor with no resistance — is not possible.



INDUCTIVE REACTANCE. (D.C.)

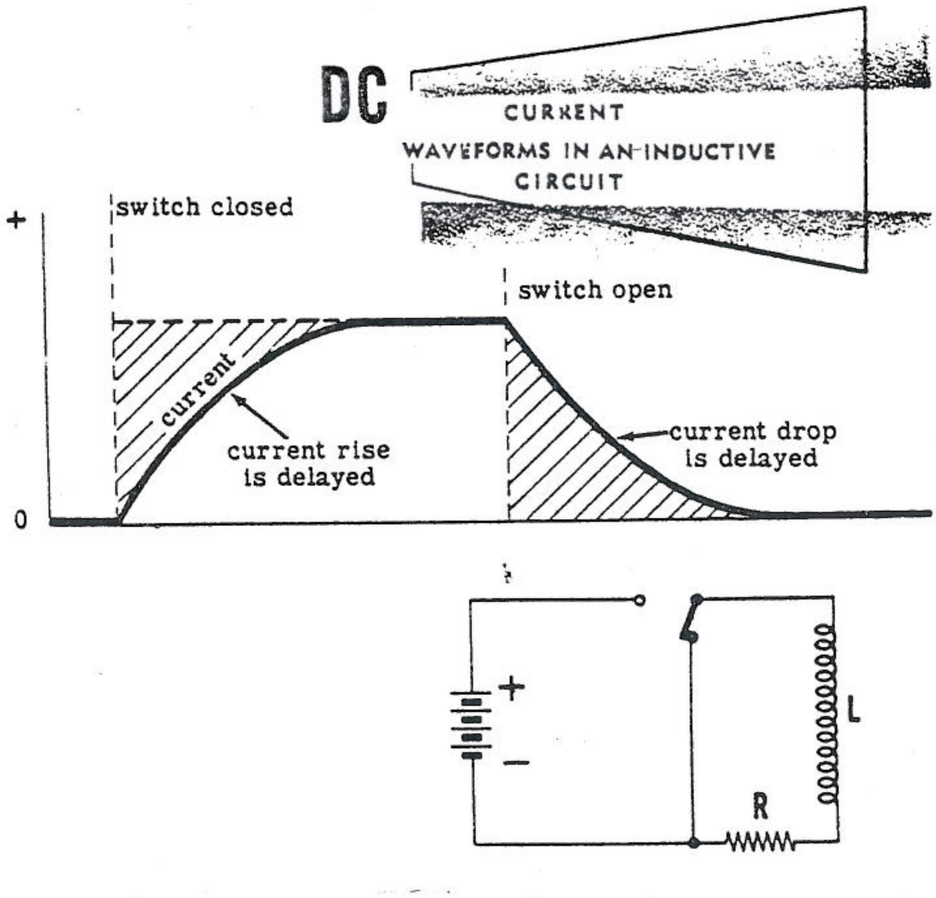
Inductive reactance is the opposition to current flow offered by the inductance of a circuit. (Resistance to A.C.)

As you know, inductance only affects current flow while the current is changing, since the current change generates an induced E.M.F. With a direct current, the effect of inductance is noticeable only when the current is turned on and off; but with alternating current (since A.C. is continuously changing) a continuous induced E.M.F. is generated.

Suppose you consider the effect of a given inductive circuit on D.C. and A.C. waveforms. The time constant of the circuit is always the same, determined only by the resistance and inductance of the circuit.

For D.C. the current waveforms would be as shown below. At the beginning of the current waveform, there is a shaded area between the maximum current current value and the actual current flow which shows that inductance is opposing the change in current as the magnetic field builds up. Also, at the end of the current waveform, a similar area exists showing that the current flow continues after the voltage drops to zero, because of the field collapse.

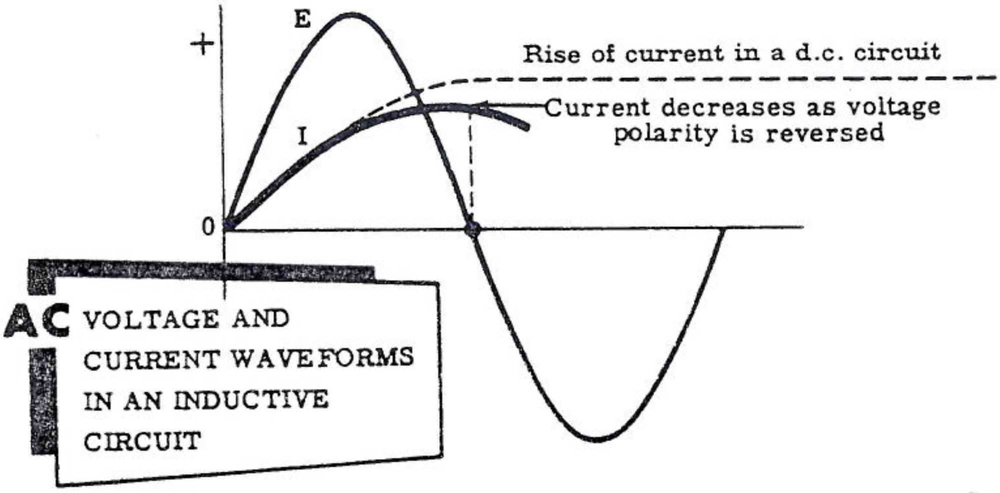
These shaded areas are equal in area, proving that the energy used to build up the magnetic field is given back to the circuit when the field collapses.



**INDUCTIVE REACTANCE.** A.C.

The same inductive circuit would affect an A.C. current waveform during its first half-cycle, in the same manner shown below. When the switch is closed, the current rises as the voltage rises; but there is a delay because of the inductance present. This delay prevents the current from attaining the value it reached in the D.C. circuit; because, before it can attain this value, the voltage reverses its polarity.

It follows that, in a circuit containing indutance, a D.C. voltage will produce a greater current than will an equivalent A.C. voltage.

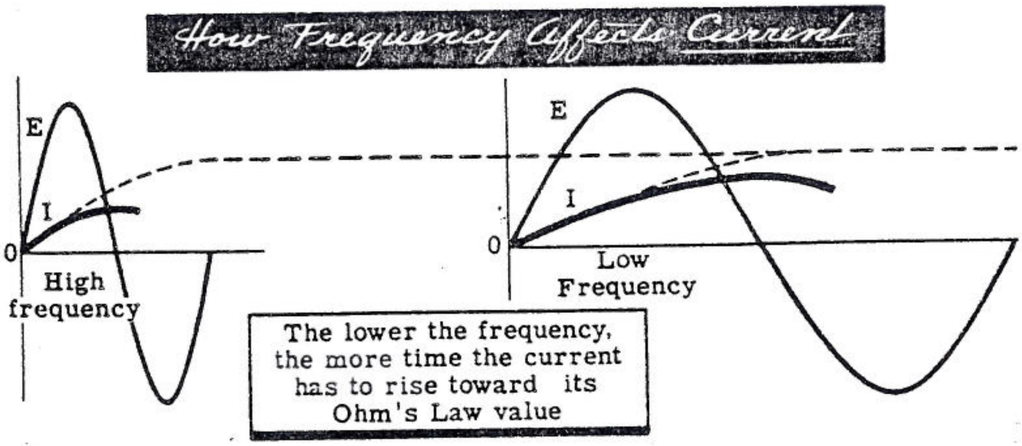



If the frequency of the applied A.C. is low, the current will have more time to reach a higher value before the polarity reverses than it would have if the frequency were high. Thus, the higher the frequency, the lower the current through an inductive circuit.

Inductive reactance is the opposition offered by an inductance to current flow. It depends not only on inductance, but also on frequency.

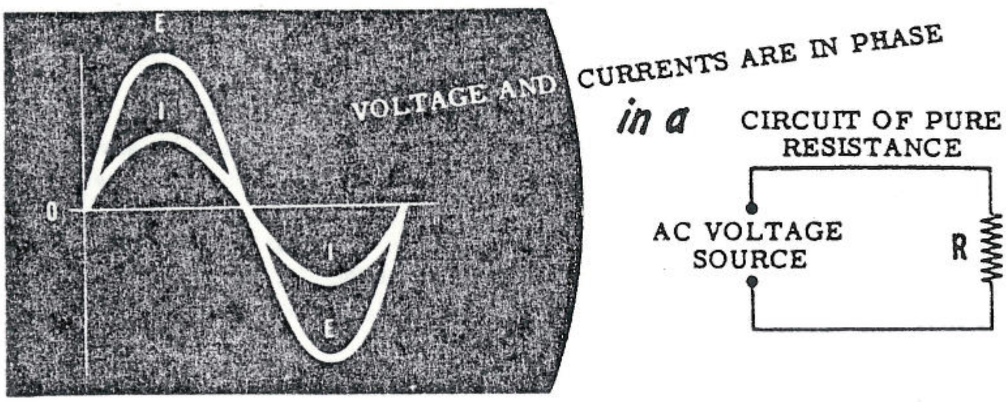
The formula used to find inductive reactance is $X_L = 2\pi fL$, where $f$ is the frequency in cycles per second, L the inductance in henries, and $\pi$ a constant number (3·14).

Since $X_L$ represents opposition to current flow, it is expressed in ohms.




INDUCTIVE REACTANCE $(X_L) = 2\pi fL$ OHMS.

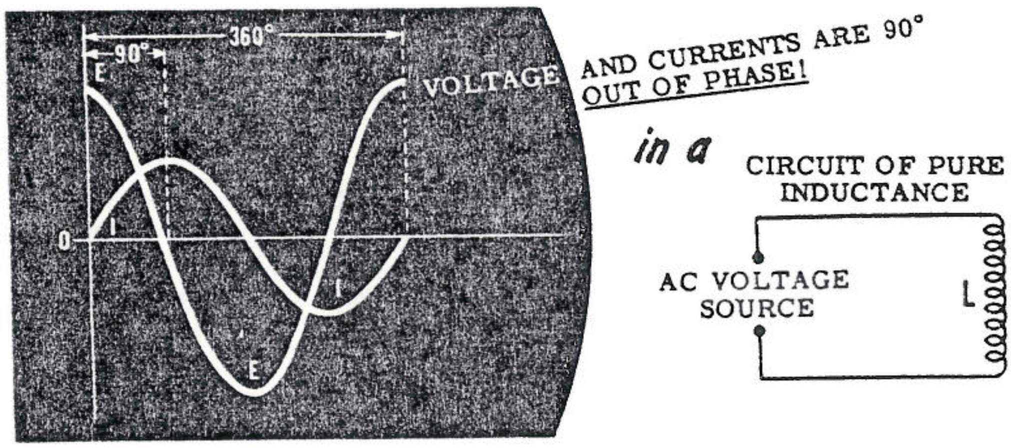
If an A.C. circuit has only pure resistance, the current rises and falls at exactly the same time as the voltage, and the the two waves are said to be in phase with each other.



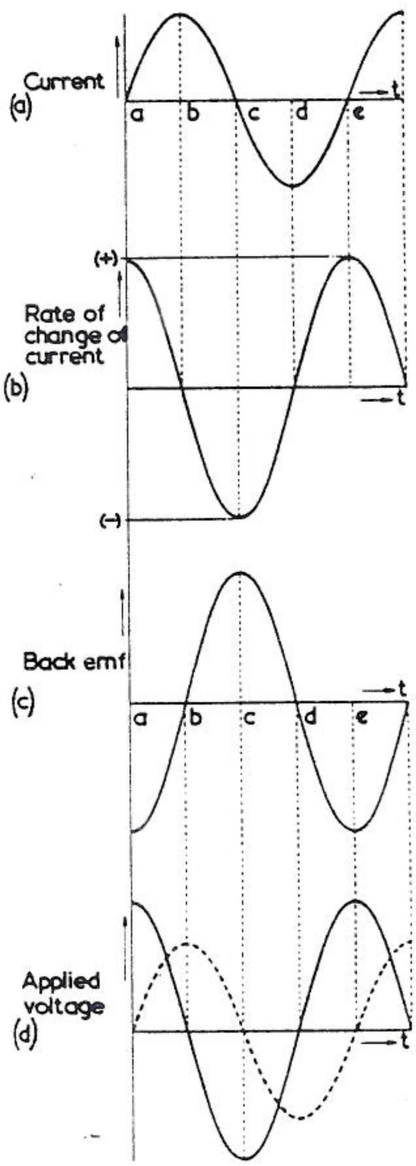

If an A.C. circuit contains only pure inductance, the current does not rise and fall at exactly the same time as the voltage. Instead, it rises to a maximum a quarter cycle later than does the voltage; and it remains a quarter of a cycle behind at all points in the cycle.

In other words, current and voltage are "out of phase" by an angle of 90°; and the current is said to "lag" the voltage by 90°.

Since all practical circuits do contain resistance, however, the current never lags the voltage by as much as 90°, but by a lesser angle whose value depends on the relation between the amount of inductance in the circuit and the amount of resistance in it.



We can see how the current lags behind the voltage if we suppose that the inductor (L) in the diagram on the previous page has no resistance, and consider the effect of the alternating current through it.




First draw the waveform of the current through the coil—curve (a). We know that this alternating current induces a back-e.m.f. in the coil which is greatest when the current is changing most rapidly and least when the current is changing slowly. If we plot a graph of the rate of change of current we can see when the back-e.m.f. is greatest and when it is least.

If you examine the current waveform (a) you can see that at point "a" the current is changing very rapidly in the positive direction. At point "b" it is changing slowly and crossing over from the positive direction (increasing) to the negative direction (decreasing). At the point "c" the current is again changing very rapidly but this time in the negative direction. By thus noting the change of rate of current as indicated by curve (a) you can draw a curve showing the rate of change of current—curve (b).

You know that the back-e.m.f. induced by the alternating current is a maximum when the rate of change of current is a maximum, and that it is of such polarity that it always opposes the change of current. From curve (b) we can therefore deduce the waveform of the back-e.m.f.; and this is drawn at curve (c).

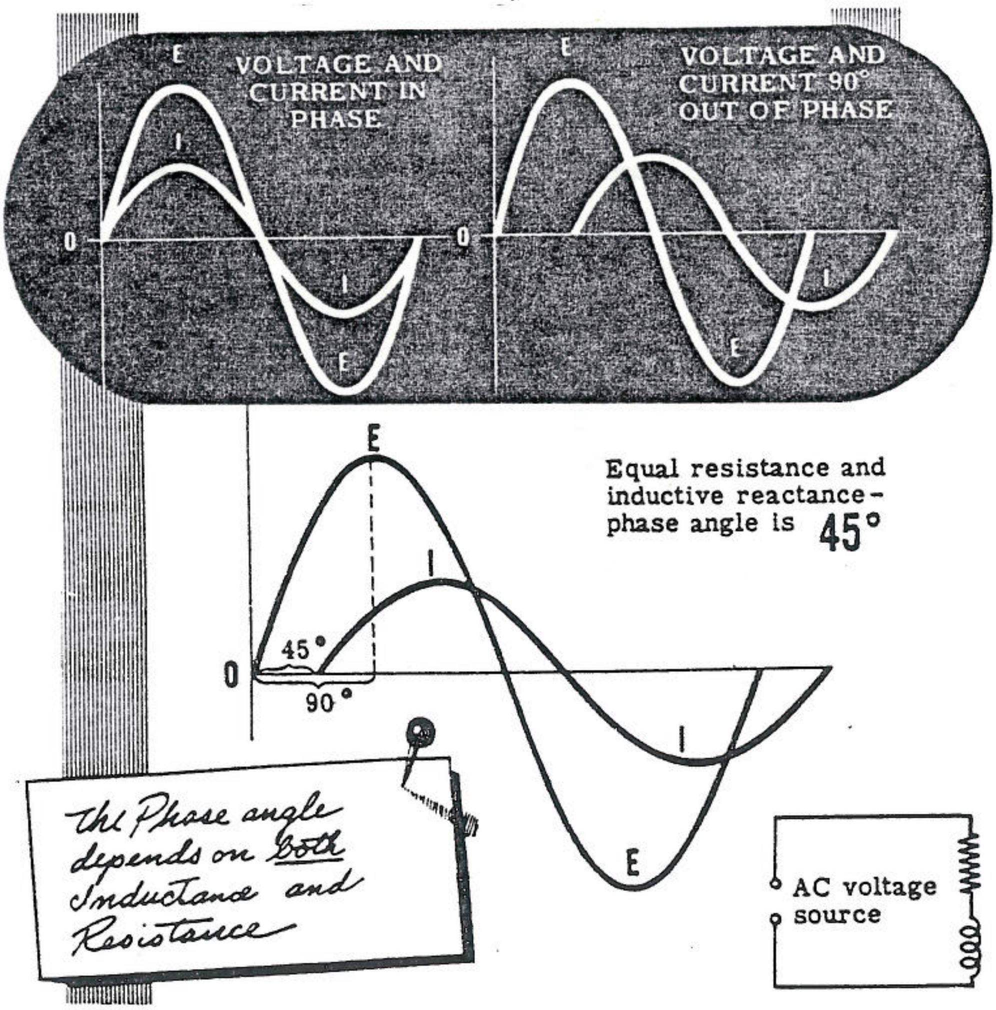
Now it is obvious that, for any current to flow at all, this back-e.m.f. must be more than overcome by the applied e.m.f. It follows, therefore, that the applied e.m.f. must always be of opposite phase to the back-e.m.f., and of greater magnitude.

The waveform for the applied E.M.F. is shown at curve (d) and current waveform is shown dotted for comparison. You see that current reaches its maximum 90 degrees later than the voltage – that is, it lags the voltage by 90 degrees.

In a circuit containing both inductive reactance and resistance, the A.C. current wave will lag the voltage wave by an amount between zero degrees and 90 degrees; or, stated otherwise, it will lag somewhere between "in phase" and "90 degrees out of phase." The exact amount of lag depends on the ratio of circuit resistance to inductance - the greater the resistance compared to the inductance, the nearer the two waves are to being "in phase"; and the lower the resistance compared to the inductance, the nearer the waves are to being a full quarter cycle (90 degrees) "out of phase." When stated in degrees the current lag is called the "phase angle."

The phase angle can be calculated using the formula $\tan \phi = X_L/R$, where $\phi$ is the phase angle.

If the phase angle between the voltage and the current is 45 degrees lagging, it means that the current wave is lagging the voltage by 45 degrees. Since this is half - way between zero degrees - the phase angle for a pure resistive circuit - and 90 degrees - the phase angle for a pure inductive circuit - the resistance and the inductive reactance must be equal, with each having an equal effect on the current flow.

