

THE 'Hodson' INDUCTION KIT

Cat: EM1973-001 'Hodson' Induction Kit

DESCRIPTION: The 'Hodson INDUCTION KIT' is a set of parts that permits the student to study and experiment on aspects of Magnetic Induction, Transformers and AC/DC Motor theory. Students wind their own coils, assemble their own iron circuits, connect to low voltage power supplies and connect amp and volt meters.

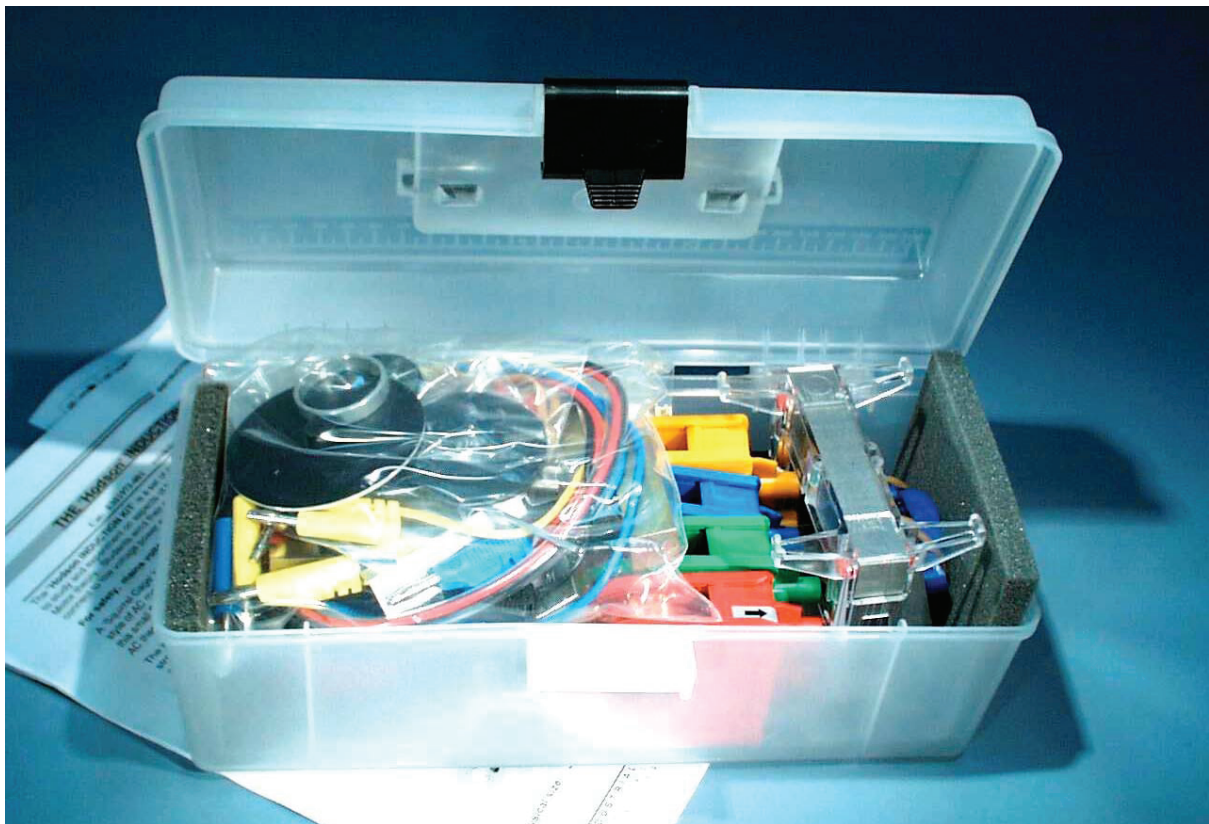
For safety, mains voltages are NOT used. Please supervise this.

A complete 'Squirrel Cage' Induction Motor is part of the kit for study and understanding of this very common style of AC motor. The Induction Kit is compatible with the popular 'Hodson' Motor Kit and this small DC motor will run when the "U" core is used as the DC field. More advanced AC theory and resonance can be studied by making chokes and using capacitors.

The instructor can adapt the kit for other purposes, like measuring the holding strength of an electromagnet or comparing the holding strength between an AC and a DC magnet, or making a vibrator or a buzzer and so on.

The kit is to be used in conjunction with text book experiments. The information and theory is general and is not intended to replace curriculum experiments.

EM1973-001 'Hodson' Induction kit



Physical size: 310x165x115mm LxWxH

Weight: 2.5 kg

**KIT CONTENTS:**

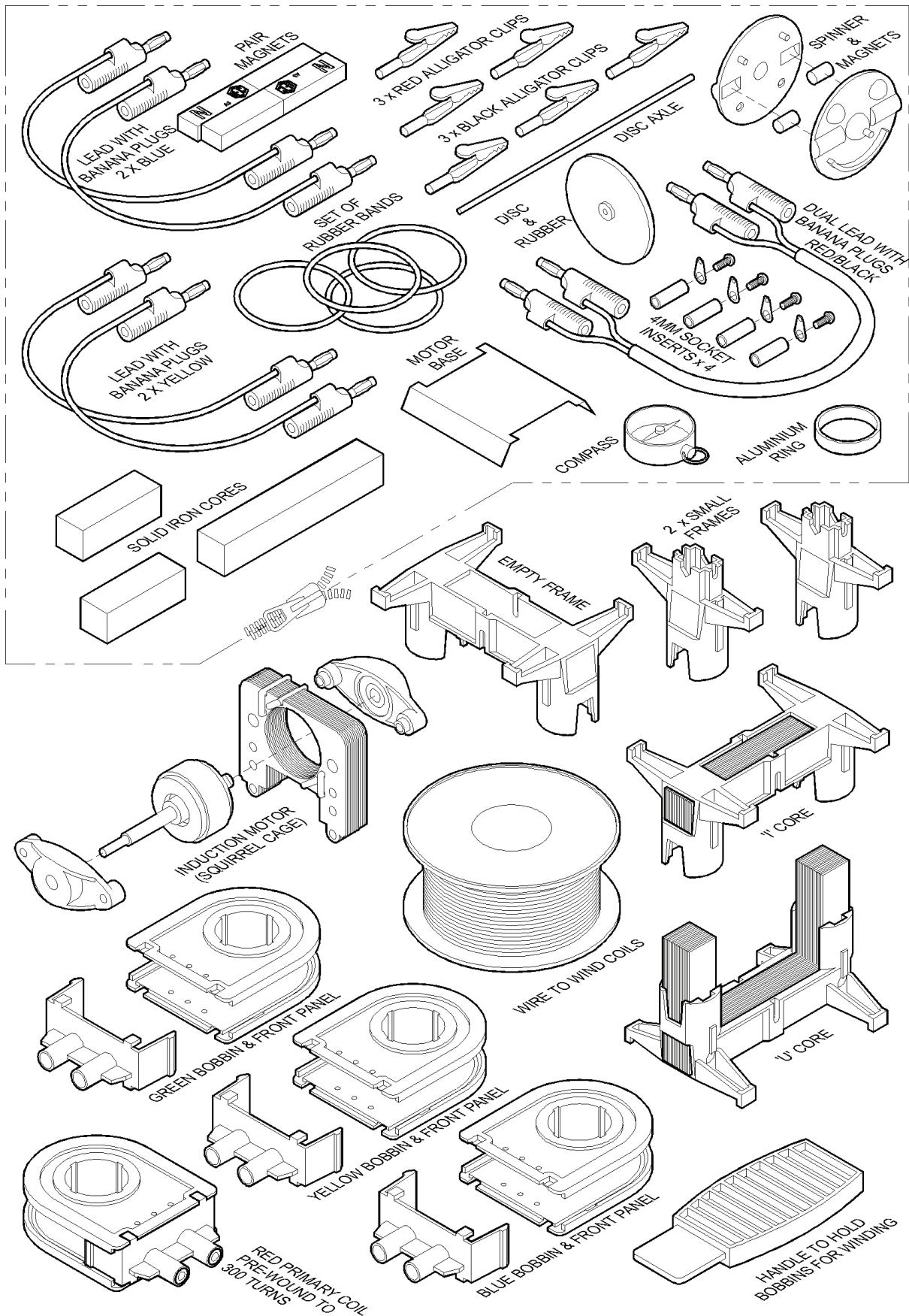
- 1 set “U” laminations, 16mm thick, mounted in plastic frame.
- 1 set “I” laminations, 16mm thick, mounted in plastic frame.
- 1 pce. Plastic frame, empty, to carry rotor and to hold iron cores and devices.
- 2 pcs. Plastic frame, small, to hold short cores and to carry disc axle.
- 1 pce. Iron bar, 16x16 square x 96mm long.
- 2 pcs. Iron bars, 16x16 square x 48mm long.
- 4 pcs. Coil bobbins for winding coils. Red, Yellow, Blue, Green. With coil fronts.
Red coil is pre-wound 300 turns and connected to 4mm sockets as the primary coil.
Another coil is pre-wound to 600 turns as a secondary and connected to 4mm sockets.
- 1 pce. Handle for holding bobbins during winding.
- 1 pce. Induction motor, AC, laminated frame, rotor, ball races and end shields.
- 1 pcs. Reel of insulated wire, large, for winding all coil bobbins.
- 1 pce. Instruction sheet and experiment manual.