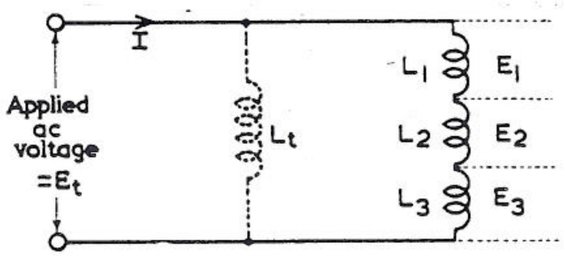


INDUCTANCES IN SERIES AND PARALLEL.

To calculate Inductances connected in series, add the total value of inductors together.

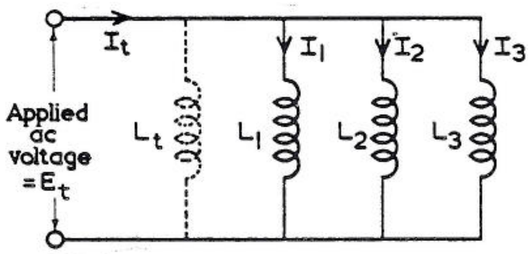
This is exactly the same as calculating resistances in series.

INDUCTORS IN SERIES.




$$L_t = L_1 + L_2 + L_3$$

To calculate Inductors in parallel is calculated as resistances in parallel.




$$\frac{1}{L_t} = \frac{1}{L_1} + \frac{1}{L_2} + \frac{1}{L_3}$$

British Rail

**Course** E.P. 2.

**Section** Seven.

**Content** Capacitors.

Units of capacitance.

Capacitors in series and parellel.

Electrolytic Capacitors.

Capacitive Time Constant.

Capacitive Reactance.

Capacitors in A.C. Circuits

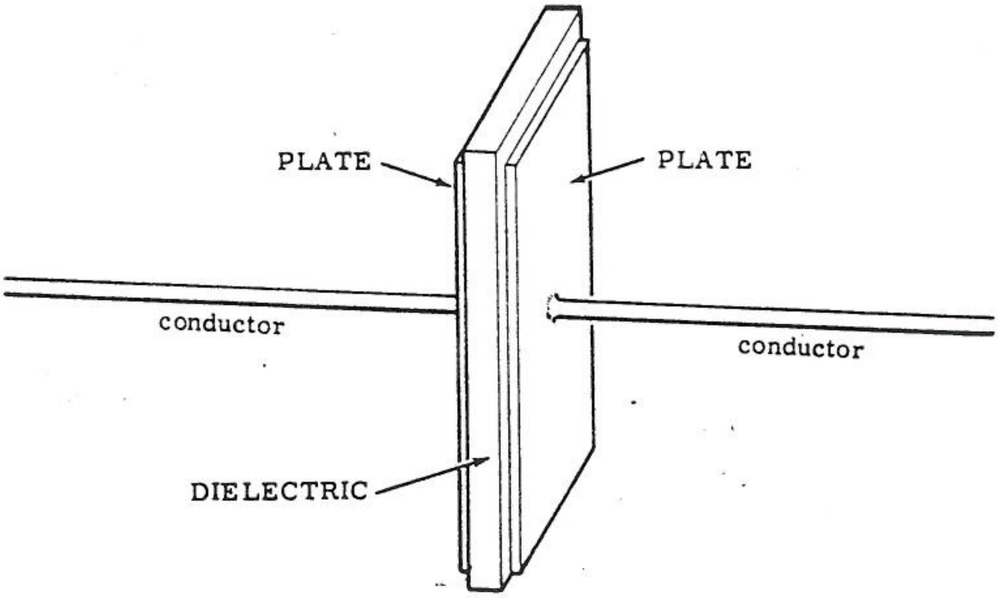
R.S. & T. E. Department

Training School York

CAPACITORS.

Basically, capacitors consist of two plates which can be charged - seperated by an insulating material called the "dielectric." While early capacitors were made with solid metal plates, newer types of capacitors use metal foil particularly aluminium foil, for the plates. Dielectric materials commonly used include air, mica and waxed paper.

**Capacitors CONSIST OF Two Plates AND THE Dielectric**



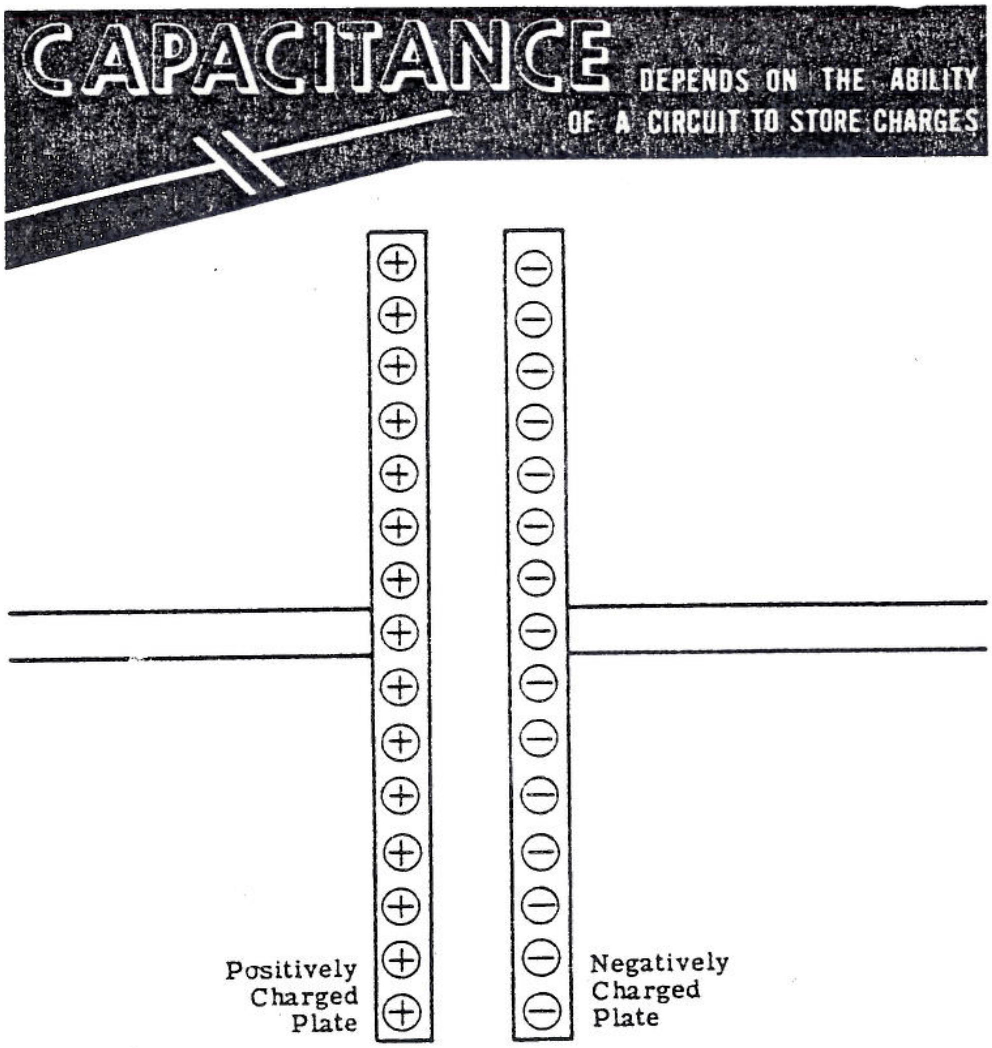

Plates are made of solid metal or metal foil.

Dielectric materials are: air, mica and waxed paper.

Three basic factors affect the capacitance of a capacitor - the area of the plates, the distance between the plates (thickness of the dielectric) and the material used for the dielectric.

Capacitance exists in an electric circuit because certain parts of the circuit can store electric charges.

Consider two flat metal plates placed parallel to one another, but not touching. The two plates can be charged either positively or negativly, depending on the charge which you transfer to them. If charged negatively, a plate will take extra electrons, but if charged positively it will give up some of its electrons. Thus the plates may have either an excess or lack of electrons.

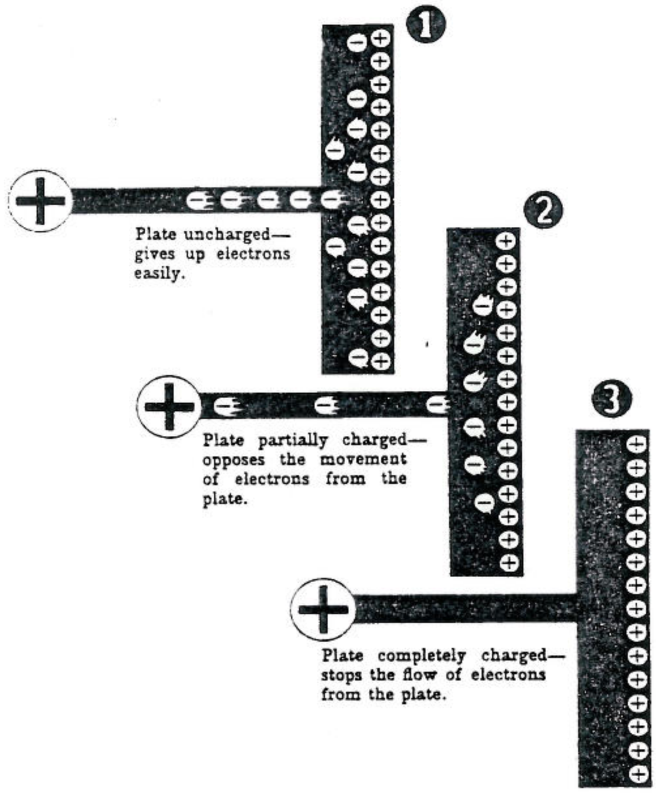


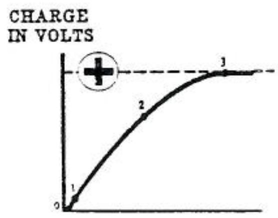

In order to charge the plates, an electrical force is required. The greater the charge to be placed on either plate, the greater electrical force required.

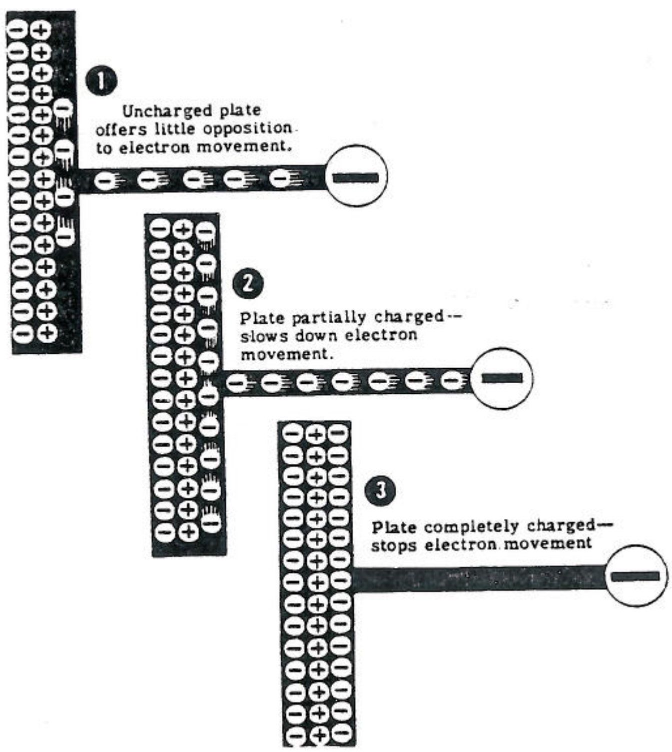
To charge a plate negatively, you must force extra electons on to it from a source of negative charge. The first few electrons go on to the plate but once there, they oppose or repel any other electrons which try to follow them. As more and more electrons are forced on to the plate, this repelling force increases, so that a greater force is required to move additional electrons. When the negative repelling force equals the charging force, no more electrons will move on to the plate.

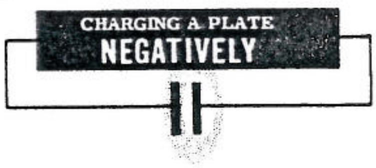
Similarly, as electrons are removed from a plate by the attraction of a positive charge, so the plate becomes more and more positively charged. The first few electrons leave quite easily; but, as more electrons leave, a strong positive charge builds up on the plate. This positive charge makes it more and more difficult for electrons to be pulled away.

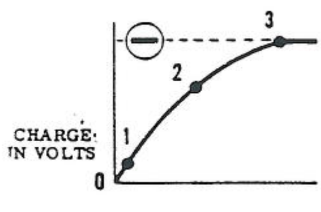
When this positive attracting force finally equals the charging force, no more electrons leave the plate.

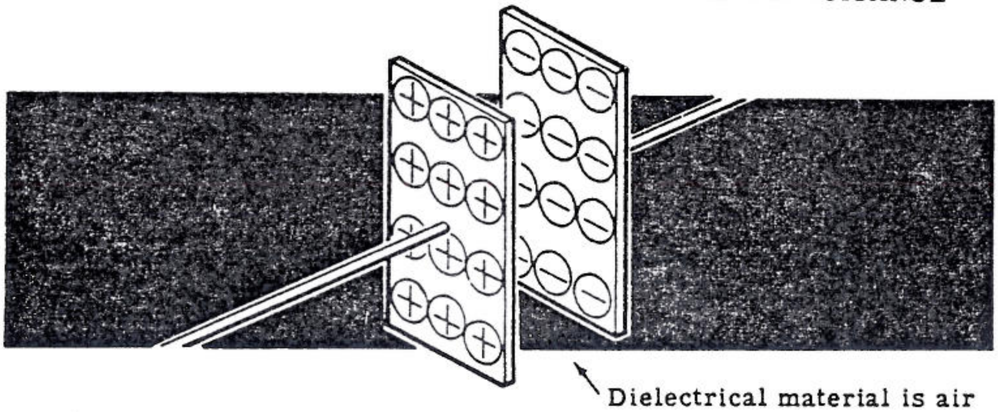



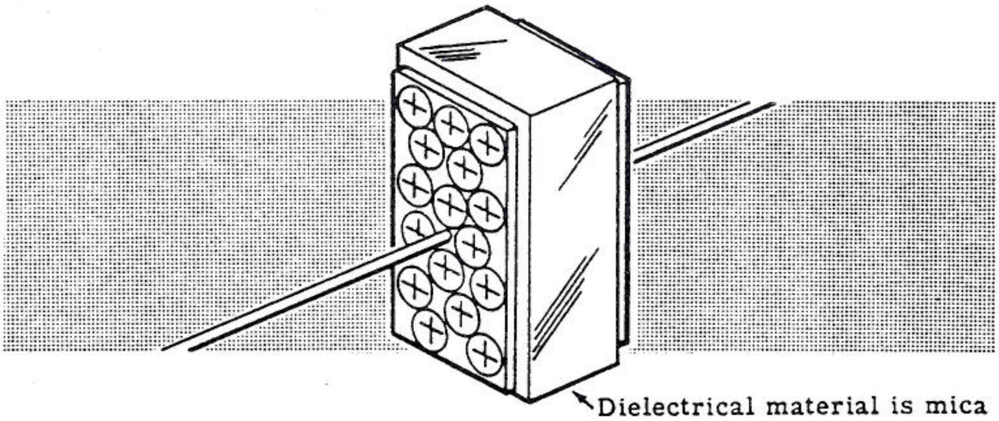



CHANGING THE *Dielectric* MATERIAL CHANGES THE CAPACITANCE



Dielectrical material is air



Dielectrical material is mica

**Mica dielectric increases the capacitance.**

Using the same plates fixed a certain distance apart, the capacitance will change if different insulating materials are used for the dielectric. The effect of different materials is compared to that of air - that is, if the capacitor has a given capacitance when air is the dielectric, other materials used instead of air will multiply the capacitance by a certain amount called the "dielectric constant."

For example some form of oiled paper have a dielectric constant of 3; and if such oiled or waxed paper is placed between the plates, the capacitance will be 3 times greater than it would be if the dielectric were air.

Different materials have different dielectric constants; and so will alter the capacitance when they are placed between the plates to act as the dielectric.

## UNITS OF CAPACITANCE.

The basic unit of capacitance is the farad. A capacitor has a capacitance of one farad when a charging current of one ampere flowing for one second causes a change of one volt in the potential between its plates.

The storage capacity of a farad is much too great to use as the unit of cap - acitance for practical electrical circuits. Because of this, the units normally used are the microfarad (μF), equal to one-millionth of a farad, and the micromicrofarad (pF ), equal to one-million-millionth of a farad. Since electrical formulas use capacitance stated in farads, you must be able to change the various units of capacitance to other units. Again the method of changing units is exactly like that used for canging units of voltage, current resistance, etc. To change to larger units, the decimal point moves to the left; while to change to smaller units, the decimal is moved to the right.

## CHANGING UNITS OF CAPACITANCE

MICROFARADS TO FARADS
Move the decimal point 6 places to the left
120 μF equals 0·000120 farad

FARADS TO MICROFARADS
Move the decimal point 6 places to the right
8 farads equals 8,000,000 μF

MICROMICROFARADS TO FARADS
Move the decimal point 12 places to the left
1500 pF equals 0·000000001500 farad

FARADS TO MICROMICROFARADS
Move the decimal point 12 places to the right
2 farads equals 2,000,000,000,000 pF

MICROMICROFARADS TO MICROFARADS
Move the decimal point 6 places to the left
250 pF equals 0·000250 μF

MICROFARADS TO MICROMICROFARADS
Move the decimal point 6 places to the right
2 μF equals 2,000,000 pF

**Symbols for Capacitance**

In electrical formulae the letter *C* is used to denote capacitance in farads. The circuit symbols for capacitance are shown below.

## CAPACITOR SYMBOLS


Fixed Electrolytic Variable Preset

The amount of charge stored depends on the capacitance and the voltage between the plates. e.g. the amount of electrons stored (Quantity)

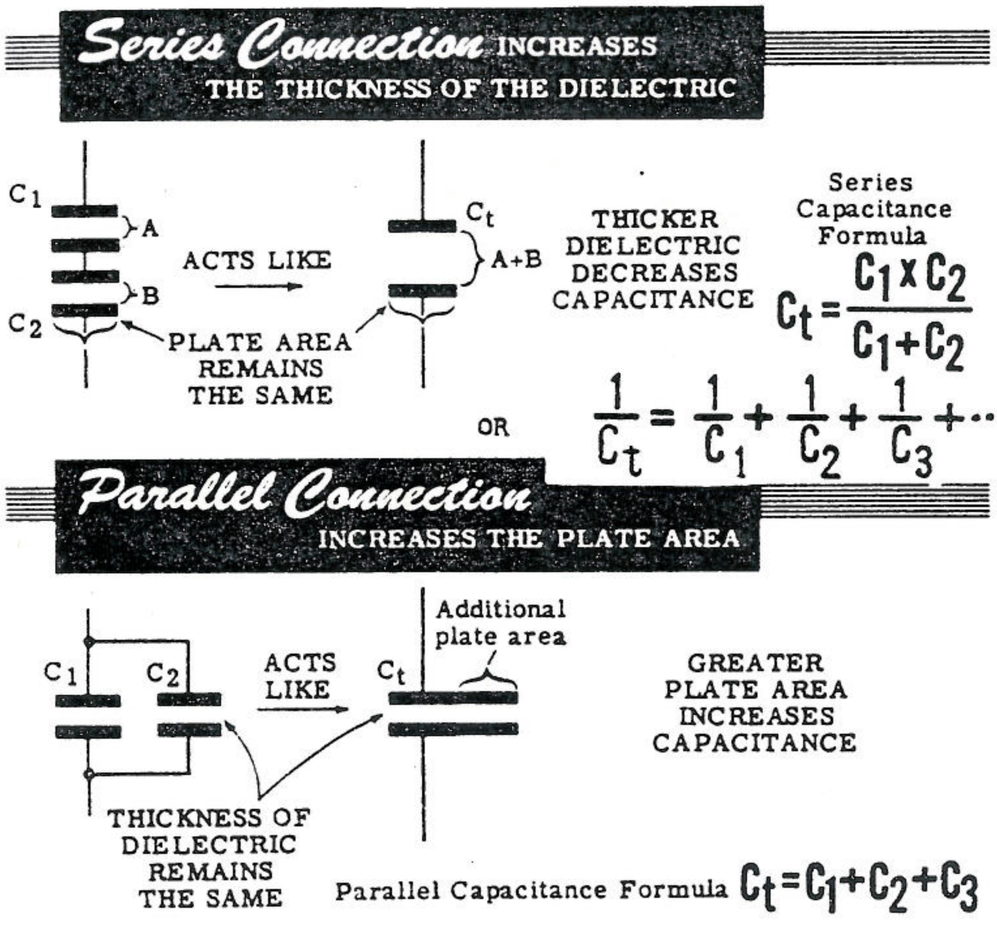
$$Q \text{ (Coulombs)} = V \text{ (Volts)} \times C \text{ (Farads)}.$$

CAPACITORS IN SERIES AND PARALLEL.

When connected in series or parallel, the effect on the total capacitance is opposite to that for similarly connected resistances.

Connecting resistors in series icreases the total resistance because it lengthens the resistance path through which current flows. But connecting capacitors inseries decreases the total capacitance, because it effectively increases the spacing between the plates.

To find the total capacitance of series connected capacitors, a formula is used similar to the formula for parallel resistances.




When resistors are connected in parallel, thetotal resistance decreases, because the cross section through which the current can flow increases. The reverse is true of parallel-connected capacitors. The total capacitance increases, because the plate area receiving the charge increases.

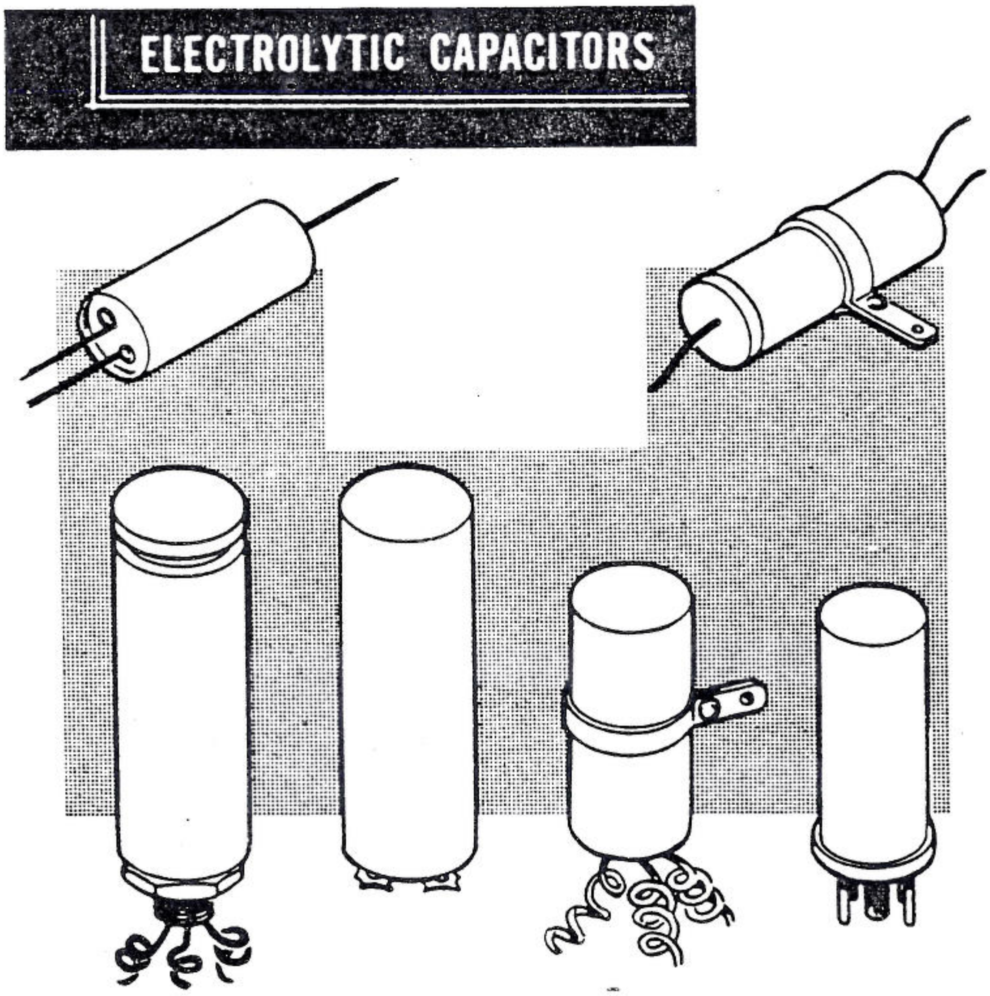
The total capacitance for parrallel-connected capacitors is found by adding the values of the various capacitors connected in parallel.

ELECTROLYTIC CAPACITORS.

Unlike other types of capacitors, the electrolytic capacitors is "polarised"! If it is connected in the wrong polarity, it will break down and act as a short circuit.

A "reversible," or non-polarised, type is sometimes used in A.C. circuits e.g. for starting a motor.

Electrolytic capacitors are constructed in a wid e variety of shapes and physical sizes, using either cardboard or metal cases, and having various types of terminal connections. Remember that unless an electrolytic capacitor is of the reversible - and so can be used with A.C. - you must be careful to connect it only in a D.C. circuit, and to observe the correct polarity.

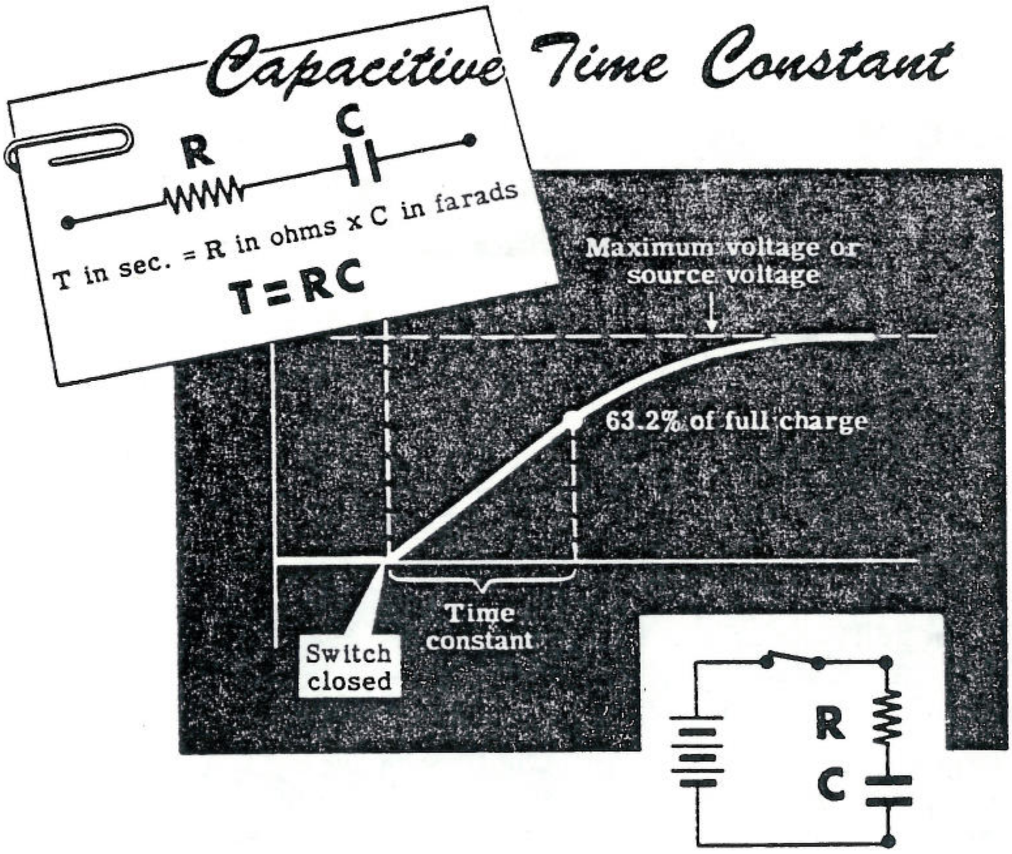


CAPACITIVE TIME CONSTANT.

When a voltage is applied across the terminals of a circuit containing capacitance, the voltage across the capacitance does not instantaneously equal the voltage applied to the terminals. You have already found that it takes time for the plates of a capacitor to reach their full charge, and that the voltage between the plates rises to equal the applied voltage in a curve similar to the current curve of an inductive circuit.

The greater the circuit resisrance, the longer the time required for the capacitor to reach its maximum voltage; for circuit resistance opposes the flow of current required to change the capacitor.

The time required for the capacitor to become fully charged depends on the product of circuit resistance and capacitance. This product RC - resistance times capacitance - is called the " time constant " of a capacitive circuit. The RC time constant gives the time inseconds required for the voltage across the capacitor to reach 63.2% of its maximum value. Similarly, the RC time constant equals the time in seconds required for a discharging capacitor to lose 63.2% of its full charge.



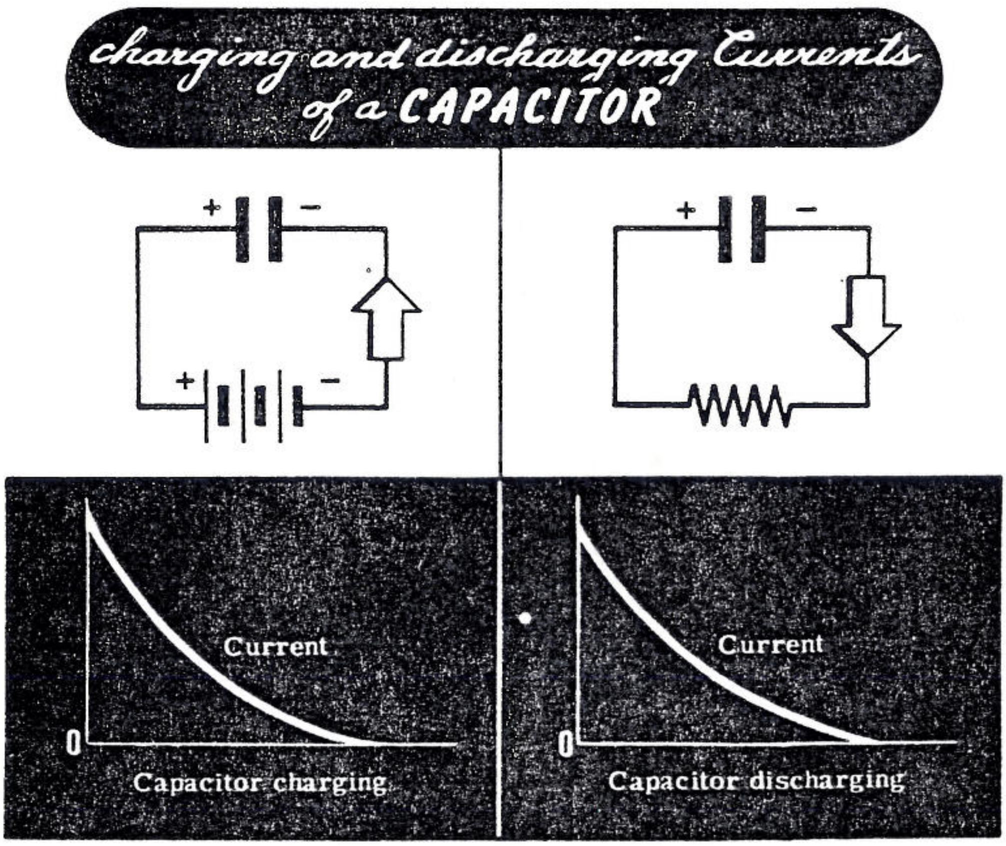
## CAPACITIVE REACTANCE.

Capacitive reactance is the opposition to current flow offered by the capacitance of a circuit. When a D.C. source is used, current flows only to charge or discharge the capacitor. Since there is no continuous flow of D.C. current in a capacative circuit, ~~the capacitive circuit~~, the capacitive reactance to D.C. is considered infinite. A.C. continuously varies in value and polarity; therefore the capacitor is continuously charging and discharging, resulting in a continuous circuit current flow and a finite value of capacitive reactance.

The charge and discharge currents of a capacitor start at a maximum value, and fall to zero as the capacitor becomes either fully charged or fully discharged In a charging capacitor, the uncharged plates offer little opposition to the charging current at first; but as they become charged, they offer more opposition, and so reduce the current flow.

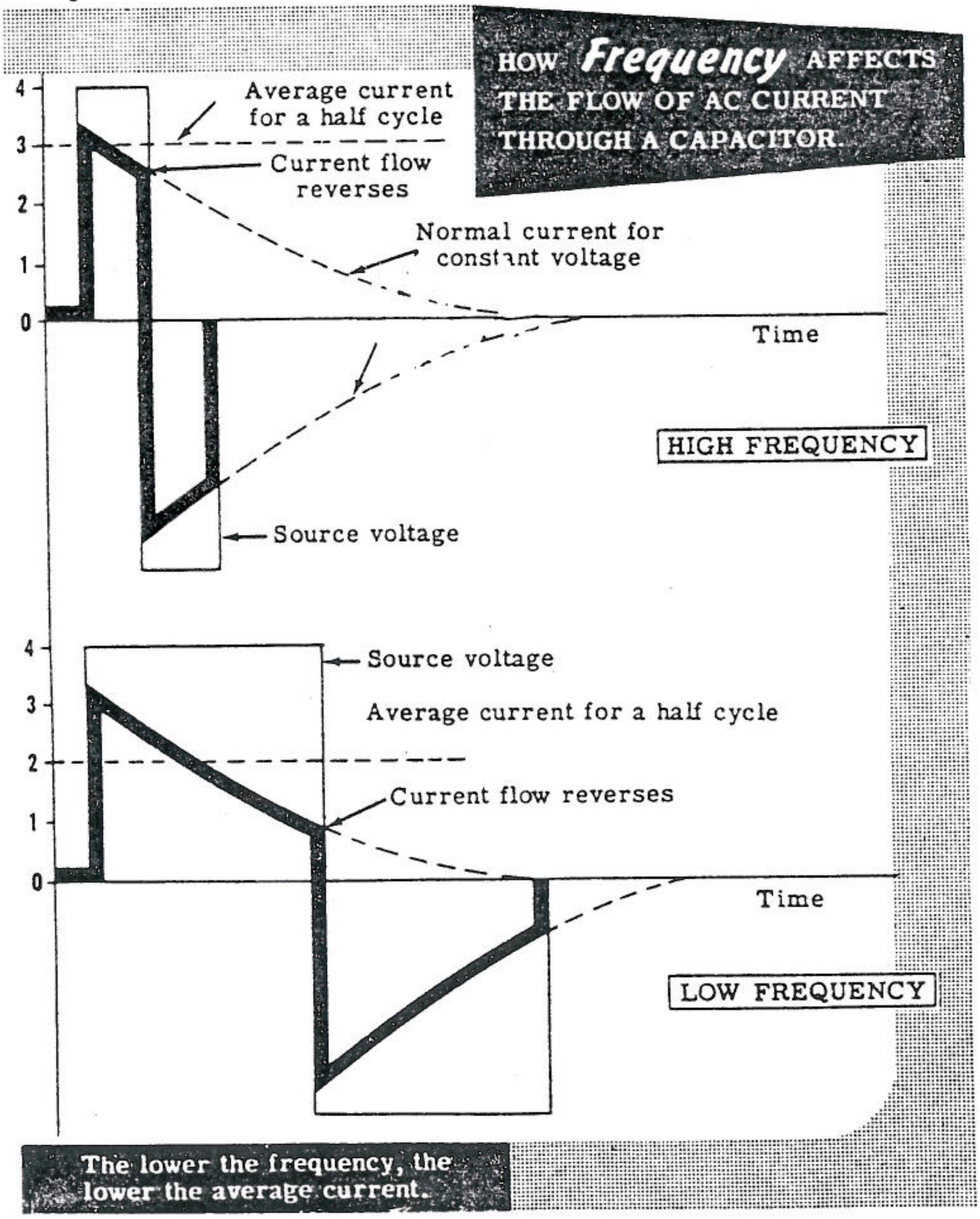
Similarly, discharge current is high when discharge begins, because the voltage of a charged capacitor is high when discharge begins, because the voltage of a charged capacitor is high; but as the capacitor discharges, so its voltage drops, and less current flows.

Since both charging and discharging currents are highest at the beginning of the charge and discharge of a capacitor, it follows that the average current is increased if the polarity be rapidly and continuously reversed.