The following items are in a separate zip bag:

- 1 set Cables, 1 pair red/black, 2 each yellow and blue, with stackable banana plugs.
- 1 set 3 red / 3 black Alligator clips.
- 4 pcs. Sockets, brass with lugs and screws, to make 4mm sockets for permanent coils.
- 1 pce. Rotor, plastic (2 halves), to carry small magnets, for studying basic AC motor theory.
- 2 pcs. Small cylindrical permanent magnets for placing into plastic rotor.
- 2 pcs. Bar magnets, 75mm long, for induction experiments.
- 1 pce. Disc, aluminium, with rubber centre, for eddy current experiments.
- 1 pce. Axle for supporting and spinning aluminium disc.
- 1 pce. Ring of aluminium for ‘Thompson’s Ring’ demonstration.
- 8 pcs. Elastic bands to stretch tightly between holder legs to pull core together.
- 1 pce. Plate, aluminium, to carry ‘Hodson’ DC motor assembly.
- 1 pce. Magnetic compass for determining polarity of magnetic poles.



PARTS FOR IDENTIFICATION:



A FEW BASIC CONCEPTS FOR TEACHERS AND STUDENTS:

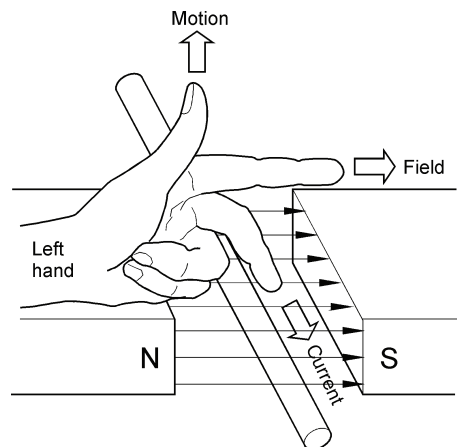
Conventions:

- 1) By convention, a magnetic field is normally depicted flowing from a North pole to a South pole.
- 2) By theory, electrons (negatively charged) flow from a more negative potential to a more positive potential whereas conventional current flows from positive potential to negative. In this booklet, we deal only with conventional current flow.

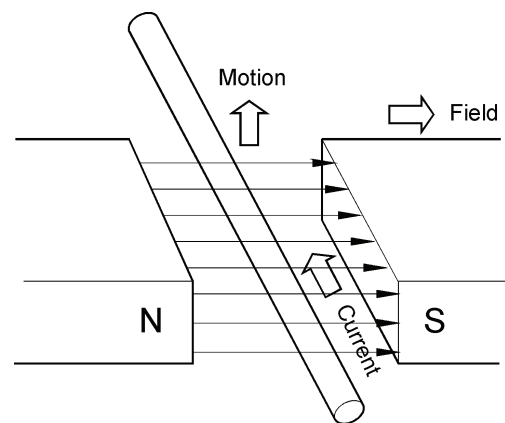
An interesting diversion regarding conventions: The tip of a magnetic compass that points north is the north pole of the needle. To confirm this, hold a bar magnet by cotton at its mid point so it can swing freely. The end marked 'north' points to the north magnetic pole of the earth. Of course, the direction to which the north end of a magnet is attracted must really be a South Pole. So, we must assume that the naming of the North and South poles of the earth is simply another "convention".

Current flow: When considering the current flow in a conductor where the conductor itself is generating the EMF, the polarity of the current flow appears to be reversed to the polarity of the current flow in the external circuit. For example, if current flows from Positive to Negative in a battery external circuit to say a lamp, it must be flowing from negative to positive INSIDE the battery.

Left Hand Rule (for motors), Right hand Rule (for generators): The left hand rule is a quick way to determine the direction of movement in a wire when the direction of the magnetic field and the direction of the current flow is known, as in the case of a motor. The Right Hand Rule using the same markings for the fingers, is used to find the direction of the current flow when the motion and the magnetic field directions are known, as in the case of a generator. Try it and see.

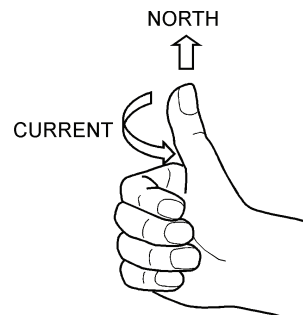
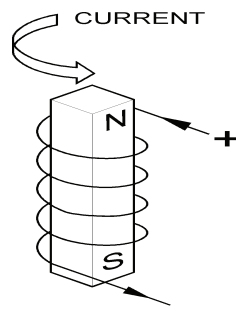


LEFT HAND MOTOR RULE
CURRENT & FIELD KNOWN, FIND MOTION



RIGHT HAND GENERATOR RULE
MOTION & FIELD KNOWN, FIND CURRENT

Right Fingers rule (for magnets): The Right Fingers Rule is useful to determine which end of an iron circuit becomes North Pole when the direction of the current in the coil is known. This is useful for magnets and transformers.



**A BRIEF GLOSSARY of TERMS:**

AC: Means Alternating Current. This is current that flows both forward and backwards following a sine wave waveform. AC does not have a + and - polarity so red and black plug and wire colours are usually not used.

BOOST: Term used to indicate that two separate windings on a transformer are connected so that one voltage adds to the other.

BUCK: Term used to indicate that two separate windings on a transformer are connected so that one voltage subtracts from the other.

CAPACITOR: A capacitor is a device that can store electric charge (something like a battery). The energy is stored as voltage is applied and current flows into it until it is 'charged'. At a later time, this energy can be released, or 'discharged' again to perform a function. These are commonly used in circuits that rectify AC to DC to try to make rectified DC smoother. When the AC waveform falls to zero, the energy stored in the capacitor is discharged to try to fill the gaps in the AC waveform. As the AC waveform rises again, the capacitor is re-charged. This occurs 100 times per second and when used in this manner, they are called 'filter capacitors'. Large filter capacitors are polarised and, if they are connected backwards to the DC voltage, they can get hot and burst with a loud 'bang'. There are many types of capacitors for various uses.

CHOKER: This is an AC device and is sometimes called an 'Inductor'. It is an iron core with only one coil fitted. The magnetic field in the iron caused by the current through the coil also cuts the turns of wire in the same coil and causes a reverse voltage in the winding that opposes the applied voltage. This tries to stop the flow of current through the coil. The AC current flowing through any coil without iron core is greatly reduced when an iron core is fitted.

CORE: Means the iron shape that is used to couple the magnetic field between two or more coils. A magnetic field can exist much more easily in an iron core than it can in air. When an iron core is used inside the coils, the induction effect is much more efficient. See 'Reluctance'.

CURRENT: This is the conventional flow of electricity through a conductor. It is caused by an EMF or voltage created causing electrons to flow in a conductor if a circuit is closed. In DC circuits, the current flows in a conductor 'in phase' (see glossary) with the voltage. In AC circuits this is not always the case, but this phenomenon is reserved for more advanced AC studies.

DC: Means Direct Current. This is current that flows in one direction only. It might be a smooth, non-varying current from a battery, or it might be a pulsating current which is obtained when AC is rectified to DC. The AC sine wave is converted by the rectifier to flow in one direction, but rises and falls 100 times per second from zero to maximum in the shape of half of a sine wave. DC has a polarity and normally red means positive and black means negative. Current flows in a DC circuit from positive to negative.