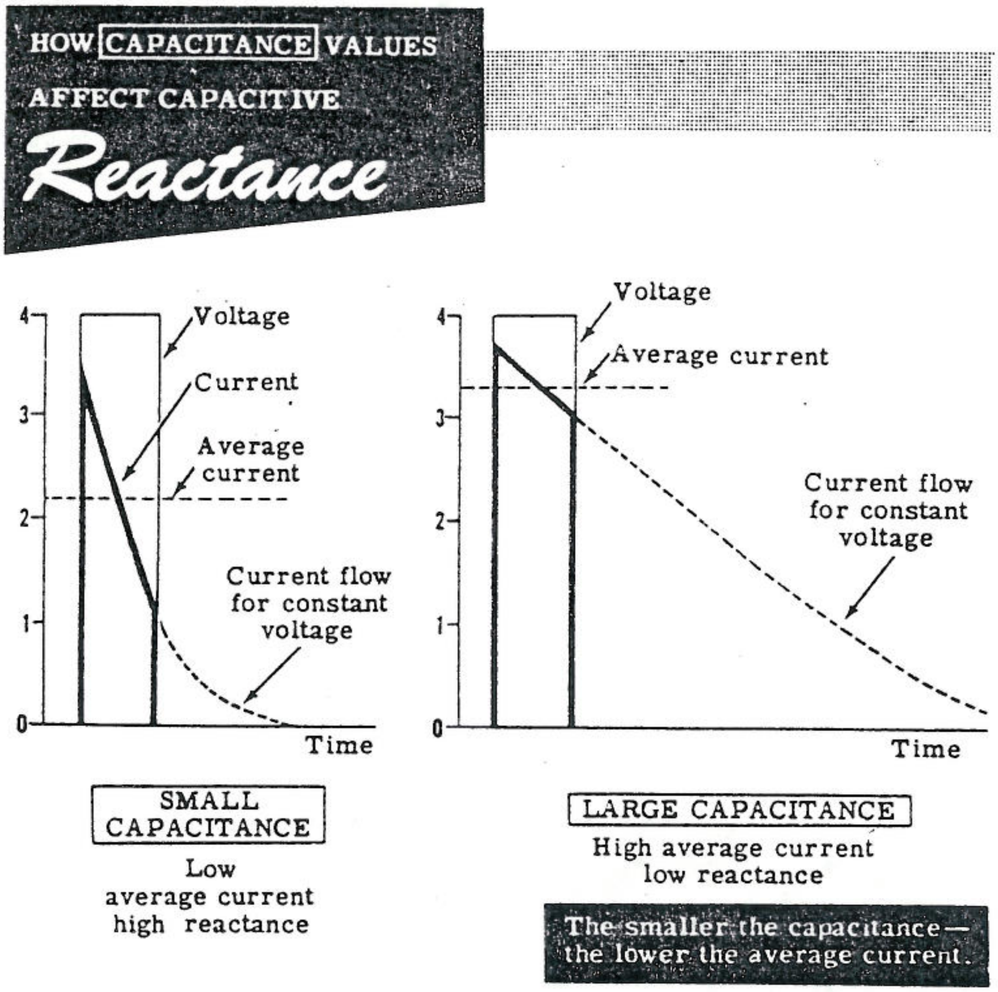
If it were possible to switch the battery connections, very quickly, in such a way that the capacitor is alternately charged in one direction and then the other, in the previous diagram.

For a given value of capacitance, the amount of current flow in the circuit depends on the frequency with which the switching is done. The higher the frequency, the greater the current flow; for the charging current in both directions will be reversed before it has time to drop to a low value. If the rate of switching is low in frequency, the current will drop to a low value before the polarity reverses, and a lower average value of current will flow.




In the same way, for a given value of capacitance the amount of current in an A.C. circuit depends on the frequency of the A.C. voltage.

Comparing the charge current curves for different values of capacitance, you see that tha larger the capacitance the longer the current remains at a high value. Thus, if the frequency is the same, a greater average current will flow through a large capacitance than through a small capacitance. This holds true only if the circuit resistances are equal, however, because the charge curve of a capacitance depends on the RC time constant of the circuit.



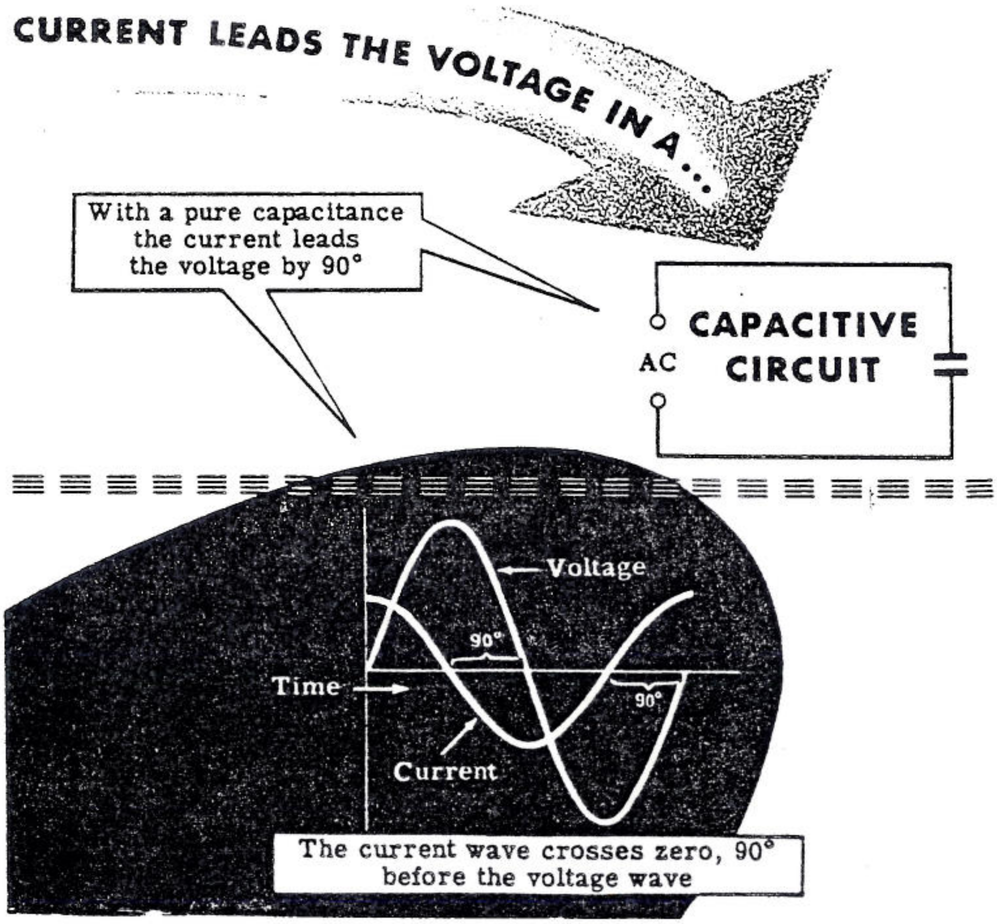

The current flow in a capacitive circuit, assuming that there is no change in the resistance, increases with an increase in either frequency or capacitance. Thus capacitive reactance - the opposition to current flow through a capacitance - must decrease when either the frequency or the capacitance increases.

The formula used to obtain capacitive reactance is $X_C = 1/2\pi fC$. In this formula $X_C$ is capacitive reactance, f is frequency in cycles per second, C is capacitance in farads, and $2\pi$ is a constant number (6.28). Since $X_C$ represents opposition to current flow, it is expressed in ohms.

The phases relationship between current and voltage waves in a capacitive circuit to which an A.C. voltage is applied is exactly the opposite to that of an inductive circuit. In a purely inductive circuit the current wave lags the voltage by 90 degrees, while in a purely capacitive circuit the current wave leads the voltage by 90 degrees.

In a theoretical circuit of pure capacitance and no resistance, the voltage across the capacitance exists only after current flows to charge the plates. At the moment a capacitance starts to charge, the voltage across its plates is zero and the current flow is maximum. As the capacitance charges, the current flow drops towards zero while the voltage rises to its maximum value. When the capacitance reaches full charge, the current is zero and the voltage is maximum. In discharging, the current starts at zero and rises to a maximum in the opposite direction, while the voltage falls from maximum to zero.

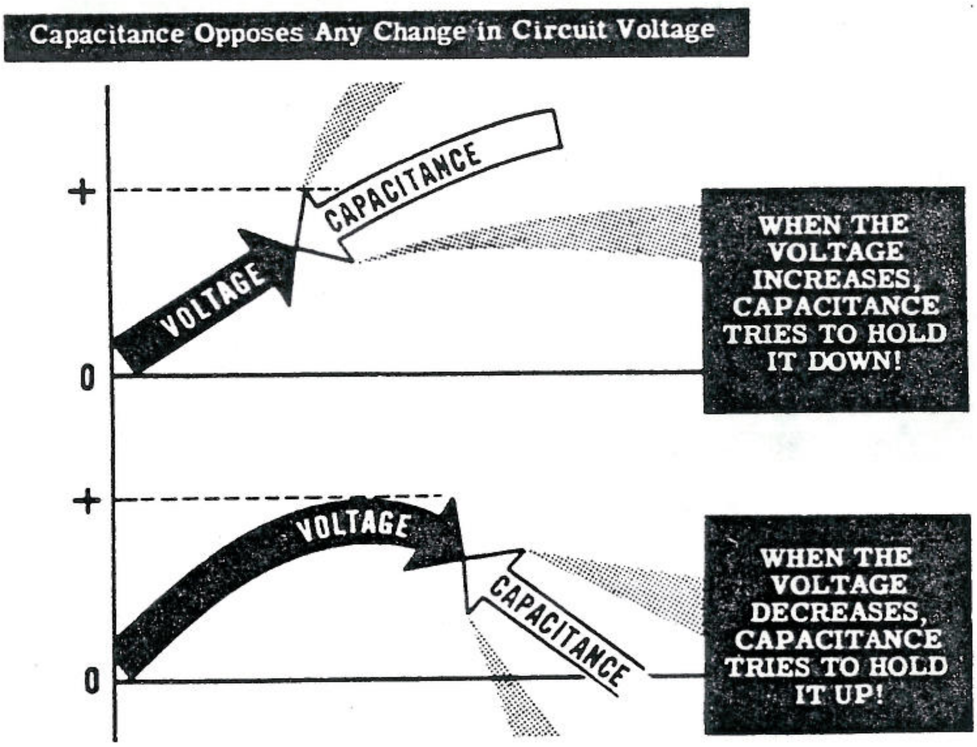
It follows that the current wave leads the voltage by 90 degrees; or, putting it the other way round, that the voltage wave lags the current by 90 degrees.



CAPACITANCE IN A.C. CIRCUITS.

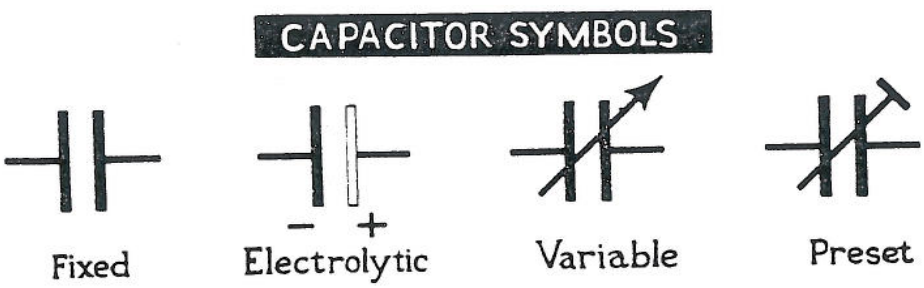
It has already been seen that in an inductive circuit, any change of current is opposed by the inductor. There are many circuits which tend to resist any changes in voltage.

When this opposition to voltage change is present, the circuit is said to contain "capacitance." Once again, you can never actually see capacitance; but but its effect, neverthe less, present in many circuits.

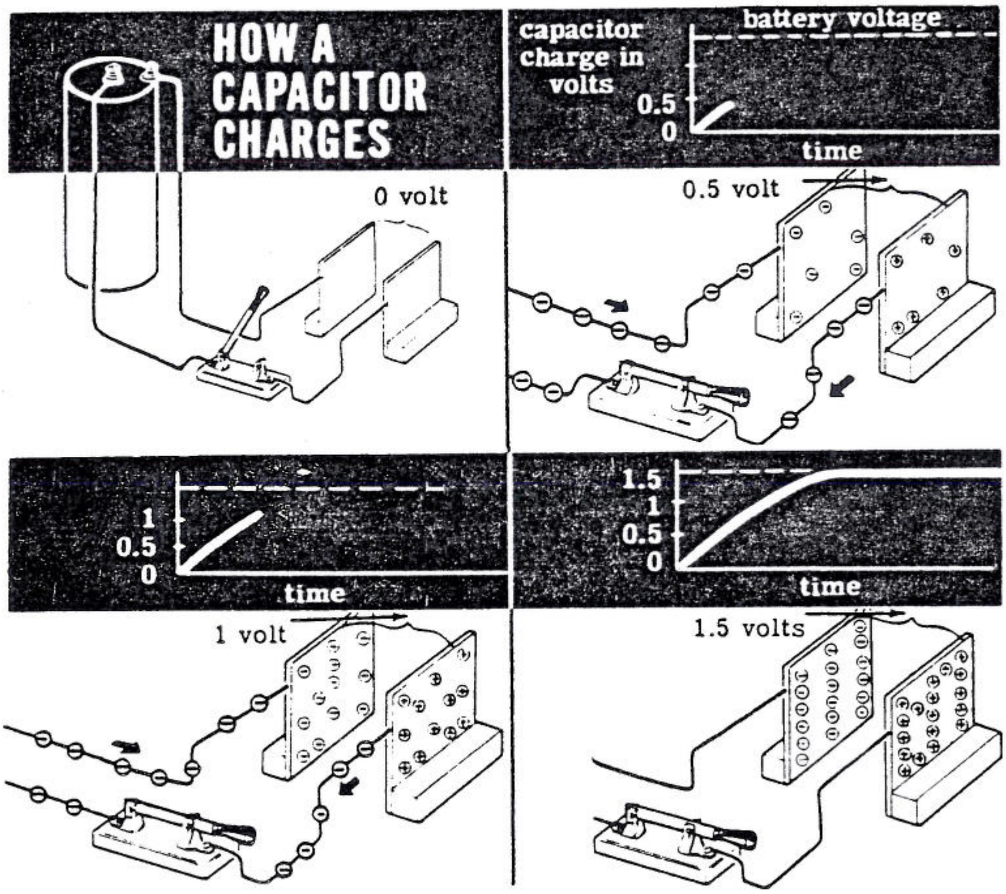



Because D.C. voltage usually varies only when it is turned on and off, capacitance affects D.C. circuits only at these times. In A.C. circuits, however, the voltage is continuously changing, so that the effects of capacitance is continuous. The amount of capacitance present in a circuit depends on the physical construction of the circuit and the electrical devices used. The capacitance may be so small that its effect on circuit voltage is negligible.

Electrical devices which are used to add capacitance to a circuit are called "capacitors." The circuit symbols used to indicate a capacitor are shown below.



To see how capacitance affects the voltage in a circuit, suppose the circuit contains a two plate capacitor, a knife switch and a dry cell as shown below. Assuming both plates are uncharged and the switch is open, then no current flows and the voltage between the two plates is zero.

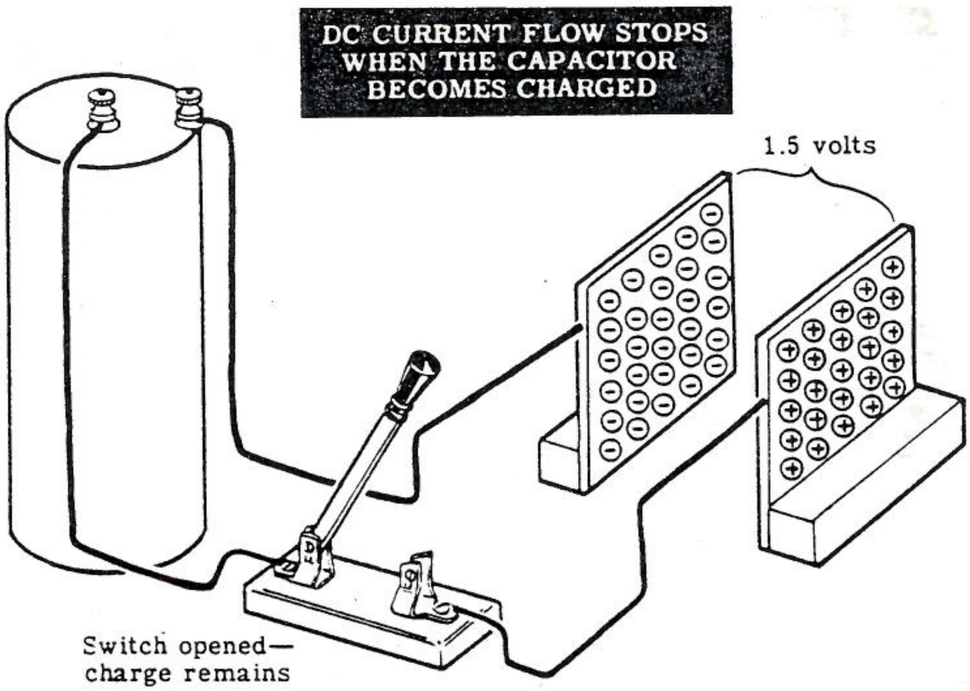



When the switch is closed, the battery furnishes electrons to the plate connected to the negative terminal, and takes electrons away from the plate connected to the positive terminal.

The voltage between the two plates will eventually equal the voltage between the cell terminals, i.e. 1·5 volts; but this will not happen at once because, for a voltage to exist between the two plates, one plate must take excess electrons to become negatively charged, while the other must give up electrons to become positively charged. As electrons move on to the plate attached to the negative terminal of the cell, however, a negative charge is built up which opposes the movement of more electrons on to the plate; and as electrons are taken away from the plate attached to the positive terminal, a positive charge is built up which opposes the removal of more electrons from that plate.

This action on the two plates is called "capacitance." It opposes the change in voltage (from zero to 1·5 volts), and delays it for a limited amount of time. But it does not prevent the change from eventually taking place.

When the switch is opened the plates remain charged, since there is no path between the two plates through which they can discharged. As long as no discharge path is provided, the voltage between the plates will remain at 1.5 volts and, if the switch is again closed, there will be no effect on the circuit since the capacitor is already charged.

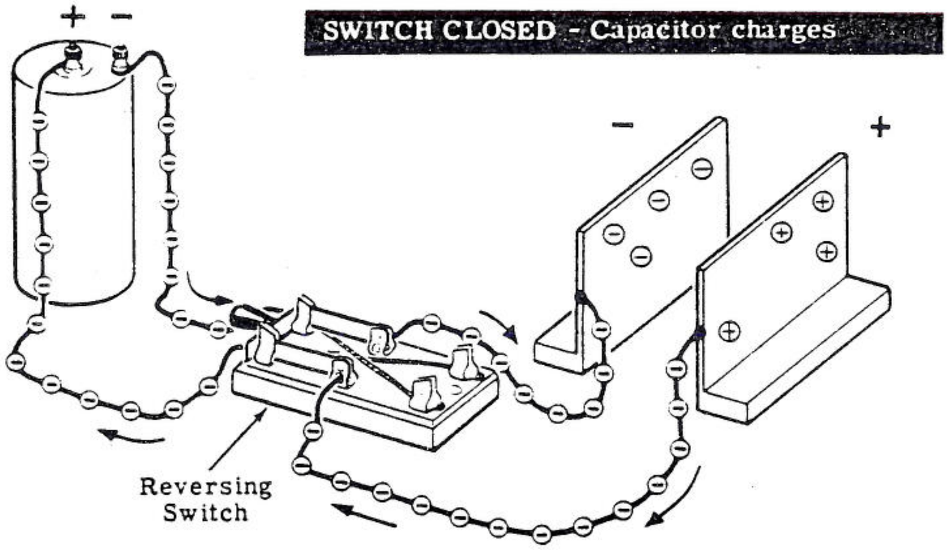



With a D.C. voltage source, then, current will fplow in a capacitive circuit only long enough to charge the capacitor. When the circuit switch is closed, an ammeter connected to read circuit current will show that a very large current flows at first, when the capacitor plates are uncharged. Then, as the plates gain polarity and oppose additional charge, the charging decreases — — until it reaches zero at the amount when the charge on the plates equals the voltage of the D.C. voltage source.

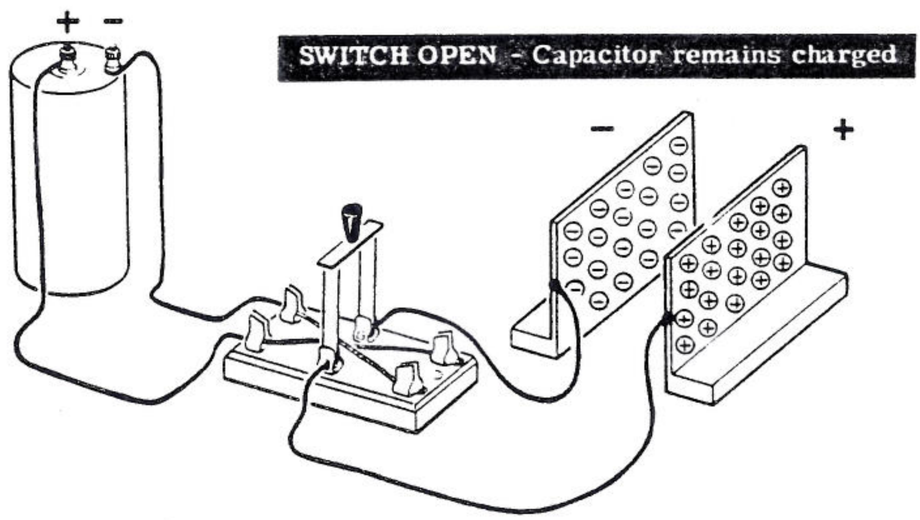
This current which charges a capacitor flows for the first moment after the switch is closed. After this momentory flow the current stops, since the plates of the capacitor are seperated by an insulator which does not allow electrons to pass through it. Thus capacitors will not allow D.C. to flow continuously through a circuit.

While a capacitor blocks theflow of D.C. it affects an A.C. circuit differently, having the apparent effect of allowing A.C. current to flow through the circuit. To see how this works, consider what happens in the D.C. circuit if a double-throw switch is used with the dry cell so that the charge to each plate is reversed as the switch is closed - first in one position and then in the other.

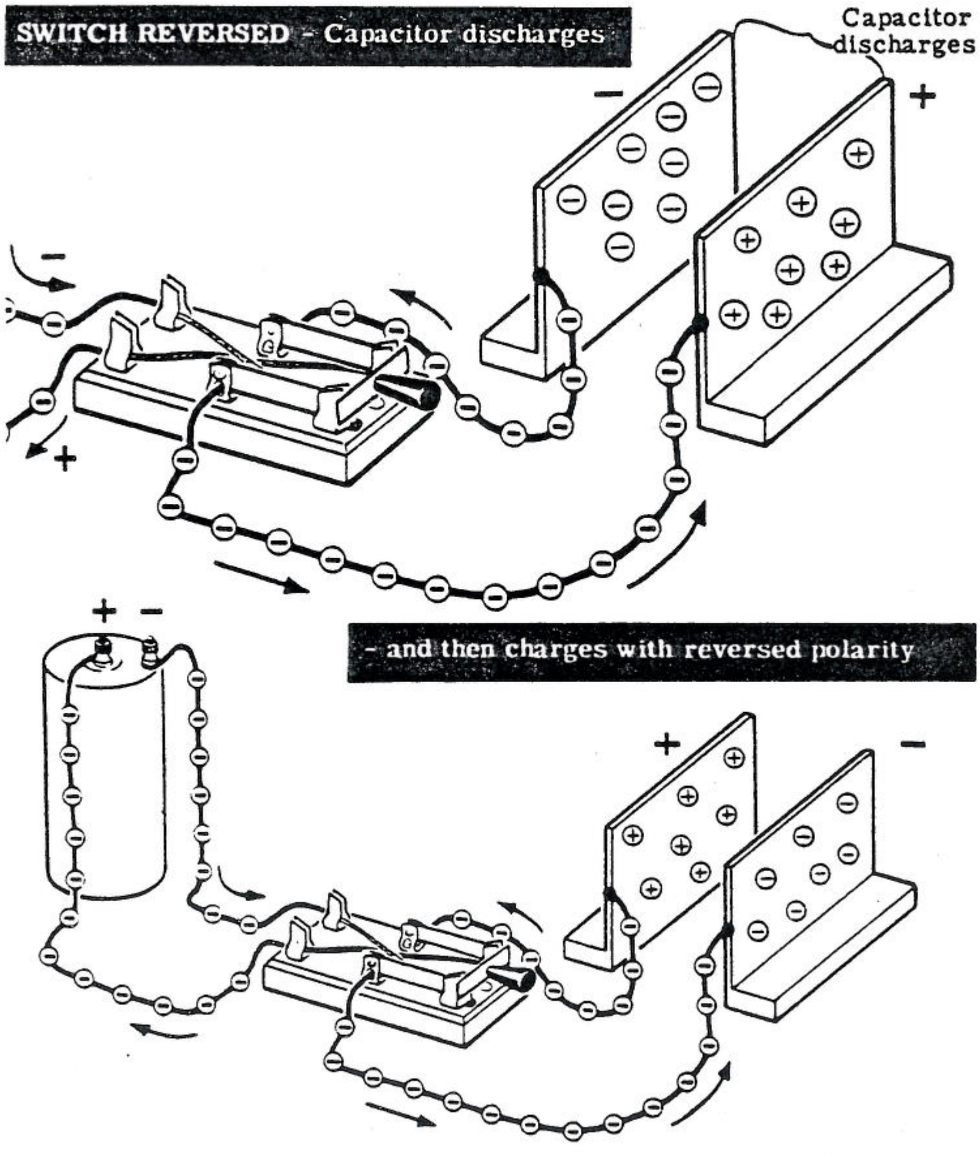
When the switch is first closed the capacitor charges, with each plate being charged in the same polarity as that of the cell terminal to which it is connected.




When the switch is opened, the capacitor retains the charge on its plates equal to the cell voltage.



If the switch is then closed in its original position no current flows, since the capacitor is charged in that polarity. However, if the switch is closed in the opposite direction, the capacitor plates are connected to cell terminals opposite in polarity to their charges. The positively charged plate then is connected to the negative cell terminal and will take electrons from the cell, first to neutralise the positive charge, then to become charged negatively until the capacitor charge is the same polarity and equal voltage to that of the cell. The negative charged plate gives up electrons to the cell, since it must take on a positive charge equal to that of the cell terminal to which it is connected.




If a centre - zero ammeter which can read current flow in both directions were inserted in series with one of the capacitor plates, it will indicate a current flow every time the plate is charged.

When the revering switch is first closed, the ammeter will show a current flow in the direction of the original charge. Then, when the cell polarity is reversed, it will show a current flow in the opposite direction as the plate discharges, then charges in the opposite polarity.

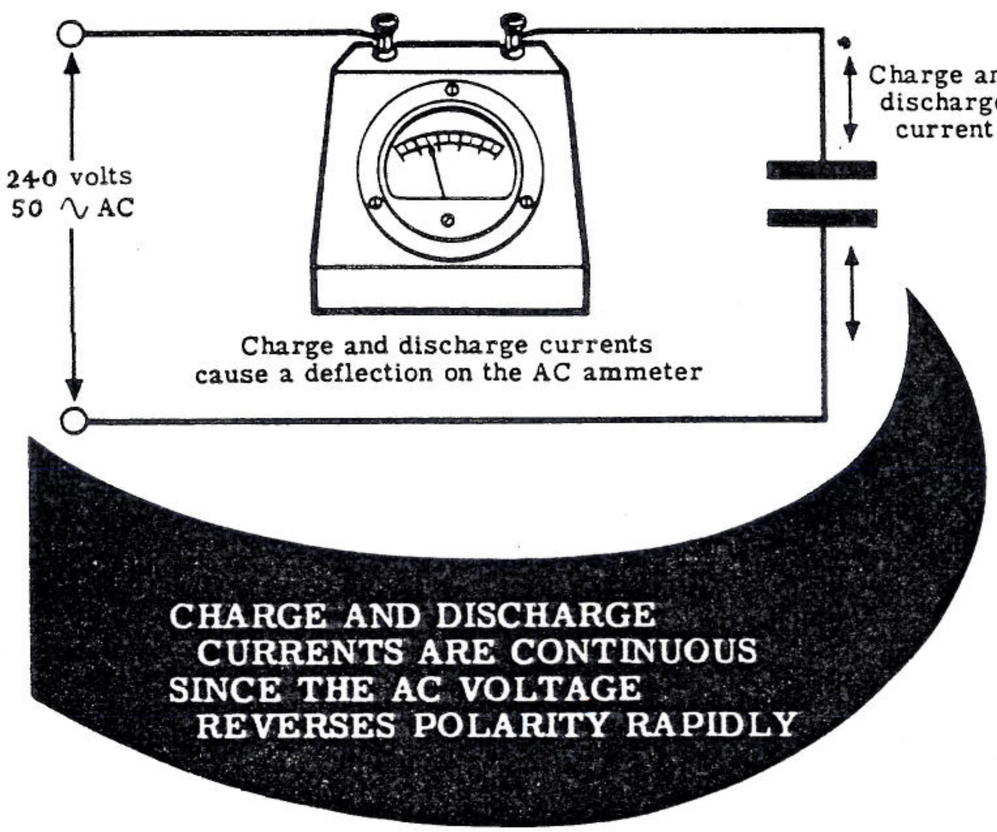
If it were possible to switch the cell polarity so fast that at the instant the capacitor plates became charged in one polarity, the cell polarity is reversed. The meter needle now moves continuously - first showing a current flow in one direction, then in the opposite direction. No electrons move through the air from one plate to the other, but the meter shows that current is continuously flowing to and from the capacitor plates.

If a source of A.C. voltage is used instead of the dry cell and reversing switch, the polarity of the voltage source is automatically changed each half cycle. If the frequency of the A.C. voltage is low enough, the ammeter will show current flow in both directions, changing each half cycle as the A.C. polarity reverses.

The standard commercial frequency is 50 c/s so that a centre - zero meter will not show the current flow, since the meter pointer cannot move fast enough. Even if it could, you would not be able to see the movement owing to its speed. However, an A.C. ammeter inserted in place of the centre - zero ammeter shows a continuous current flow when the A.C. voltage source is used, indicating that in the meter and in the circuit there is a flow of A.C.

Remember that this current flow represents the continuous charging and discharging of the capacitor plates, and that no actual electron movement takes place directly between the plates of the capacitor. Capacitors are considered to pass A. C. because current actually flows continuously in all parts of the circuit except through the insulating material between the capacitor plates.

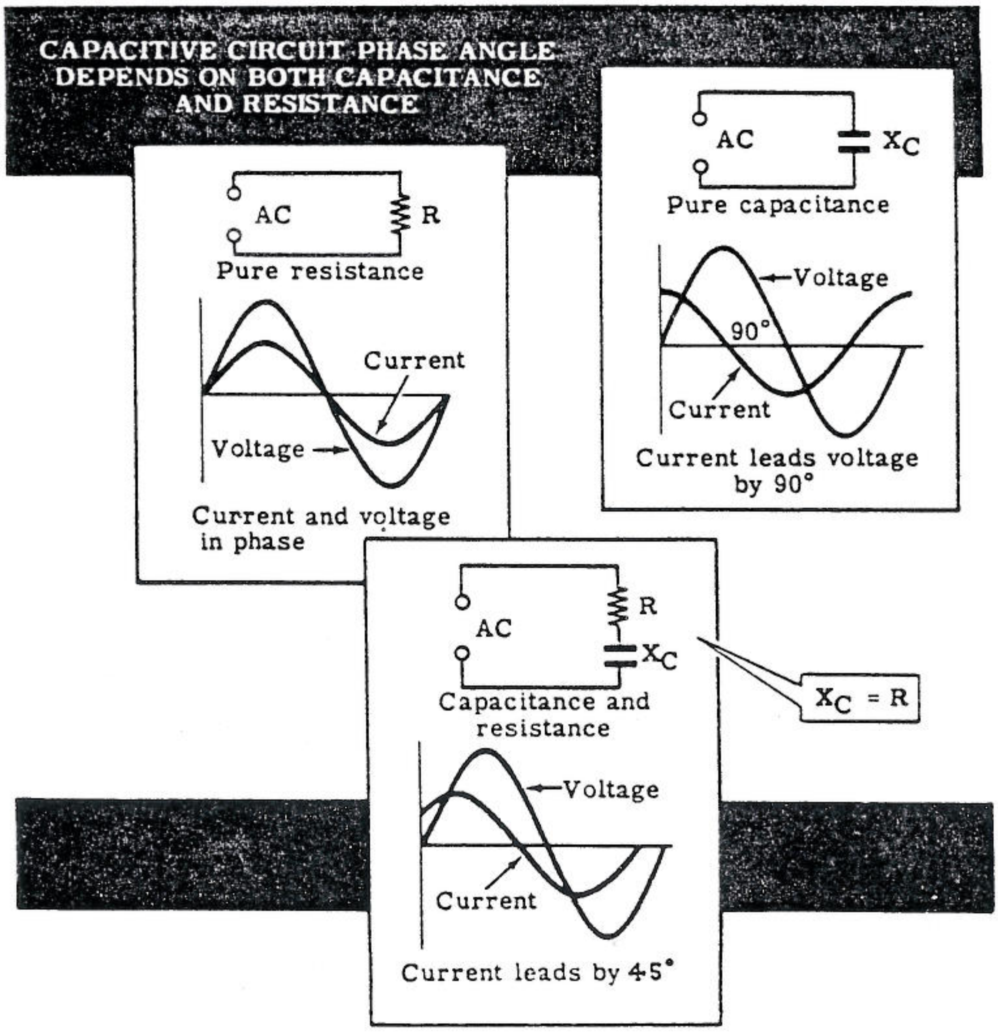
## AC CURRENT in a capacitive circuit



Resistance affects capacitive circuits in the same way as it affects inductive circuits. Remember that, in an inductive circuit containing both inductance and resistance, the current wave lags the voltage wave by an angle between zero degrees and 90 degrees, depending on the ratio of inductive reactance to the resistance. For a purely capacitive circuit, current leads the voltage by 90 degrees; but, with both resistance and capacitance in a circuit, the amount of lead - or the'phase angle' as it is called - depends on the ratio between the capacitive reactance and the resistance.

The phase angle can be calculated using the formula $\tan \phi = X_C / R$, where o is the phase angle.

If the capacitive reactance and the resistance are equal, they will have an equal effect on the angle of lead; and this will reult in a phase angle of "45 degrees leading." The current wave then leads the voltage by 45 degrees, as shown below.



British Rail

Course E.P. 2.

Section Eight.

Content Impedance.

R.S. & T.E. Department

Training School York

## IMPEDANCE.

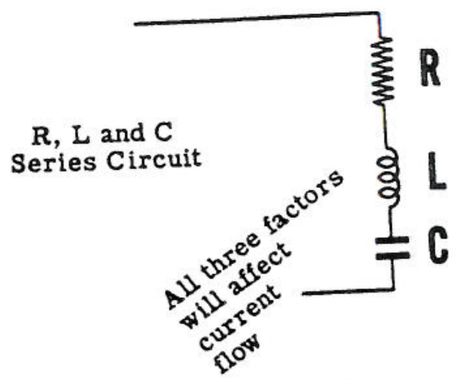
Every electrical circuit contains a certain amount of resistance (R), inductance (L) and capacitance (C).

Inductance and capacitance cause inductive and capacitive reactance ($X_L$ and $X_C$), which oppose the flow of A.C. current in a circuit, so that A.C. circuits contain three factors which oppose current flow; R, $X_L$ and $X_C$. In any given circuit, however, any of these factors may be so negligible that it can be disregarded.

The combined effect of R, $X_L$ and $X_C$ is the total opposition to A.C. current flow and is called Impedance.

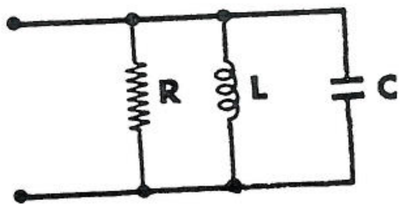
The symbol for impedance is Z.

SERIES




$$Z = \sqrt{R^2 + (X_L - X_C)^2}$$

PARALLEL

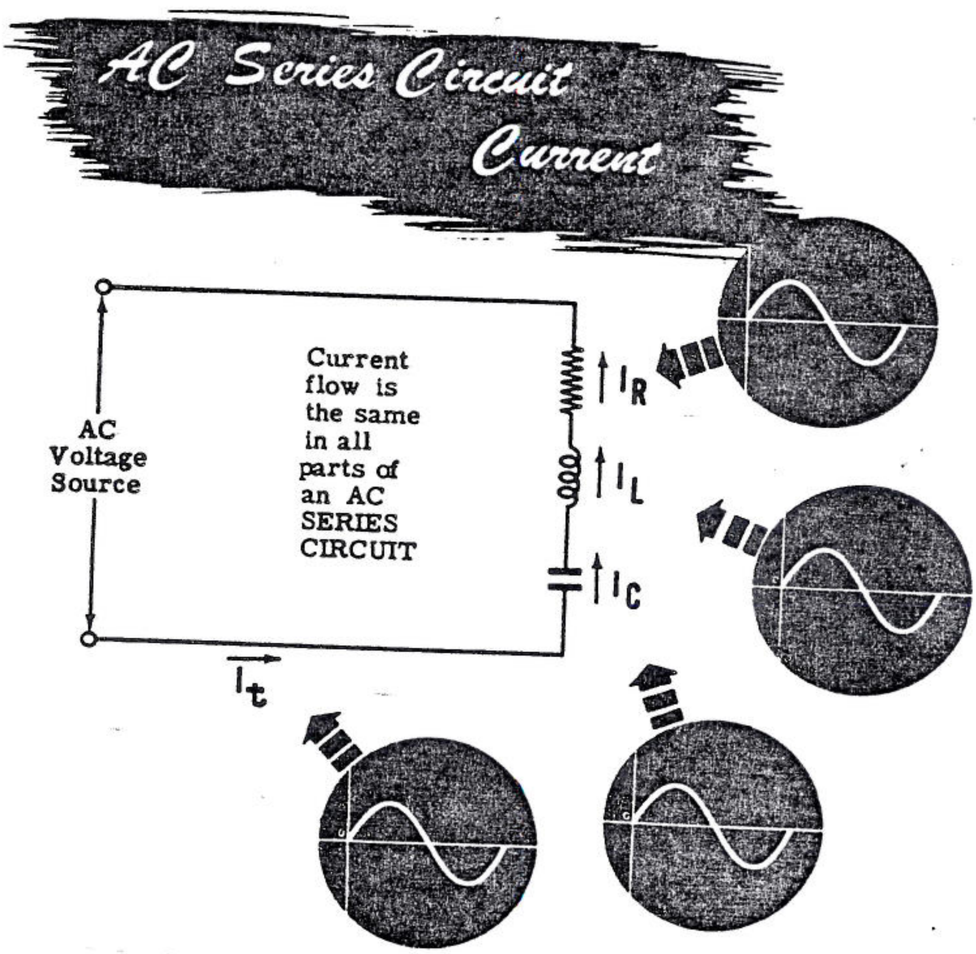



$$Z = \frac{1}{\sqrt{(1/R)^2 + (1/X_C - 1/X_L)^2}}$$

In an A.C. series circuit, as in a D.C. series circuit, there is only one path for current flow around the complete circuit. This is true regardless of the type of circuit: R and L, R and C, L and C or R, L and C. Since there is only one path around the circuit, the current flow is exactly the same in all parts of the circuit at any one time; and therefore all phase angles in a series circuit are measured with respect to the circuit current, unless otherwise stated.