EMF: Means Electro Motive Force. This is the voltage generated in a conductor. The voltage is like the pressure of electricity and, when the circuit is closed, a current is forced through the conductors because of the presence of an EMF. The amount of current flowing depends on the magnitude of the EMF and the resistance of the circuit (Ohm's Law).

FIELD: This is a general name given to magnetic lines of force either in an iron core or in air.

FILTER: When AC voltage is rectified to create DC, the DC is not smooth like a battery. It follows the AC sine wave shape and, although it does not reverse direction, it rises from zero volts up to a peak and falls again 100 times per second (full wave rectification) or 50 times per second (half wave rectification). A filter, which is usually a large value capacitor connected across the DC, tries to level out the humps and make it closer to a smooth DC. The effect is best seen on an oscilloscope.

FLUX: Is a general term meaning the magnetic field present usually in an iron core.



FREQUENCY: This is the number of times per second that the AC wave passes through one full cycle of rising from zero to maximum, then falling through zero to minimum and then rising to zero again. The unit is Hertz. Normal mains power in Australia has a frequency of 50Hz. Other countries such as USA and Canada (and many others) use a 60Hz power system.

IMPEDANCE: In the world of DC, resistance (ohms) is the factor that controls the current in a circuit. In the world of AC, there is a mixture of both Resistance and Reactance which alter the flow of current through an AC circuit. The term Impedance means the combination of these two phenomena. The term 'Low Impedance' means a circuit that has only small total resistive effect to an AC current flow.

INDUCTANCE: This is the measurement of a coil's inductive effect in Henrys. Inductance depends on the number of turns in the coil and the amount of iron in the core. Coils of low inductance (micro Henrys) are used in radio sets for tuning stations and coils of larger inductance (milli Henrys or Henrys) are used as Chokes for power supply filters or high power oscillators and special equipment.

INDUCTION: Means the inducing of a voltage in a coil of wire by the application of a magnetic field from either a magnet or another coil of wire. The coils of wire are usually not electrically connected.

INDUCTOR: An inductor is a coil of many turns of wire mounted on an iron core (see Choke).

LAMINATIONS: Iron cores in an AC device are made from thin strips of iron instead of from solid blocks of iron. These thin strips are called laminations and are insulated electrically so current cannot flow from one to another. This is to reduce or eliminate wasteful and unwanted circulating currents in the iron.

LEAKAGE: This is stray magnetic field that appears outside the iron core. Any field leaking outside the iron core cannot be used by the transformer in driving the secondary coil. Transformer design tries to keep magnetic leakage to a minimum.

LOSSES: This is the name given to energy provided by the Primary coil to the system but not available as usable energy from the secondary coils. Transformer losses include:

- The energy required in magnetising and de-magnetising and reversing the magnetisation in the core 100 times per second. Special iron used for transformers has low losses.
- Resistance in the copper wire of the windings causing voltage loss and heat generated.
- Circulating currents in the iron core causing heating of the iron.
- Loss of magnetic field (leakage) into the air from the iron core.

MAGNETISING CURRENT: This is the current drawn from the power source by the primary coil required to magnetise the iron core and to overcome leakage and losses. Transformer design tries to keep the magnetising current as small as possible because it is wasted energy from the power source and causes unwanted heating in the primary coil.

PHASE: If you raise both arms and lower them together, they are 'in-phase'. If one arm rises as the other arm falls, they are 'out of phase'. The timing relationship of two voltages or two currents or a voltage compared to a current is called the 'phase relationship'. In the world of DC, currents and voltages are usually 'in phase'. This is not always the case in the world of AC.

As an AC voltage rises in a coil with an iron core, the current through the coil rises slightly later than the voltage. Therefore the magnetic field also rises slightly later than the voltage. The voltage induced in a secondary coil therefore appears at a different instant when compared to the applied voltage. Look at these voltages on a double beam oscilloscope. If a secondary coil is wound the same direction (clockwise or anti-clockwise) as another secondary coil, the AC voltage on these two coils will be rising and falling at exactly the same time. This means they are 'in phase'. If they are connected in series, their voltages will add (see 'boost' in the glossary). If one coil is wound in the opposite direction, they will be 'out of phase' and their voltages will subtract (see 'buck' in the glossary). Phase angle is from 0 to 360 degrees. The term 'in phase' means a shift of zero degrees in phase. 'out of phase' means a shift of 180 degrees in phase.

PRIMARY; The name given to the transformer winding that is connected to the power source. It provides the energy to both magnetise the iron core and to transfer to the secondary winding(s).



REACTANCE: The world of DC has Resistance (Ohms) that controls the flow of DC current in a circuit and generates heat (Watts). In the world of AC, resistance exists but, in addition to resistance, AC circuits have Reactance. It behaves like resistance but does not generate heat. Reactance depends on the Inductance (Henrys) of a coil and the Frequency (Hertz) of the AC current flowing through it. Reactance is reserved for a more advanced study of AC theory.

RECTIFICATION: AC can be changed to DC by 'rectification'. If a single diode is used, only one half of the AC waveform passes through the diode as DC and the voltage appears as 50 humps per second. If 4 diodes are connected in a 'bridge' configuration 'full wave' rectifier, both halves of the AC waveform are rectified and the DC appears as 100 humps per second. If a transformer winding has a 'centre tapping', only 2 diodes are required to create 'full wave' rectification. Rectification is reserved for electronic study and is not fully covered in this booklet.

RELUCTANCE: The ability of a material to support a magnetic field is called the 'reluctance' of the material. Air has a very high reluctance and iron has a low reluctance. The special laminated iron used to make transformer cores usually has a very low reluctance.

RESISTANCE: Means the ease or difficulty that electrons have in flowing through a circuit. Glass does not conduct electricity, so it can be said that it has an extremely high resistance. Metals allow easy flow of electrons, and can be said to have a very low resistance. Every material has resistance value in OHMS. 'Kilohms' means thousands of ohms. 'Megohms' means millions of ohms.

Ohm's law: 1 volt EMF causes 1 AMP of current to flow through 1 OHM of resistance.

ROTOR: The rotor of a motor is the part that rotates

SECONDARY: The name given to winding(s) of a transformer that are not the 'Primary' winding.

STATOR: The stator of a motor is the part that does not rotate.

TAPPING: If a coil is wound part way (say 20 turns) and the wire is then looped from the bobbin to a connection point and then returned to the coil and the coil wound further, the coil is said to have a tapping. Transformer coils can have as many tapings as desired to provide many voltages from the one coil. If two coils of say 50 turns are connected in series, this is the same effect as one 100 turn coil tapped at the mid point.

TRANSFORMER: This is a device where two or more coils of wire are coupled by an iron core so that the magnetic field in the iron created by one of the coils (the primary coil) induces a voltage in the other coils. The coils are not normally electrically connected to each other. Depending on the number of turns of wire on the coils, the voltage applied to the primary coil can be changed or transformed to a different voltage on the secondary coil(s).

VOLTAGE: This is the electrical 'pressure' that is created in a conductor when a conductor moves relative to a magnetic field to cut the lines of magnetic force. The voltage cannot cause current to flow until the circuit is closed. The voltage is dependent on the strength of the field and the speed of motion of the conductor. Voltage can be created also chemically as in a battery or by heat or light or by electric charge as in static electricity, lightning and similar.

WATTS: When a voltage causes a current to flow through a resistance, heat is generated in the resistance. The power generated is called Watts. For a DC circuits, Volts x Amps = Watts. For AC circuits it is more complicated and this is reserved for later study.

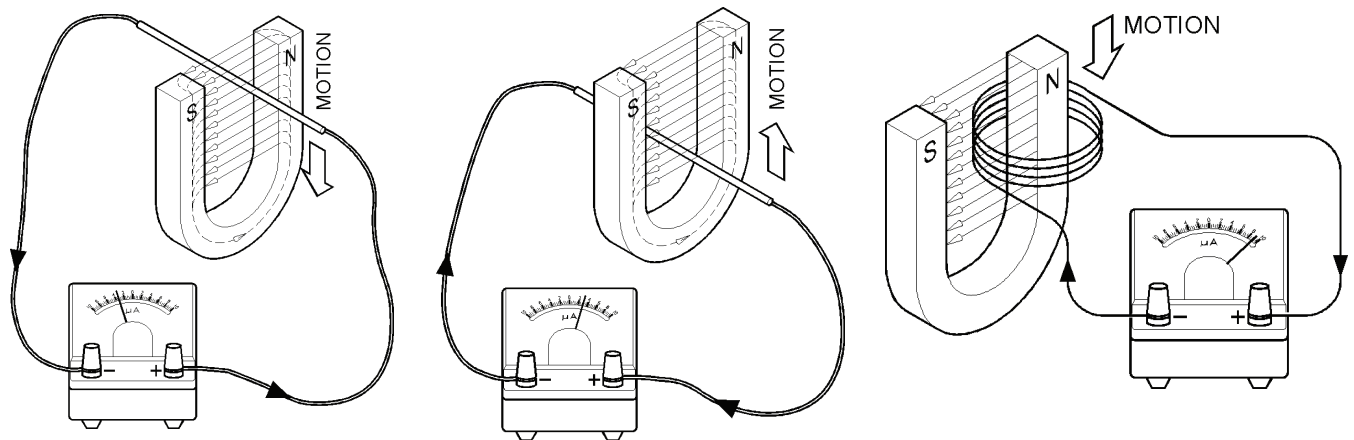
THEORY OF INDUCTION:

If a conductor is moved in a magnetic field so that the conductor cuts the lines of magnetism, a small EMF (Electro Motive Force or Voltage) is induced in the conductor whilst it is moving. The voltage reverses if the direction of motion reverses. If motion stops, the EMF is zero.

If the conductor is moved so that the conductor moves **parallel to** but **does not cut** through the lines of magnetic force, the EMF produced is zero.

The size of the EMF increases if the magnetic field is stronger, if the motion is faster or if many turns are used (see drawing below).

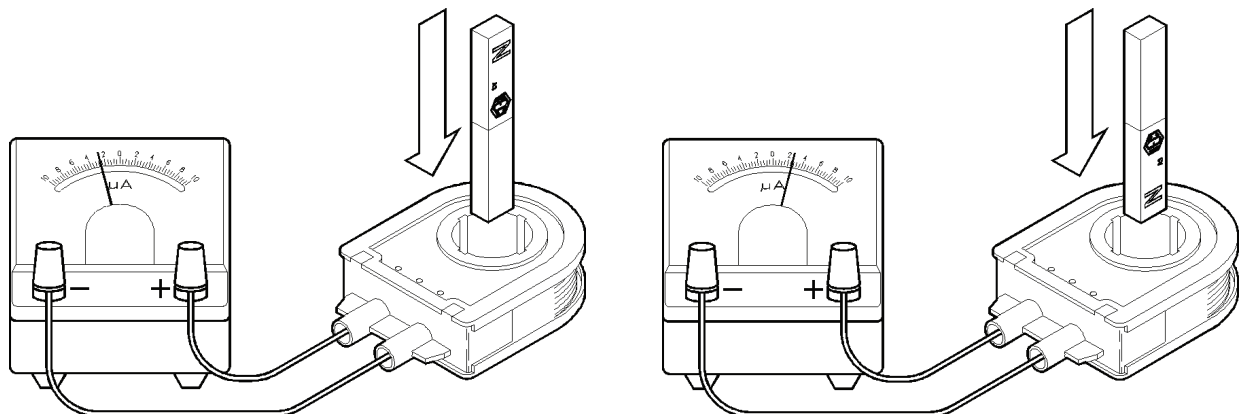
NOTE TO TEACHERS: To measure the current in the circuits below, a very sensitive galvanometer is required. The EMF generated in the wire is very small, so it is very important that the **impedance** of the galvanometer is very low (this is often difficult to arrange). It is possible that a coil of 20 turns or more will be required to generate a high enough voltage to drive a school meter.



LEAVE THE COIL ALONE AND MOVE THE MAGNETIC FIELD:

Connect a coil as shown and move a bar magnet as shown. Notice the voltage is generated in the coil only while the magnet is moving. If the magnet could be made to go back and forth continuously, there would be a 'back and forth' voltage generated continuously. Try it and see.

The direction that the galvanometer deflects depends on the direction of the winding of the coil (clockwise or anti-clockwise), the end of the magnet (north or south) and the direction of movement (up or down). Reverse the various things and try it. Remember that if a coil is simply turned over, the direction of the coil (clockwise or anti-clockwise) reverses.



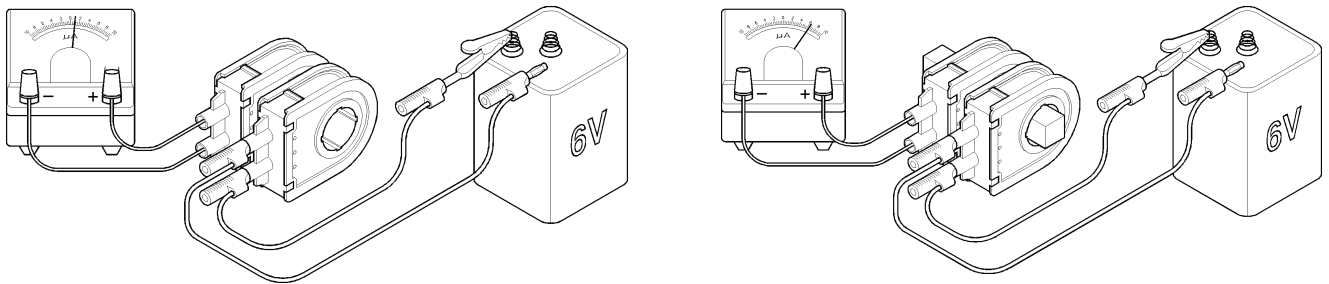
USE ANOTHER COIL TO PROVIDE THE MAGNETIC FIELD:

The magnetic field does not need to be provided by a permanent magnet. Another coil can be used to create a magnetic field. Prove this by placing the long iron bar inside the 300 turn primary coil and apply say 2 or 4 volts DC from a battery to the coil terminals. Notice that the iron bar becomes magnetised. Use the magnetic compass to prove the bar is magnetised north at one end and south at the other end. If you know the direction of the winding, use the 'Fingers Rule' to check the north and south ends of the iron bar.

Place two coils side by side and connect as shown below. One can be the 300 turn primary coil and the other can be one that you wound yourself with say 100 turns. Apply DC voltage from a battery to the coil that is not connected to the galvanometer. Notice that when the coil is first connected and the magnetic field is first created, the other coil causes the galvanometer to deflect momentarily. Notice that when the battery is disconnected and the field collapses, the galvanometer deflects momentarily in the opposite direction.

Reverse the polarity of the connection and see the galvanometer deflect the opposite direction during connection and disconnection.

When the magnetic field is established and no longer forming or collapsing (not varying) the galvanometer shows zero current.



In the left side arrangement, the two coils are coupled only by air. If an iron bar is placed inside the coils, the coupling is greatly improved and the galvanometer deflection is increased. It is proven that an 'Iron Circuit' inside the coils greatly improves the magnetic coupling between them.

NOTE: Use a battery for smooth DC current to be applied to the coil to form the magnetic field.

USING AC INSTEAD OF DC:

Using the same arrangement of two coils and the iron bar as shown in the right side illustration above, take a power pack and apply 6 volts AC to the coil from a power supply instead of DC. AC reverses its direction 100 times per second. This means that the induced EMF in the other coil will reverse 100 times per second. This is so fast that the galvanometer cannot follow the changes and the galvanometer needle just vibrates slightly and appears to read zero. Replace the Galvanometer (a DC instrument) with an AC voltmeter which is designed to read AC voltages.

If an oscilloscope is used instead, the AC waveform (a sine wave) can easily be seen.