Thus in a circuit containing R, L and C, such as the one illusrated below, the current which flows into the capacitor to charge it will also flow through the resistor and the inductor.

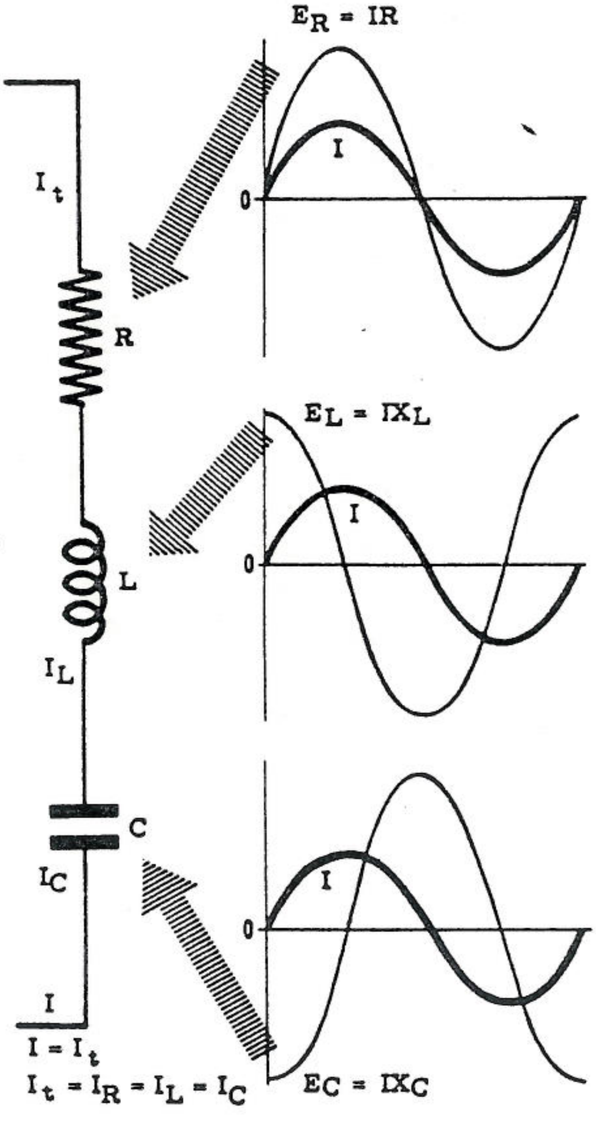
When current flow reverses in the capacitor, it reverses simultaneously in the inductor and the resistor. If plotted, the current waveforms, through the resistor, inductor and capacitor in such a circuit, it would be found that they were identical in value and phase angle. The total circuit current, $I_t = I_R = I_L = I_C$.



The total voltage of an A.C. series circuit cannot be found by adding the individual voltages across the resistance, inductance and capacitance of the circuit. The reason for this is bacause the individual voltages across R, L and C are not in phase with each other.

The illustration below shows the phase angles for resistance, inductance and capacitance in a series circuit.

## AC SERIES CIRCUIT VOLTAGE




The voltage $E_R$ across $R$ is in phase with the circuit current, since current and voltage are in phase in pure resistive circuits.

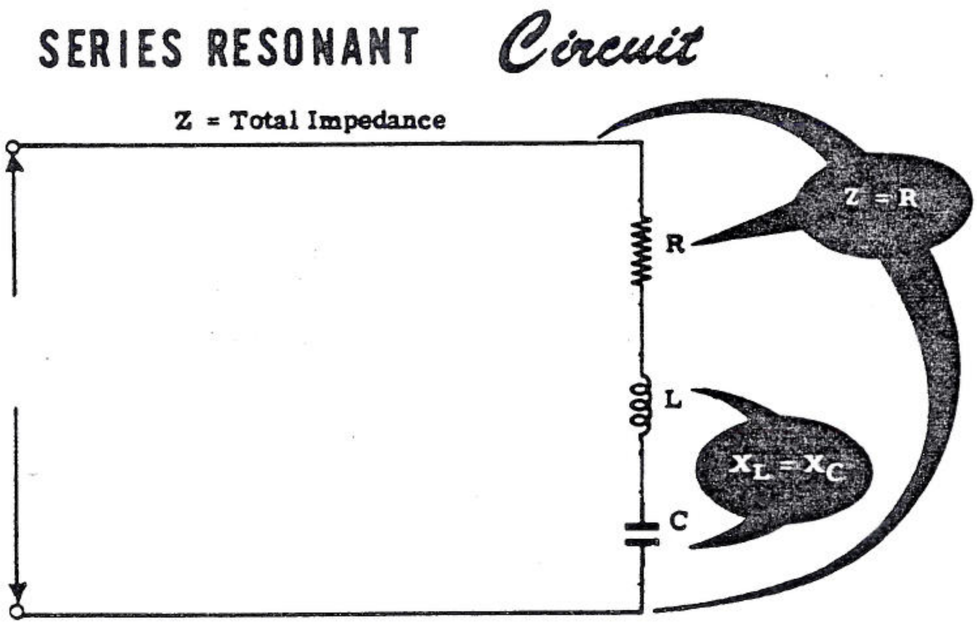
The voltage $E_L$ across $L$ leads the circuit current by 90 degrees, since current *lags* the voltage by 90 degrees in purely inductive circuits. Thus $E_L$ crosses the zero axis going in the same direction, 90 degrees before the current.

The voltage $E_C$ across $C$ lags the circuit current by 90 degrees since current *leads*.the voltage by 90 degrees in purely capacitive circuits. Thus $E_C$ crosses the zero axis, going in the same direction, 90 degrees after the current wave.

SERIES RESONANCE.

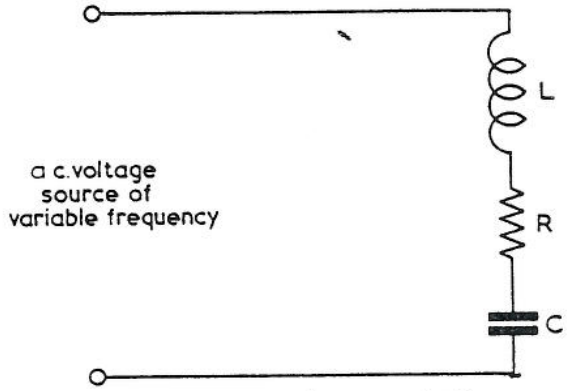
In any series circuit containing both L and C, the current is greatest when the inductive reactance $X_L$ equals the capacitive reactance $X_C$, since under these conditions the impedance is equal to R.

Whenever $X_L = X_C$ the opposition to current flow is at its minimum within the circuit. This is, in simple terms, that the change of phase angle which is caused by the inductance (the current lagging the voltage by 90 degrees) is in effect cancelled out by the capacitive effect (the current leading the voltage by 90 degrees). Therefore, as long as $X_L$ and $X_C$ remain equal the total opposition to current flow must only be resistance of the circuit. When $X_L$ and $X_C$ are equal the circuit is said to be "at resonance." Such a circuit is called a series resonant circuit.

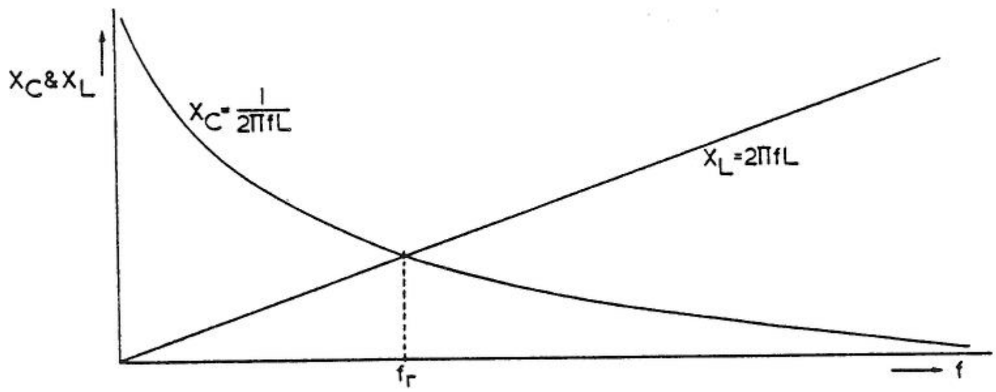


## RESONANT FREQUENCY.

If an A.C. voltage of variable frequency is applied to a circuit consisting of an inductor and a capacitor in series. The inductor is represented in the circuit below by a pure inductance (L) in series with a resistor (R) and the capacitor (C).




As the frequency of the applied voltage rises, the capacitive reactance $X_C$ decreases but the inductive reactance $X_L$ increases. The graph, which is shown below, show how $X_C$ and $X_L$ vary with changes in frequency.




It can be seen that at one frequency $X_C = X_L$. This is called the resonant frequency $f_r$. The frequency at which a particular circuit will resonate can be calculated as follows:

$$X_C = X_L$$

$$2\pi f_r L = \frac{1}{2\pi f_r C}$$

$$f_r^2 = \frac{1}{2^2\pi^2 LC}$$

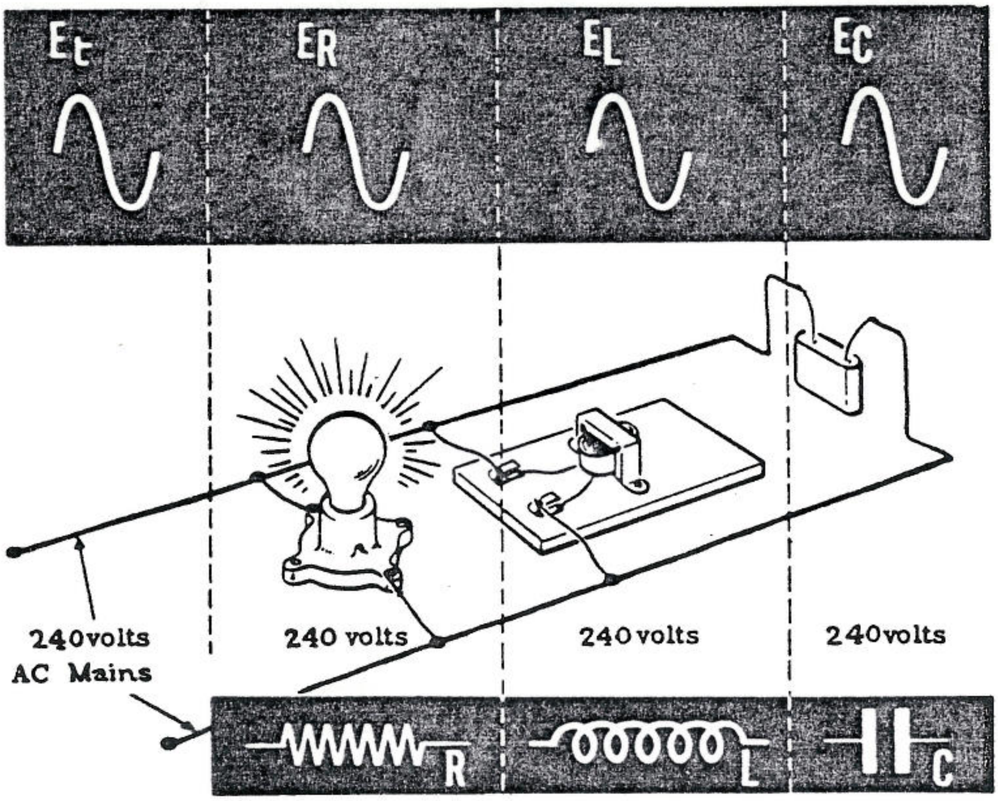
$$f_r = \frac{1}{2\pi\sqrt{LC}}$$

PARALLEL RESONANCE.

As in the series connected circuit, the same combinations of R, L, and C which are used to form the various types of series circuits may also be used to form parallel circuits. If one factor is negligible, the three possible combinations are R and L, R and C, or L and C, while a fourth type of parallel circuits contains R, L and C.

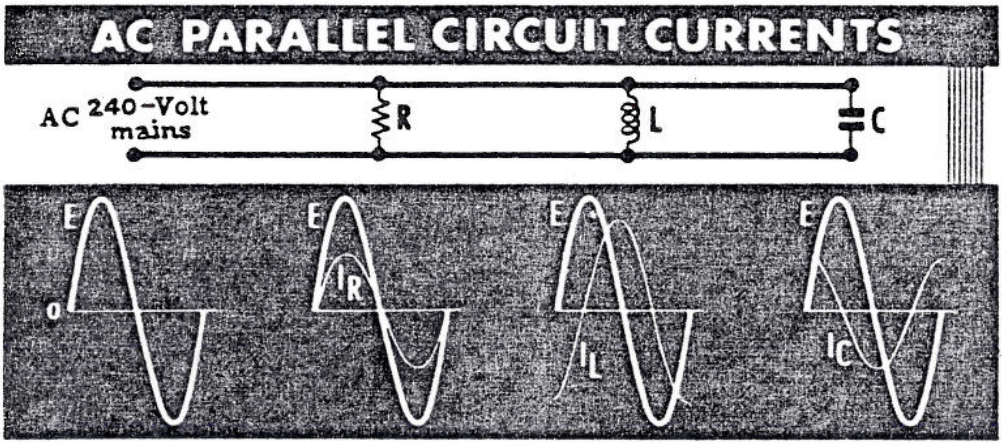
In a similar manner to a parallel D.C. circuit the voltage across each of the parallel branches is equal. This is also true of A.C. parallel circuits. The voltages across each parallel branch are equal; and they are also in phase.

For example, if the various types of electrical equipment shown below - - a lamp (resistance) a coil (inductance) and a capacitor (capacitance)- are all connected in parallel, the voltage across each is exactly the same.




Regardless of the number of parallel paths, the value of the voltage across them is equal and in phase. All of the connections to one side of a parallel combination are considered to be one electrical point, as long as the resistance of the connectiong wire may be ignored.

The current flow through each branch is determined by the opposition offered by that branch. If the circuit consists of three branches - one a resistor, another an inductor and the third a capacitor - the current through each branch depends on the resistance or reactance of that branch. The resistor branch current in is in phase with the circuit voltage, while the inductor branch current lags the circuit voltage by 90 degrees and the capacitor branch current leads the voltag by 90 degrees.




Because of the phase differences between the branch currents of an A.C. parallel circuit, the total current cannot be found by adding the various branch currents together, as it can for a D.C. parallel circuit.

When the waveforms for the various circuit currents are drawn in relation to the common circuit voltage waveform, $X_L$ and $X_C$ are again seen to cancel each other out the inductive current and the capacitive current are opposite in polarity at all points.

The resistance branch current, however, is 90 degrees out of phase with both the inductive current and the capacitive current, and to determine the total current flow the resistive current muust be combined with the difference between the inductive current and capacitive current.

British Rail

Course E.P. 2.

Section Nine.

Content Transformers.
Rectifiers.

R.S. & T.E. Department

Training School York

## TRANSFORMERS.

In earlier studies of A.C. theory it was said that alternating current, as a source of power, has certain advantages over direct current.

The most important advantage of A.C. is that the voltage level can be raised or lowered by means of transformers.

Alternating current voltages can be increased or decreased easily and without much power loss.

This is a very important factor in the transmission of electrical power.

Very often very large amounts of power must be transmitted, and this is best done using high voltages.

At a power station the voltage is "Stepped up" by transformers to high voltages, and sent over the transmission lines to the various points that power is required.

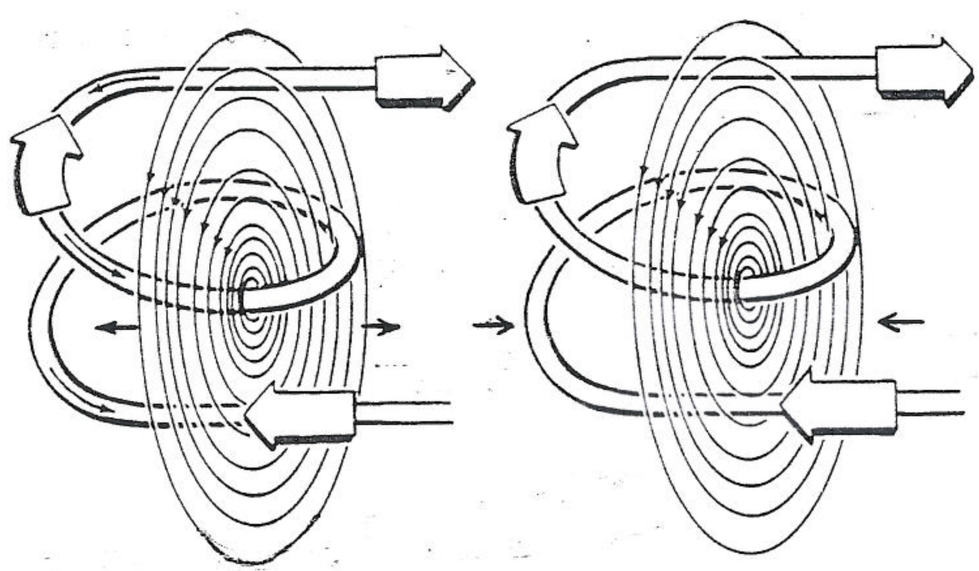
At the point at which power is required it is "Stepped down" to the various voltages requird by use of further transformers.

Transformers are used in most types of electrical and electronic equipment. It is important that you become familiar with transformers and know how they work. How they are connected into circuits and what precautions have to be taken when using them.

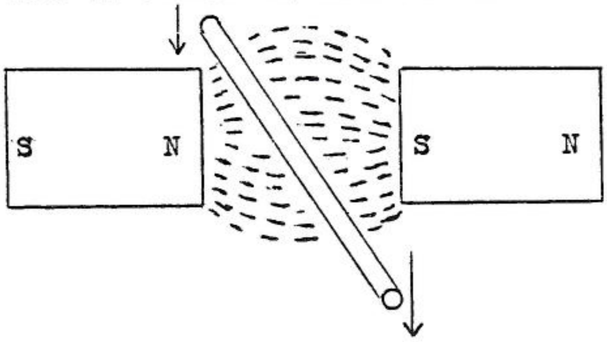
### Transformer Operation.

When alternating current flows through a coil, an alternating magnetic field is generated around the coil.

This alternating magnetic field expands outwards from the centre of the coil, and collapses into the coil as the current through the coil varies from zero to a maximum and back to zero with each half cycle.



If a wire is passed through a magnetic field a current is caused to flow within the wire. This is called the induced current.



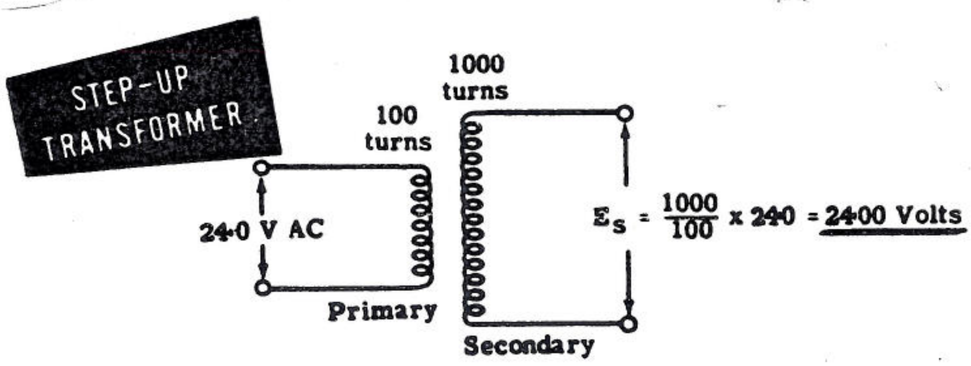

In the same way, if a wire is placed in a moving magnetic field a current is induced into the wire in a similar manner.

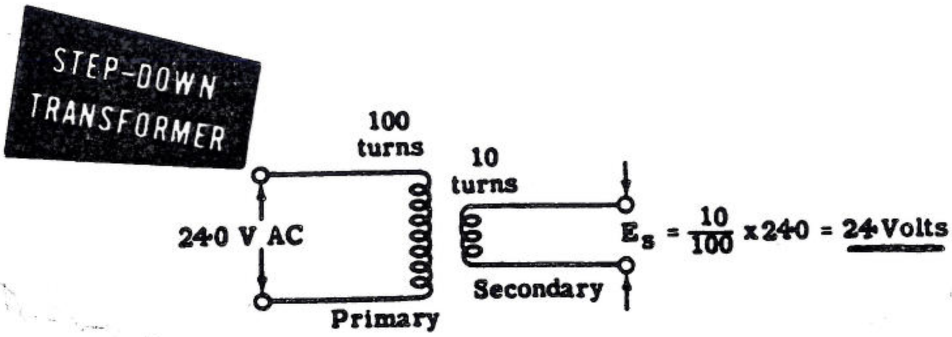
If two coils are placed very close together, electrically insulated from each other, and an A.C. supply is connected to one coil, an induced E.M.F. is created in the second coil. This is called "Tansformer Action".

In transformer action, electrical energy is transfered from one coil to the other. From the "Primary coil" to the Secondary coil".

This is caused by means of the varying magnetic field of the Primary coil inducing an E.M.F. into the the Secondary coil.

The amount of E.M.F. induced into the Secondary winding is dependant on two things. The voltage applied and the ratio of the number of turns in the Secondary winding to the number of turns in the Primary winding.



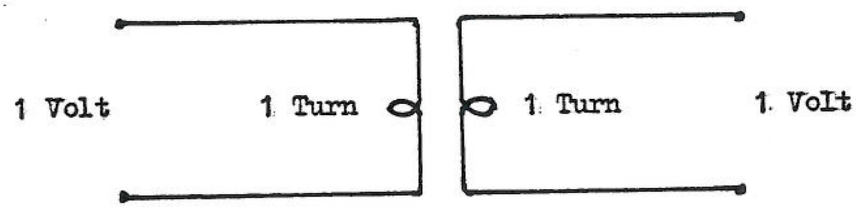




These are the two main functions of a transformer.

Volts per Turn.

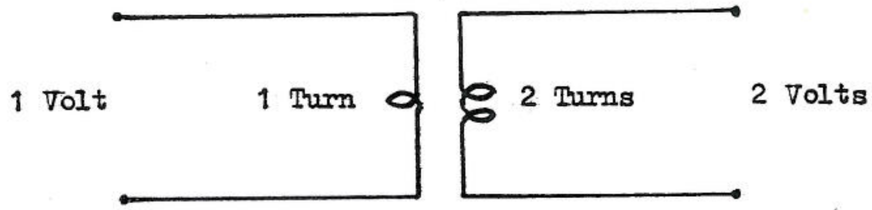
When dealing with transformers it is important to realise the relevance between the voltage applied and the number of turns of the coils.

For Example

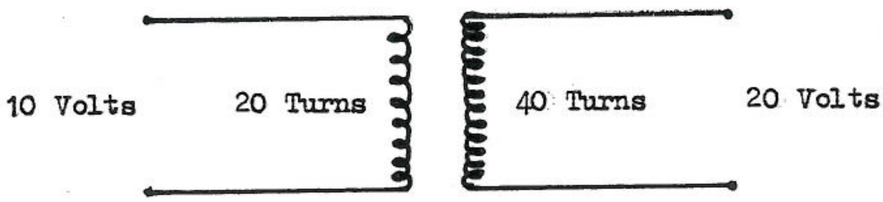



If the Primary winding remains the same, but the Secondary winding is increased, the Secondary voltage will also increase by the same ratio.

For Example




What ever the volts per turn of the Primary winding, then the Secondary winding is the same.




Primary Winding = 10 Volts divided by 20 Turns = 0.5 Volts per turn.

Secondary Voltage = 40 Turns x 0.5 Volts = 20 Volts

If, however, there are less Secondary windings than there are Primary, the Secondary Voltage will also be less than the Primary Voltage.

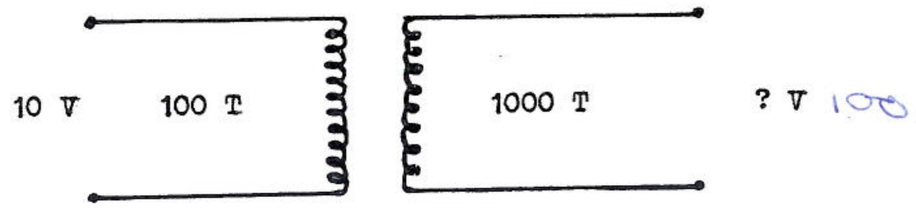
FURTHER EXAMPLES ARE SHOWN ON THE FOLLOWING PAGES.

2 9 4

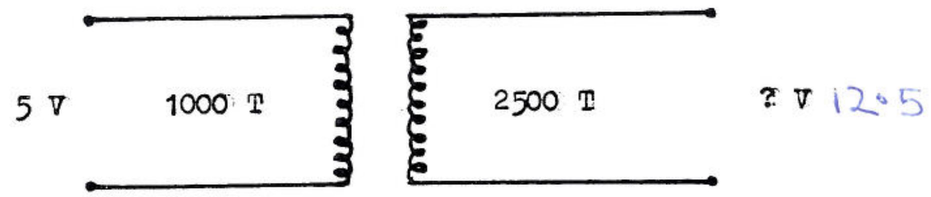
EXERCISE.

From the following examples work out the turns per volt, and the Secondary Voltage.

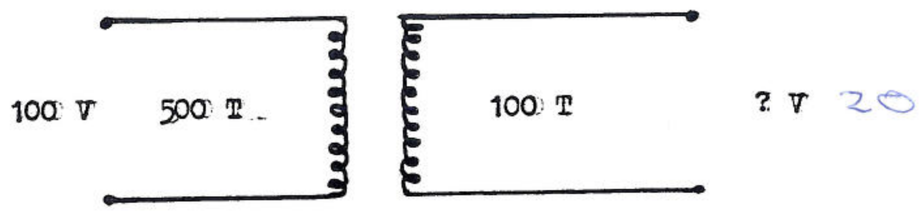
1.




2.




3.



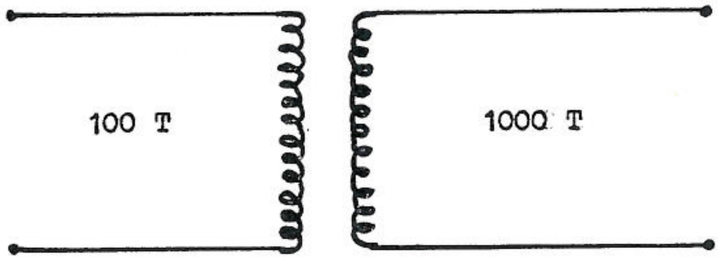
A transformer does not generate power. It transfers power from one coil to the other coil by means of magnetic induction.

The power output is determined by the power input.

E.G. POWER IN = POWER OUT.

1 amp

10 volts




0·1 amp

100 volts

10 watts

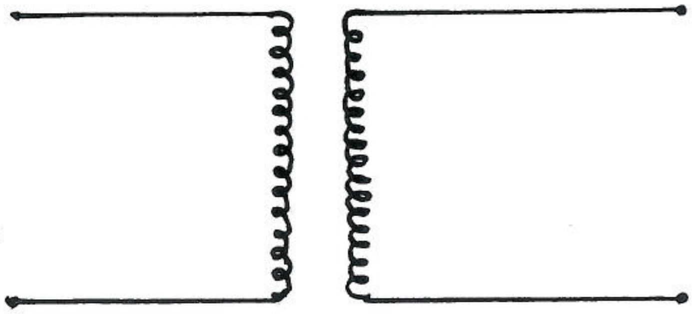
10 watts

When refering to transformer power the term Volt/Amp is used rather than watts.

Example.

1 amp

660 volts



6 amps

110 volts

660 watts

660 watts

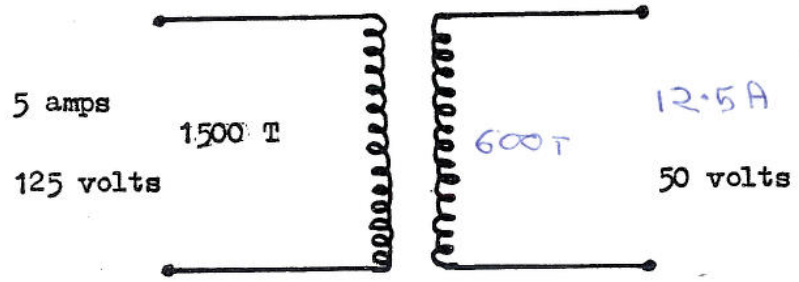
The 660 watts would be expressedas ·6 K.V.A. (Kilo Volt Amps)

The reason being that true power, as in D.C. is not calculated.

This will be dealt with at a later stage of this course.

EXERCISE.

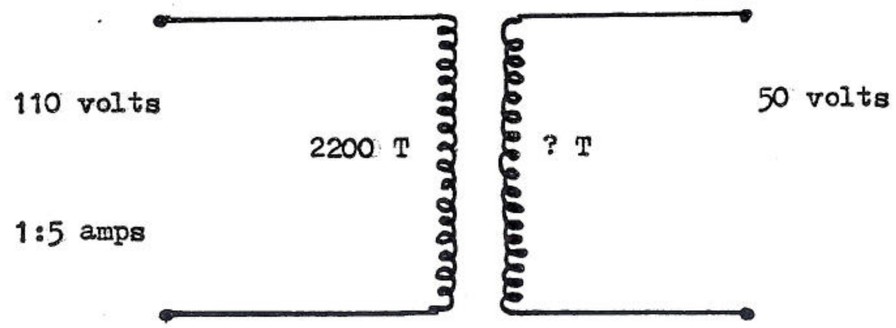
1.




Find :- Secondary Current 12·5A

Secondary Turns 600

2.




Calculate :- Secondary Turns. 1000T

Primary Power. 165 VA

Secondary Current. 3·3 A

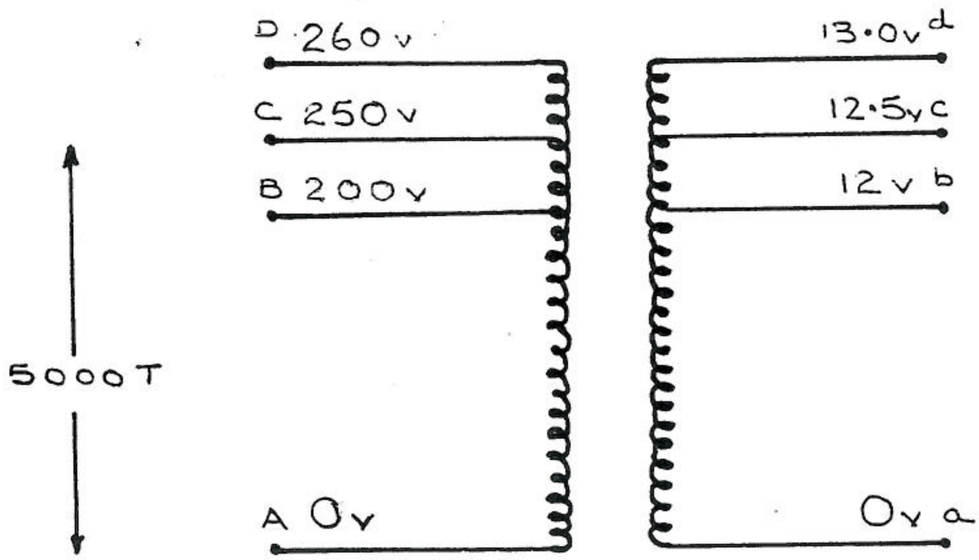
From the following example calculate the number of turns between:-

A — B 4000

B — C 1000

C — D 200

If there are 5000 T between A and C terminals and 250 Volts on the Primary side of the transformer, how many turns will be required to produce 12 Volts between terminals a and b. 240 T



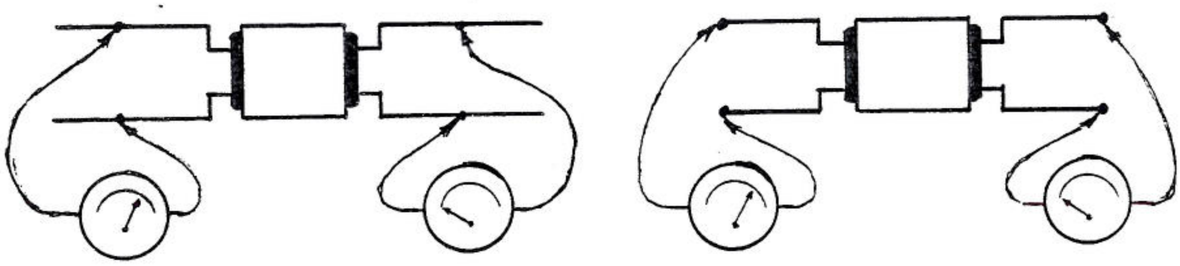
## TRANSFORMER FAULT FINDING.

The threethings that cause transformer failures are open circuit windings, shorted windings, and shorts to earth.

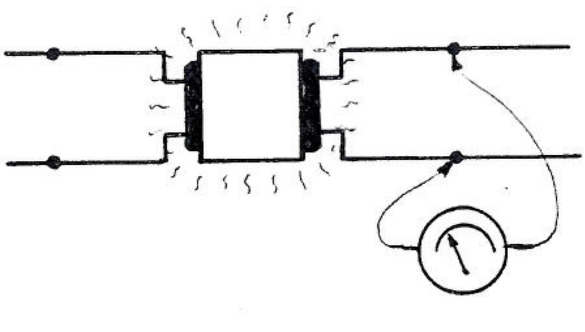
When one of the windings in a transformer developes an open circuit, no current can flow and the transformer will not deliver any output. The symptom of an open-circuited transformer is therefore that the circuits that derive power from the transformer go dead. A check with an A.C. voltmeter across the transformer output terminals will show a reading of zero volts. A voltmeter check across the transformer input terminals shows the voltage is present. Since there is a voltage at the input and no voltage at the output, one of the windings must be open circuited.

To find the fault, disconnect the transformer and check the windings for continuity, using an ohmmeter. Continuity (a continuous circuit) is indicated by a fairly low resistance reading, while an open circuit winding will indicate an infinate resistano on the ohmmeter.

In most cases the transformer will have to be replaced, unless of course the break is accessible and can be repaired.(e.g. A lead wire).

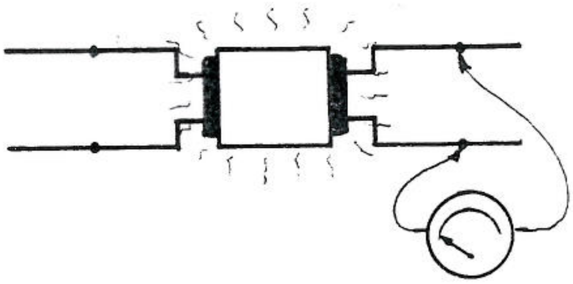


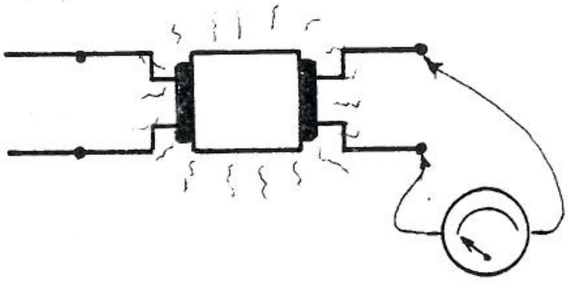
When a few turns of a secondary winding are short circuited, the output voltage drops, and the transformer may overheat by reason of the increase in current in secondary winding. The winding with the short gives a lower reading on the ohmmeter than normal. If the winding happens to be a low voltage winding, its normal resistance reading is so low that a few shorted turns cannot be detected by using an ordinary ohmmeter. In this case, a sure way to tell if the transformer is bad is to replace it with another transformer. If the replacement operates satisfactorily, it will prove the original was, in fact faulty, and should be replaced.