The presence of a proper closed iron circuit between the coils greatly improves the efficiency of the system, **but we now have a simple device that is fed with an AC current and continually generates an AC voltage in another coil. This device is called a Transformer.**

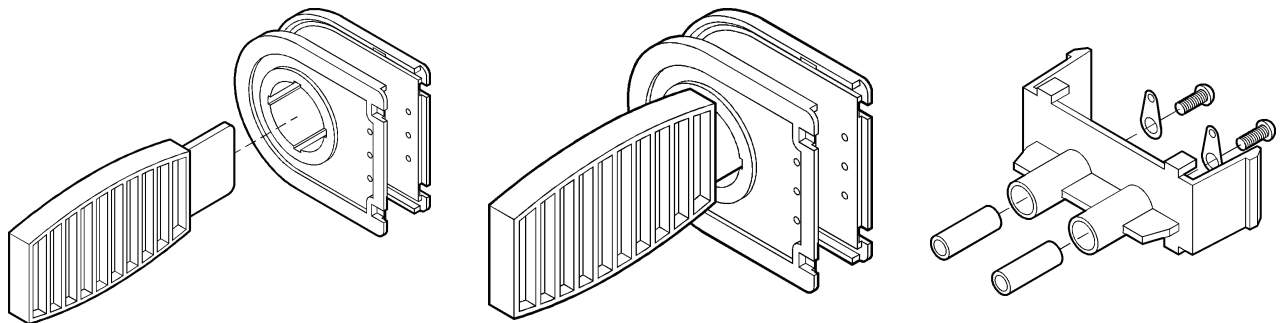
TRANSFORMERS and 'Hodson Induction Kit' COILS:

The red Primary coil supplied in the kit has 300 turns already wound on it. This is the correct number of turns for the primary coil and will fully magnetise the iron core when connected to 12 volts AC. If connected to 12 volts DC, the current will be too high and the coil will get hot. If DC operation is desired, use a lower voltage of say 2 to 6 volts DC.

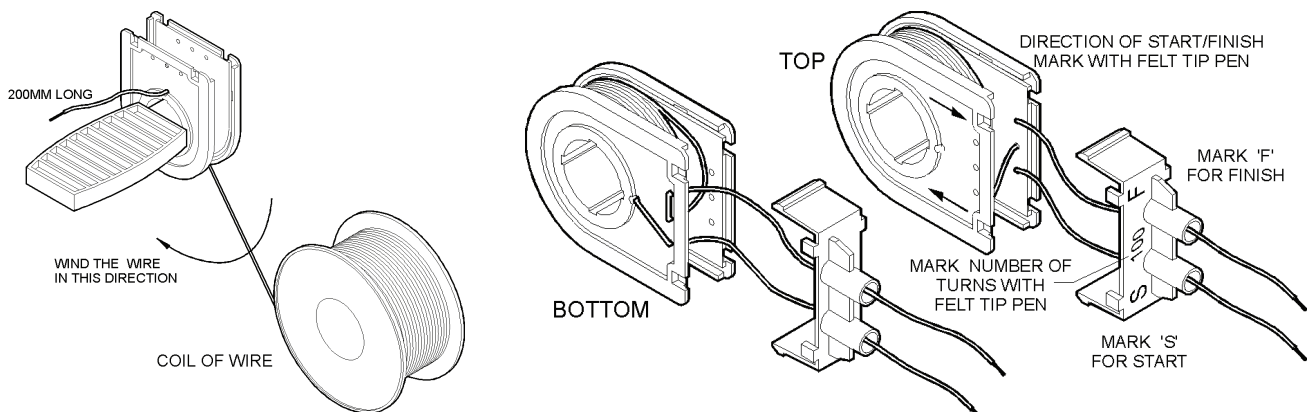
The coils wound by students will usually be less turns than the primary coil. With 12 volts AC on the primary coil and with the iron core fitted, 100 turns wound on a secondary coil will provide an output voltage from the coil of close to 4 volts AC. If say 30 turns is wound on a secondary coil, it will provide an output voltage of about 1.2 volts AC. AC voltmeters are required for measurements.

The primary coil provided has its wire terminated to 4mm sockets so that banana plugs can be used for connection. Coils wound by students usually will have the ends of the coil wire simply threaded through the holes provided in the coil panels provided. There is usually no need to terminate the wires inside the coil, but extra 4mm sockets are provided in the kit if this is desired.

Illustration below shows assembly of sockets to a front panel. Wires should be soldered to the lugs. The front panel of the primary coils can be pulled off the bobbin to see the connection method.



HOW TO WIND A COIL: Fit the winding handle as shown above. The handle makes winding the coil much easier. Take the insulated wire from the large spool and from the inside between the two bobbin sides, poke the wire through the hole close to the central hole. Leave about 200mm of wire exposed. Wind the wire as shown in the sketch below. Count the turns carefully.



After winding the desired number of turns, to finish the winding, cut the wire and poke the end out one of the three holes near the edge of the bobbin and then thread back through another hole. The wire that is from the start of the coil is threaded back through the third hole so that the start and the finish are both now **between** the two sides of the bobbin.

Take a coil panel of the same colour as the bobbin and thread the two wires through the two tubes to protrude from the front. Click the front panel into place between the bobbin sides.



Take the sheet of labels supplied in the kit and, if paper, cut them out with scissors or if self adhesive, peel off to stick to the bobbin. Mark the number of turns on the label.

If the direction arrows are wrong for the clockwise or anti-clockwise direction of winding of your coil, these can be cut off the strip and positioned on the opposite side of the bobbin. For an example, look at the 300 turn primary bobbin supplied in the kit.

With a felt pen, mark the number of turns and (if desired) the resistance value in ohms of your coil. The 'S' means 'Start' of the coil and the 'F' means 'Finish' of the coil. By convention, the start of the coil is the wire you threaded through the hole close to the central hole in the bobbin. It is easier to see the direction of the finish of the coil on the outer layer and you then know that the start must be in the opposite direction.

The previous image shows a coil wound clockwise with the start coming from the left hand tube and finish coming from the right hand tube. **This is the normal and best configuration.**

CLOCKWISE or ANTI-CLOCKWISE:

The direction of the winding is important to predict the polarity of the induced EMF. Notice that if the coil is turned upside down, the direction of the winding is reversed and clockwise (same direction as clock hands move on a clock's face) becomes anti-clockwise when looking from above the coil.

When using DC, the magnetic field produced by the coil will be reversed if the coil winding direction is reversed or if the coil is turned over.

When using AC, if the coil is turned over, the 'phase' of the voltage produced in the coil will be reversed (see 'Phase' in the glossary). If one secondary coil is reversed to another secondary coil, their phases will be reversed. This means that while the voltage is rising during 100th of a second in one coil, the voltage in the other coil will be falling during that short time. If they were joined in series, one coil voltage would subtract from the other coil voltage (see 'buck' in the glossary). If both coils had equal turns, the resultant voltage would be zero. If both coils were the same direction, the resultant voltage would be double (see 'boost' in the glossary).

CHOOSING METERS FOR MEASUREMENT:

For basic induction work, sensitive DC meters or sensitive Galvanometers are best. Galvanometers measure very small currents of around 20 to 50 microamps. This is required to see currents flowing as single conductors are moved in a magnetic field.

Student analogue bench meters of 0-1mA or 0-10mA DC are required for monitoring currents if coils with many turns are creating current with bar magnets and so on.

For transformer work, AC meters are always required. 0-20V.AC analogue student bench meter is probably best for primary coil volts. Another one or two 0-20V.AC or 0-10V.AC would be required for monitoring secondary coils for experiments.

Two analogue student bench AC ammeters around 0-1A / 0-10A.AC. either single or dual range will be needed for primary currents. An additional 0-10A.AC analogue meter would be useful for showing short circuit currents and similar in secondary coils. Your supplier should stock our wide range of 'Technos' Student AC bench meters to do the job as required.

Good student type bench meters are much better to use than digital meters so students can see sudden fluctuations and they are less confusing to the student and teacher alike. Also they are easier to see from a distance.

Analogue multi-meters can be used but many do not have AC ranges of current that suit the experiments. Also there is a risk of selecting the wrong voltages or currents.

WHY DO TRANSFORMERS USE 'AC' INSTEAD OF 'DC' ?

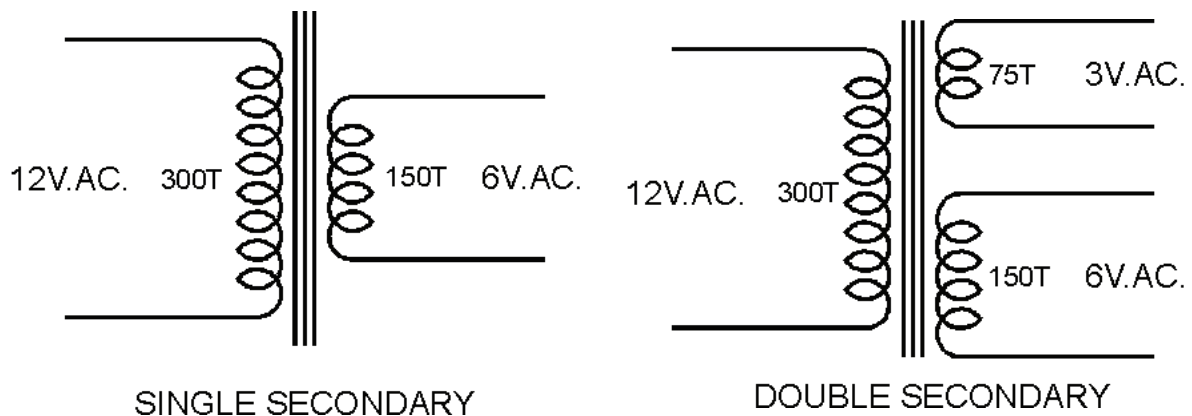
We have seen that the EMF is created in the second coil only when the DC magnetic field changes. There is no EMF when the magnetic field from the first (the primary) coil is steady. Therefore, if AC is used and the field is continually rising falling and reversing 100 times per second, a continuous AC EMF is generated in the second coil. This means that a useful amount of energy is continuously being transferred from one coil to the other.

This Induction Kit is to learn about transformers which are devices that run on AC only. AC is applied to one coil and an iron circuit couples the energy from this coil to another coil. If the number of turns in each coil is the same, the voltage applied to the primary coil will induce the same voltage in the secondary coil because the same magnetic field is coupled by the iron core through both coils.

If the secondary coil has say half the number of turns of the primary coil, the voltage from the secondary coil will be half the voltage applied to the primary. If the secondary coil has 10 times the number of turns of the primary coil, the voltage on the secondary will be 10 times the primary voltage. This is the main function of a transformer – to TRANSFORM one voltage to another voltage. This is how the dangerous 240V.AC. from the power point can make say a safe 6 volts to charge a mobile phone. The little black box that is used contains a Transformer.

Another function of a Transformer is to provide a voltage that is not electrically connected to the original power source (called an Isolating Transformer). This results because the two coils are not electrically connected to one another and the energy is passed from one coil to the other by the magnetic field in the iron circuit that couples them.

Transformers can be depicted in several ways, but a common method is shown below. The first transformer shows a primary coil and a single secondary coil and the second transformer shows a primary coil with two secondary coils. The parallel bars represent the iron core that links the primary and secondary coils together.



In some cases, if a very high voltage is required, a secondary winding might have many thousands of turns and in other cases, for very low voltages, the secondary might have only one single turn. Usually, if the secondary turns are many, the current available from the secondary is small and, conversely, if the secondary turns are small, the current can be thousands of amps for welding or electro-plating or similar purposes.

Multiple secondary coils can be connected in different ways to provide different voltages from the transformer. In the right hand example, if the two secondary coils were connected in series, it is equivalent to a coil of 225 turns. Examples will be seen later in this booklet.

LAMINATIONS:

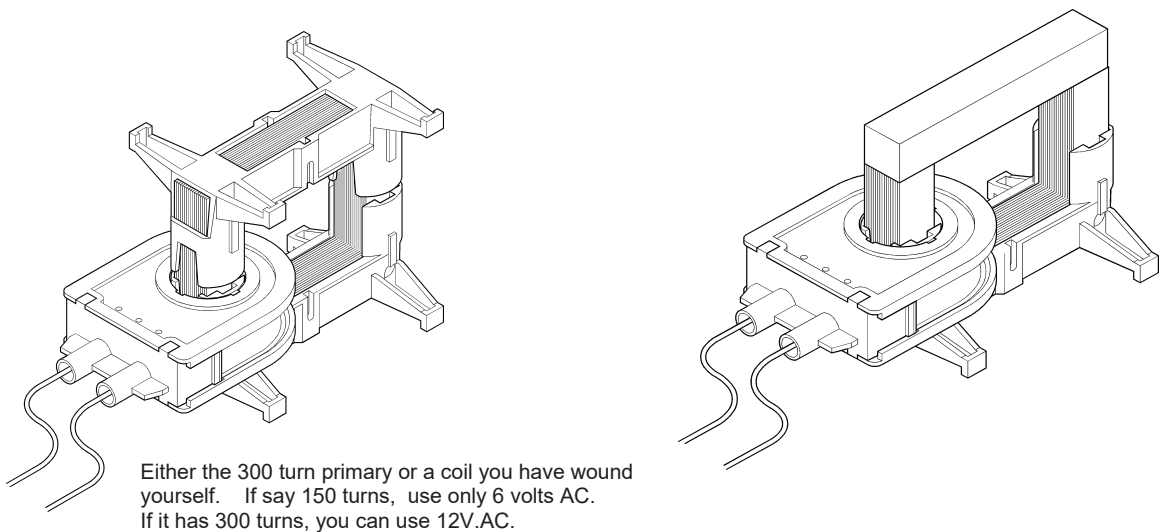
Why is the iron core 'laminated' instead of using a solid iron core ?

We know that when the AC magnetic field is created, the lines of magnetic force (called Flux) cut the turns in the secondary coil and produce a voltage. Current can flow from the secondary coil only if an external circuit is connected to the secondary coil.

But the same flux cuts the iron too and the iron material is also a conductor of electricity. A small voltage is induced across the thickness of the iron core and because of this small voltage across the iron core, a strong current can flow inside the iron core as if it were a secondary coil with a short circuit connected. This current robs energy from the primary coil and also makes the iron heat up.

To prove this important point, proceed as follows: Lift the 'I' core and remove the secondary coil. Re-fit the 'I' core and connect an AC ammeter in series with the primary coil and connect to 12V.AC. Make note of the amps flowing into the primary.

Then remove the laminated 'I' core and replace it with the solid bar of iron. See below.



Measure the primary current again. The current taken by the primary coil to only magnetise the iron core is called the 'Magnetising Current'. For an efficient transformer this wasteful and useless energy loss is avoided and reduced to a minimum by good transformer design.

With the solid bar in place, notice the big rise in magnetising current because of the unwanted currents flowing in the iron bar. Leave the system for say 5 or 10 minutes. Notice the rise in temperature of the iron bar as the energy of the circulating currents heats up the iron.

If a laminated iron core is used, the separate laminations stop most of the circulating current in the iron and the serious loss of energy stops. You will notice that all AC devices, transformers, magnets or motors etc. always use laminated cores.

If the motor or magnet device is a DC device, lamination of the iron core is not necessary because the magnetic flux is steady and not constantly cutting the iron 100 times per second. Therefore there are no circulating currents induced in the iron.

Circulating currents in solid materials are sometimes called 'Eddy Currents'.

USEFUL EDDY CURRENTS:

When moving magnetic fields cuts through solid metal materials, circulating currents, or 'Eddy Currents' flow inside the solid materials. These currents create a magnetic field of their own and these magnetic fields oppose the magnetic fields that created them.