Sometimes a winding has a complete short across it. The short may be in the external circuit connected to the winding, or in the winding itself. Again, one of the symptoms is excessive overheating of the transformer by reason of the very large circulating current. The heat often melts the insulating materials inside the transformer, a fact which you can quickly detect by the smell. Also, there will be no voltage output across the sorted winding, and the circuit across the winding will be dead. In equipment which is fused, the heavy current flow will blow the fuse before the transformer is damaged completely. But if the fuse does not blow, the shorted winding may burn out.

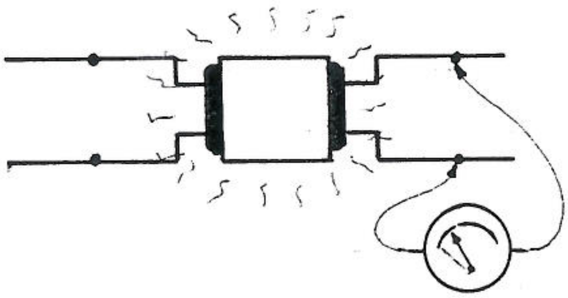
The way to isolate the short is to disconnect the external circuit from the winding. If the voltage is normal with the external circuit disconnected, the short is in the external circuit. But if the voltage across is still zero, it means the short is in the transformer, and it will have to be changed.

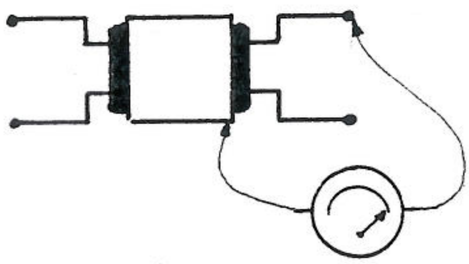




Earth faults are another type of fault which sometime occur. This is when, at some point, the insulation in the winding breaks down, and the wire becomes exposed. It may touch the inside of the transformer caes, shorting the wire to the case and so earthing the winding.

If a winding developes a short to earth, and a point in the external circuit connected to this winding is also earthed, part of the winding will be shorted out. The symptoms will be the same as those for a shorted winding, and the transformer will have to be replaced. You can check whether a transformer winding is shorted to earth by connecting a megger between one side of the winding in question and the trasformer case, after all the transformer leads have been disconnected from the circuit. A zero or low reading on the megger shows that the winding is earthed.





## RECTIFIERS.

Rectifiers are used to convert A.C. to D.C. and also to "Pass" D.C. current in one direction only.

When certain metallic materials are pressed together to form a junction, the combination acts as a rectifier having a low resistance to current flow in one direction and a very high resistance to current flow in the opposite direction. The combinations of metals most often used as in the manufacture of rectifiers are copper and copper oxide, and cadmium alloy (or tin) and selenium.

Metal rectifiers are constructed of discs ranging in size from less than half an inch to more than six inches in diameter. Copper-oxide rectifiers consist of discs of copper coated on one side with a layer of copper oxide; and selenium rectifiers are constructed of discs made of a metal such as nickel, iron or aluminium, coated on one side with selenium, on top of which has been deposited a surface electrode in the form of a layer of cadmium alloy or tin.

Metal rectifier elements (an element is a single disc) are generally made in the form of washers which are assembled on a mounting bolt, in any desired series or parallel combination, to form a rectifier unit. The symbol shown below is used to represent a metal rectifier of any type.

Since these rectifiers were made before the electron theory was used to determine the direction of current flow, the arrow points in direction of conventional current flow but in the direction opposite to the electron flow. Thus the arrow points in the opposite direction to that of the current flow according to the electron theory.

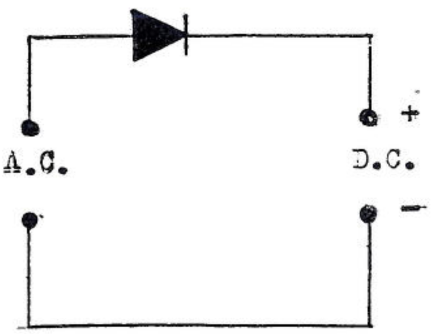
A single metal rectifier element will stand only a few volts across its terminals; but if you stack several elements inseries, the voltage rating is icreased.

Similarly, a single element can pass only a limited amount of current. When greater current is desired, several series stacks are connected in parellel to provide the desired amount of current.

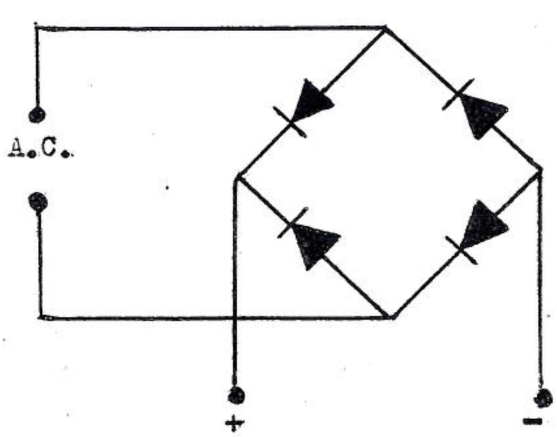
By connecting rectifier elements either in parallel or series, a rectifier of any desired voltage or current rating can be produced.

Metal rectifiers are very robust and have an almost unlimitd life if not abused.

HALF WAVE RECTIFIER

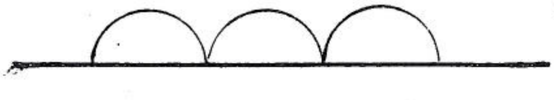



FULL WAVE RECTIFIER

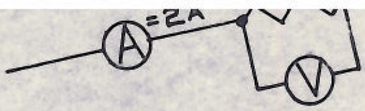



Pulsating D.C.

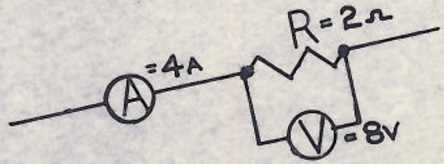
Unsmoothed D.C.



AGE (V)




ATTS (W)




✓ 32

NAL INDICATOR IS 350Ω
ANCE WHAT CURRENT WILL FLOW
REE VOLTS ARE APPLIED

✓ 8·6 mA

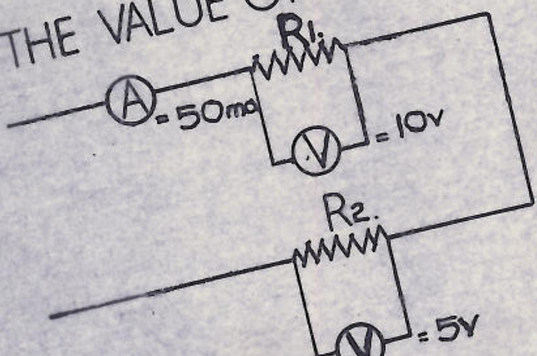
T CURRENT FLOWS WHEN A BULB
D TWELVE VOLT SIX WATT IS LIT

✓ 0·5A

E THE RESISTANCE OF THE BULB IN
UESTION .F.

✓ 24 Ω

VHAT IS THE VALUE OF R1.& R2.




✓ 200 Ω

✓ 100 Ω

A POINT INDICATION BULB IS RATED
12v. 2·4W.
WHAT CURRENT FLOWS
WHAT IS ITS RESISTANCE

✓ ·2A
✓ 60Ω

EXPRESS AS DEC

½
¼
¾
⅛
1/10
1/100
1/1000
1 1/5
1 1/3
1 3/5

EXPRESS AS F

·1
·7
·65
·25
·175
·02
·0
·7
·0

COMPLE

A

| | | | |
|---|---|---|---|
| …V | 30 amps | 2 Ω | 2.25 W |
| 7.5 V | 7.5 A | 25 Ω | 1000 W |
| 100 V | 300 ma | 10 Ω | 1250 W |
| 250 V | 10 A | 50 Ω | 0.12 W |
| 1.2 V | 5 amps | 12 Ω | 0.03125 W |
| .125 V | 100 ma | .5 Ω | 18 W |
| 30 V | .25 amps | 50 Ω | 250 W |
| 500 V | .6 amps | 1 KΩ | 1 W |
| 1 V | .5 A | 1 Ω | |
| | 1 A | | |

...40

...NG

| | | |
|---|---|---|
| DRAWN | | CORR. |
| CHECKED | | AUTH. |
| APPROVED | | DATE |

FOR USE IN THE TRAINING SCHOOL YORK

DRG. No 66 - Y.S.S 34.

BRITISH RAILWAYS

EXERCISE

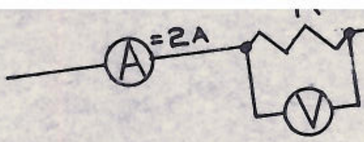
N.E. REGION

AMENDMENTS

B.R. 888/4.

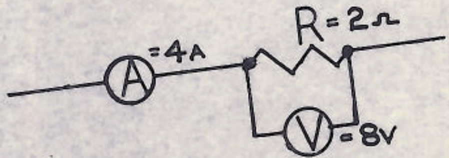
FILE No

ND VOLTAGE (V)




✓ 8 V

FIND WATTS (W)




✓ 32

A SIGNAL INDICATOR IS 350Ω RESISTANCE WHAT CURRENT WILL FLOW IF THREE VOLTS ARE APPLIED

✓ 8·6 mA

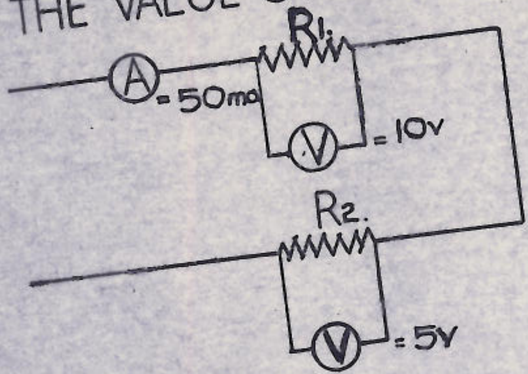
WHAT CURRENT FLOWS WHEN A BULB RATED TWELVE VOLT SIX WATT IS LIT

✓ 0·5A

G. GIVE THE RESISTANCE OF THE BULB IN QUESTION .F.

✓ 24 Ω

H. WHAT IS THE VALUE OF R1.& R2.




✓ 200 Ω

✓ 100 Ω

.I. A POINT INDICATION BULB IS RATED 12v. 2·4W.
WHAT CURRENT FLOWS
WHAT IS ITS RESISTANCE

✓ ·2A

✓ 60Ω

EXPRESS

EXPRES

CO

A

| | | | |
|---|---|---|---|
| 250v | | | |
| 50v | A | | |
| 30v | 15 amps | 2Ω | |
| 30V | 30 amps | 1Ω | 900W |
| 15v | 7.5A | 2Ω | 112.5W |
| 7.5V | 300ma | 25Ω | 2.25W |
| 100v | 10A | 10Ω | 1000W |
| 250v | 5 amps | 50Ω | 1250W |
| 1.2v | 100ma | 12Ω | 0.12W |
| .125V | .25 amps | .5Ω | 0.03125W |
| 30v | .6 amps | 50Ω | 18W |
| 500v | .5A | 1.KΩ | 250W |
| 1v | 1A | 1Ω | 1W |

| | |
|---|---|
| DRAWN | |
| CHECKED | |
| APPROVED | |
| CORR. | |
| AUTH. | |
| DATE | |

FOR USE IN THE TRAINING SCHOOL YORK

BRITISH RAILWAYS

N.E. REGION

EXERCISE

AMENDMENTS

FILE No

DRG. No 66 - Y.S.S 34.

B.R. 888/4.

75
300
800

CIMALS

0·5 ✓
0·25 ✓
0·25 ✓
0·125 ✓
0·1 ✓
0·01 ✓
0·001 ✓
1·2 ✓
1·3 ✓
1·6 ✓

TIONS

1/10 ✓
7/10 ✓
65/100 ✓ 13/20
1/4 ✓
175/1000 ✓ 7/40
2/100 ✓ 1/50
1/1000 ✓
3/4 ✓
25/1000 ✓ 1/40

OLLOWING

3/4 ✓
·3 ✓
4·35 ✓
·86 ✓
2 ✓
1/4 ✓
·128 ✓

COMPLETE THE BLANK SPACES IN THIS TA

| VOLTS | CURR | RESIS | WATTS |
|---|---|---|---|
| 250v | 250ma. ✓ | 1 KΩ | 62·5 |
| 50 v | A ✓ | 50 Ω | 50W |
| 30v | 15 amps ✓ | 2 Ω | 450 |
| 30V | 30 amps ✓ | 1Ω | 900 |
| 15v | 7·5A ✓ | 2Ω | 112· |
| 7·5V | 300ma ✓ | 25Ω | 2·25 |
| 100v | 10A ✓ | 10Ω | 1000 |
| 250v | 5 amps ✓ | 50Ω | 1250 |
| 1·2v | 100ma ✓ | 12Ω | 0·12 |
| ·125V | ·25 amps ✓ | ·5Ω | 0·0312 |
| 30v | ·6 amps ✓ | 50Ω | 18W |
| 500v | ·5A ✓ | 1.KΩ | 250 |
| 1v | 1 A ✓ | 1Ω | 1 W |

| DRAWN | | CORR. | |
|---|---|---|---|
| CHECKED | | AUTH. | |
| APPROVED | | DATE | |

FOR USE IN THE TRAINING SCHOOL YORK

BRITISH RAILWAYS N.E. REGION

EXERCISE

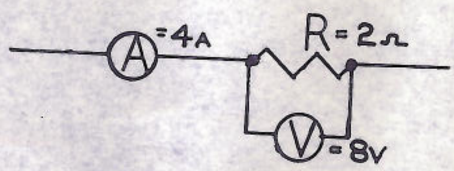
DRG. Nº

AMENDMENTS

B.R. 888/4.

66 - YSS 34

.D. FIND WATTS (W)




✓ 32

.E. A SIGNAL INDICATOR IS 350Ω RESISTANCE WHAT CURRENT WILL FLOW IF THREE VOLTS ARE APPLIED

✓ 8.6 mA

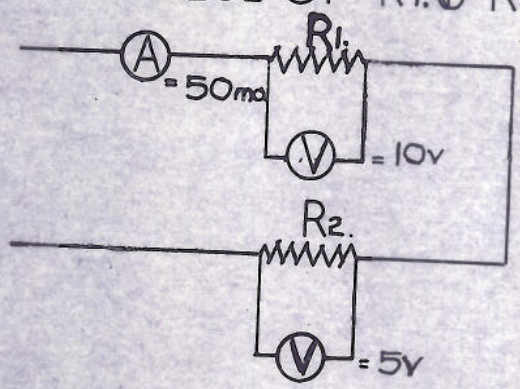
.F. WHAT CURRENT FLOWS WHEN A BULB RATED TWELVE VOLT SIX WATT IS LIT

✓ 0.5A

.G. GIVE THE RESISTANCE OF THE BULB IN QUESTION .F.

✓ 24 Ω

.H. WHAT IS THE VALUE OF $R_1$ & $R_2$.




✓ 200 Ω

✓ 100 Ω

.I. A POINT INDICATION BULB IS RATED 12v. 2.4w.
WHAT CURRENT FLOWS
WHAT IS ITS RESISTANCE

✓ .2A

✓ 60Ω

A

| |
|---|
| 75 |
| 300 |
| 800 |

CIMALS

0·5
0·25
0·25
0·125
0·1
0·01
0·001
1·2
1·3r
1·6

TIONS

1/10
7/10
65/100 13/20
1/4
175/1000 7/40
2/100 1/50
1/1000
3/4
25/1000 1/40

OLLOWING

3/4
·3
+·35
·86
2
1/4
·128

COMPLETE THE BLANK SPACES IN THIS TAB

| VOLTS | CURR | RESIS | WATTS |
|---|---|---|---|
| 250v | 250ma. | 1 KΩ | 62·5 |
| 50 v | A | 50Ω | 50w |
| 30v | 15 amps | 2Ω | 450 |
| 30V | 30 amps | 1Ω | 900 |
| 15v | 7·5A | 2Ω | 112·5 |
| 7·5V | 300ma | 25Ω | 2·25 |
| 100v | 10A | 10Ω | 1000 |
| 250v | 5 amps | 50Ω | 1250 |
| 1·2v | 100ma | 12Ω | 0·12 |
| ·125V | ·25 amps | ·5Ω | 0·03125 |
| 30v | ·6 amps | 50Ω | 18W |
| 500v | ·5A | 1.KΩ | 250 |
| 1v | 1A | 1Ω | 1W |

| | | | |
|---|---|---|---|
| DRAWN | | CORR. | |
| CHECKED | | AUTH. | |
| APPROVED | | DATE | |

FOR USE IN THE TRAINING SCHOOL
YORK

BRITISH RAILWAYS N.E. REGION

EXERCISE

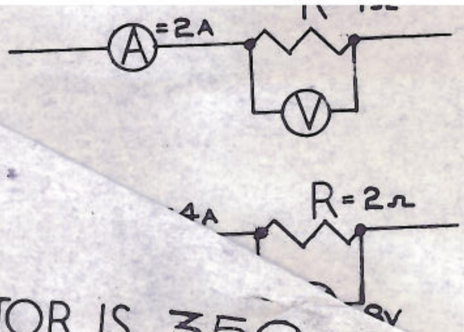
DRG. Nº

AMENDMENTS

B.R. 838/4.

66 - YSS 34

.D. FIND WATTS




✓ 8V

✓ 32

.E. A SIGNAL INDICATOR IS 350Ω RESISTANCE WHAT CURRENT WILL FLOW IF THREE VOLTS ARE APPLIED

8.6 mA

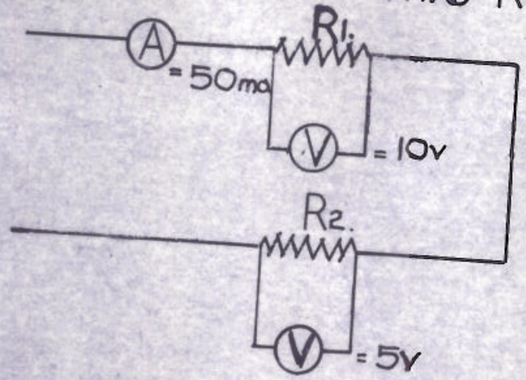
.F. WHAT CURRENT FLOWS WHEN A BULB RATED TWELVE VOLT SIX WATT IS LIT

✓ 0.5A

.G. GIVE THE RESISTANCE OF THE BULB IN QUESTION .F.

✓ 24 Ω

.H. WHAT IS THE VALUE OF $R_1$ & $R_2$.




✓ 200 Ω

✓ 100 Ω

.I. A POINT INDICATION BULB IS RATED 12V. 2.4W.
WHAT CURRENT FLOWS
WHAT IS ITS RESISTANCE

✓ .2A

✓ 60 Ω

A