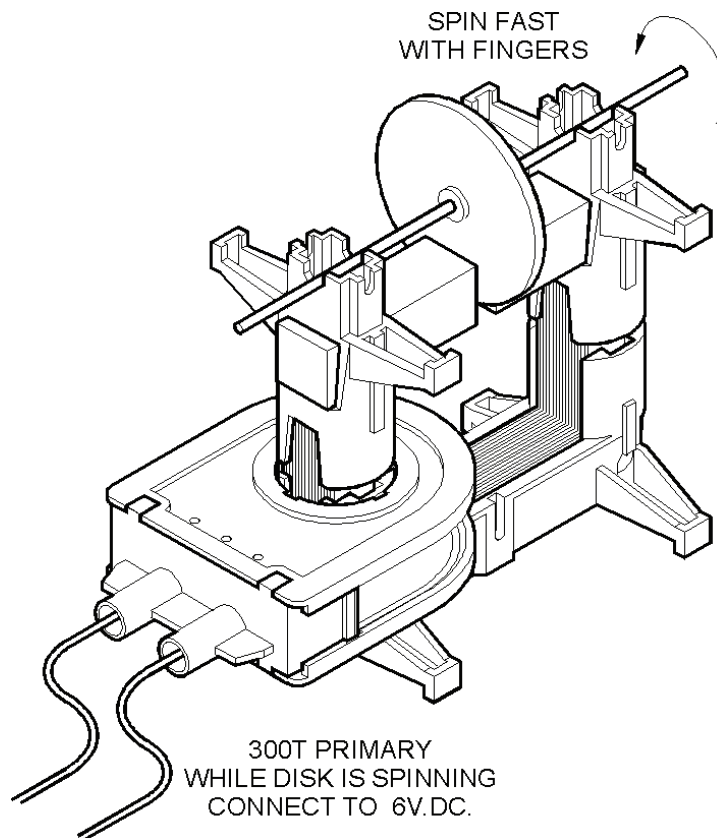
The 'Hodson' Induction Kit can show the effect of these currents and fields.

Place the 300 turn primary coil (or any other coil) on one leg of the 'U' core and position 2 short iron cores as shown in the illustration below. Clamp them down to the tips of the 'U' core using the small plastic frames and rubber bands.

Make the air gap between the poles about 4 or 5mm.

Take the metal disc with the rubber centre and press the metal axle through the rubber so the disc is about the mid point of the axle. Be sure the disc is straight and does not wobble sideways.

Rest the axle in the small 'Vee' slots in the tops of the plastic frames so that the disc hangs between the poles in the air gap. Spin the axle with the fingers so that the disc spins fast. If it just touches the poles momentarily it does not matter, but it is better if it does not touch as it spins. Practice spinning it a few times with the finger tips of one hand.



While the disc is spinning fast, connect the coil momentarily to a DC power source (battery or DC power supply at about 6 volts DC). **Notice what happens to the spinning disc.**

The reason the disc stops spinning quickly is that when the DC field is applied to the air gap, 'Eddy Currents' flow in the disc as it spins through the magnetic field. The resulting magnetic field around the disc caused by the eddy currents flowing in the disc metal opposes the field in the poles. This opposition of the two fields slows the disc rapidly.

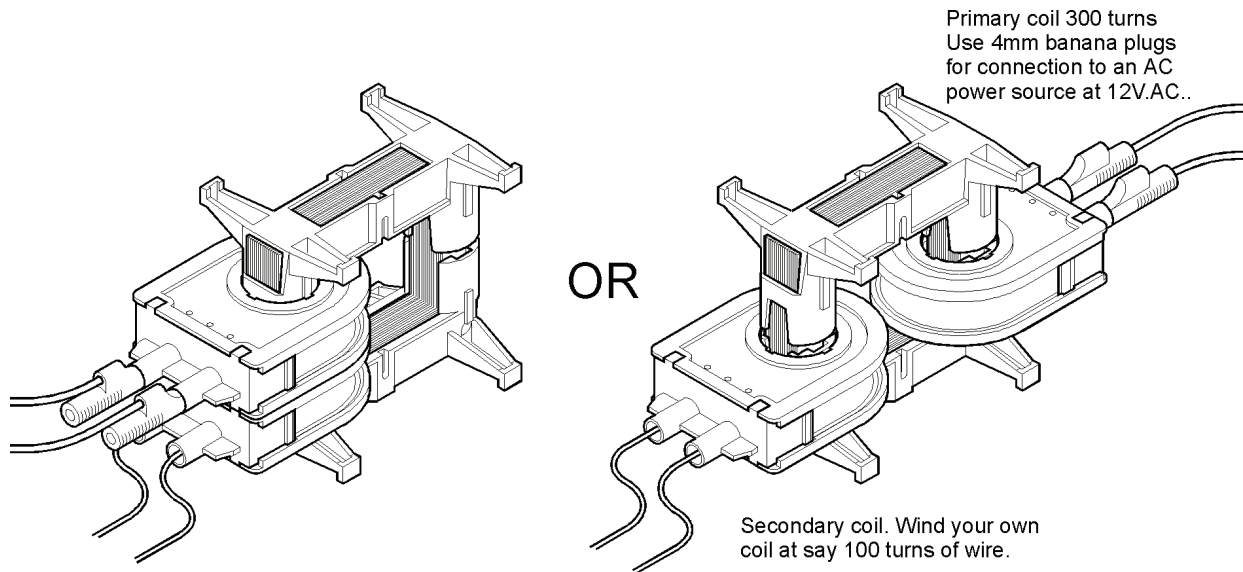
This principle is used in industry as a type of braking system for spinning devices such as disc drives in computers and so on.

THE TRANSFORMER:

Take the 'U' core in the plastic holder and 'I' core in the plastic holder. Place the 300 turn primary coil over one leg of the 'U' core and place a secondary coil that you have wound yourself over the other leg of the 'U' core.

Invert the 'I' core and carefully place it over the 'U' core as shown below.

TAKE CARE NOT TO CATCH AND BEND THE THIN LAMINATIONS OF THE 'U' CORE AS YOU PLACE THE 'I' CORE ON TO IT.



The 4x rubber bands can be stretched between the legs, top to bottom, to hold the two halves of the transformer firmly together.

Apply say 12 volts AC to the 300 turn primary coil and, using an AC voltmeter, measure the output voltage from the 150 turn secondary coil that you wound yourself. It should be close to 6V.AC.

Two coils can be fitted to either side of the transformer core and they can face from the ends of the iron core or across the iron core. It does not matter which are the primary and which are the secondary coils because the iron circuit passes through them on either side of the transformer, but the 300 turn coil supplied is normally used as the primary coil and is connected to 12 Volt AC power source with the cables supplied with the banana plugs fitted.

For transformer study, normally the iron core is fitted and the iron is closed tightly so there is no air space between the iron laminations and therefore minimum magnetic leakage. The rubber bands supplied pull the iron tightly together. If the iron core is not fully closed tightly, the voltages measured on the secondary coils will not accurately follow transformer theory.

LEAKAGE:

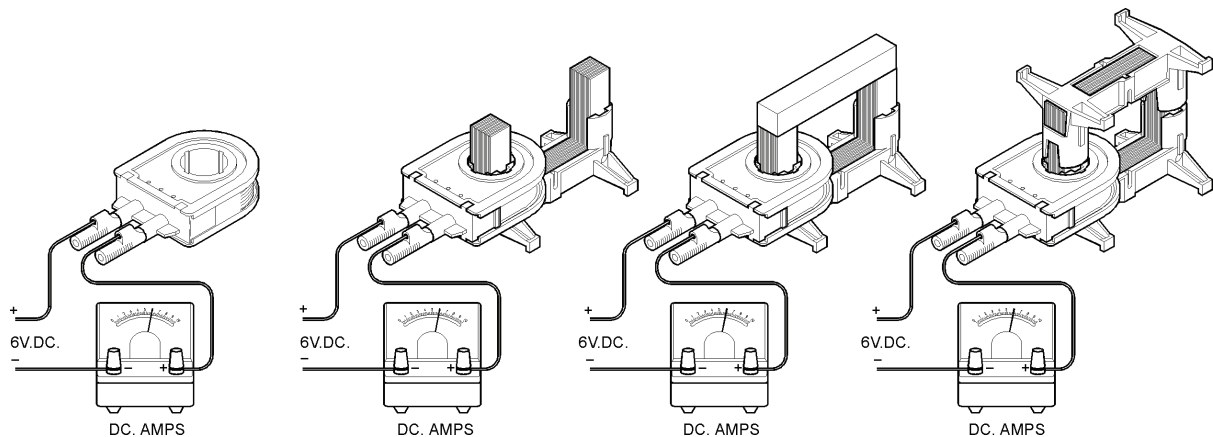
To test for magnetic leakage, take the small axle used for the Eddy Current disc and hold it close to the corners of the transformer core. If leakage is present, a vibrating magnetic field will be felt in the axle. Place small pieces of paper between the tips of the 'U' core and the 'I' core to create small 'Air Gaps' between the cores. Check for leakage again. Check again at different primary voltages. At 12V.AC, check the difference in coil magnetising current with and without the paper present.

EXERCISES:

Measure DC magnetising current: DC would be used only if electro-magnets are to be made. If a coil is fed with a DC voltage, the 'I' core will be attracted to the 'U' core. Feel how strongly the cores are attracted. Try to pull them apart. Using a steady voltage of say 4 to 6 volts DC, compare the DC current flowing through the coil when it has:

- No iron core fitted.
- Only the 'U' core fitted.
- With 'U' core and solid iron bar 'I' core positioned.
- With 'U' core and laminated 'I' core positioned.

Notice that there is no change in the DC current that creates the magnetic field. The steady magnetic field with or without iron has no effect on the coil's resistance.

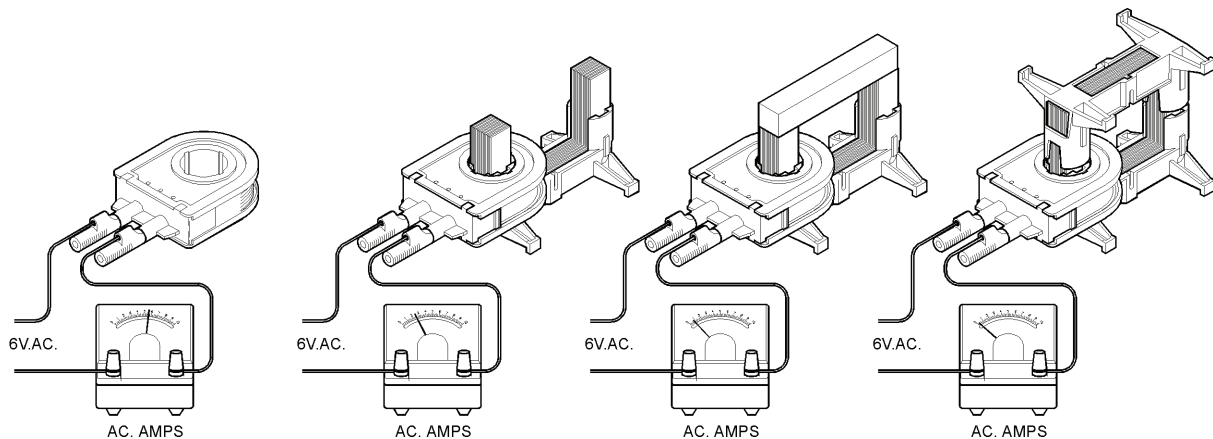


Measure AC magnetising current: AC is used if the device is to transform. The 'I' core will be attracted to the 'U' core to create an AC electro-magnet, but when pulled apart, the noise of the 100 magnetic pulses per second can be heard and felt on the hand. Now, using say 12V.AC on the primary, compare the AC current flowing through the coil when it has:

- No iron core fitted (apply for very short time only).
- Only the 'U' core fitted (for short time only).
- With 'U' core and solid iron bar 'I' core positioned.
- With 'U' core and laminated 'I' core positioned.

Notice that there is a great change in the AC current that creates the magnetic field. A properly designed transformer tries to keep the magnetising current to a minimum.

The lowest current is achieved when the iron core is fully closed and when the iron is all laminated.



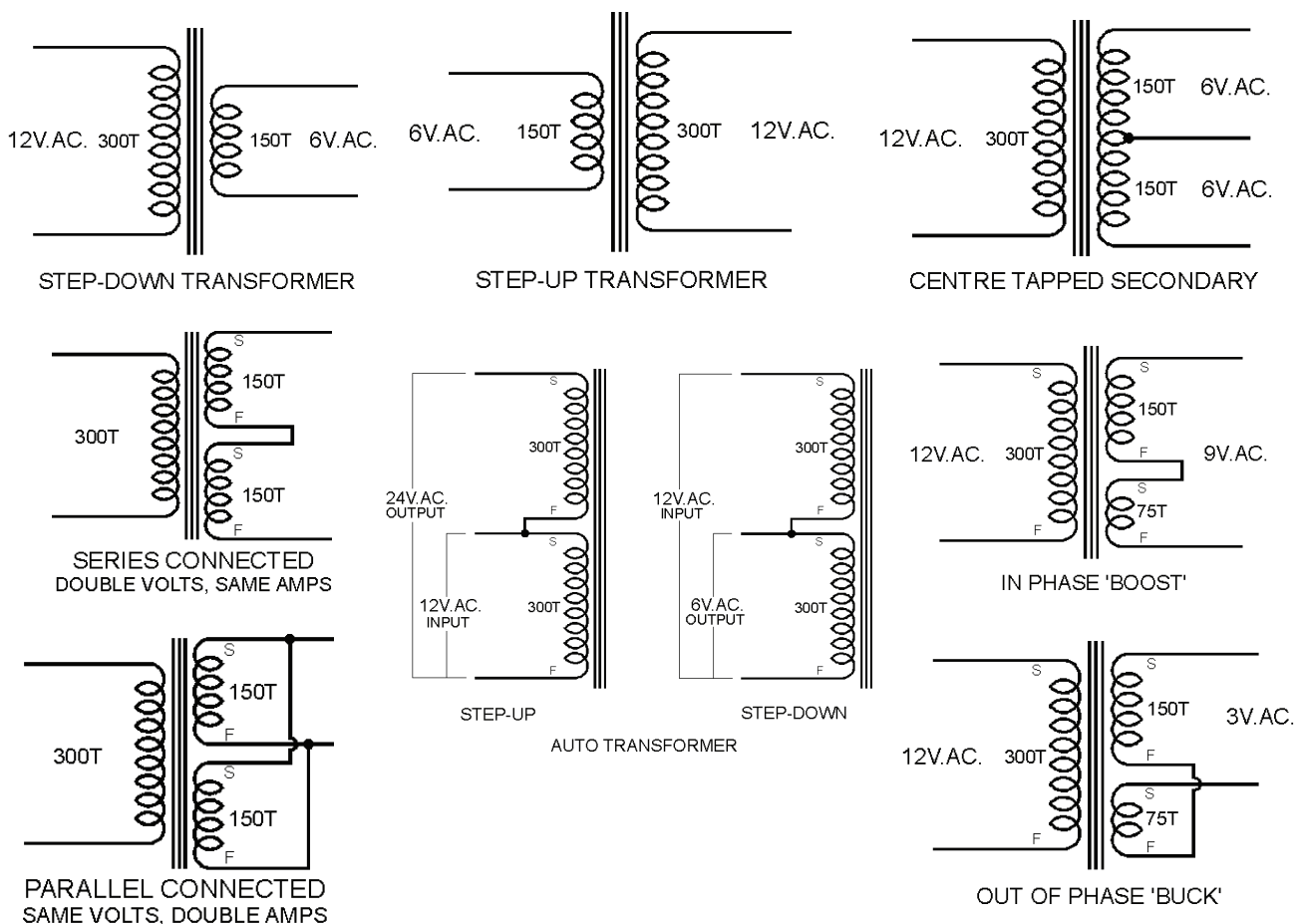
Connect coils in different ways to obtain different voltages:

Series or Parallel connections:

See the images below to learn the difference between series and parallel connections. Assuming primary of 300 turns connected to 12V.AC. Assuming 2 secondary coils wound at 100 turns. If the primary is connected to 12V.AC, each secondary will deliver close to 6V.AC. The images show the Start and Finish of the coils to make the connection and result more obvious.

- If secondary coils in series and 'in phase', voltages add.
- If coils in series and 'out of phase' (one coil reversed), voltages subtract. Result zero.
- If secondary coils in parallel and 'in phase', voltage unchanged but double current available.
- If secondary coils in parallel and 'out of phase', a large current flows between them and they get hot. Voltage will be zero. **CONNECT LIKE THIS ONLY FOR A SHORT TIME.**
- Wind and fit a coil with 75 turns and try connecting to buck and boost the voltages.

The following images provide various simple examples of transformer connections. Try them and check the results. Work out some connections for yourselves and maybe connect up 2 separate transformers to one another.



An 'Auto Transformer' has only one winding and a tapping part way along, or it can be formed by using two coils joined in series as shown above. If 12V.AC is applied to one coil, 24V.AC will appear across both. If 12V.AC is applied across both, 12V.AC will appear across one coil. Coils can be a different number of turns and the voltages will vary accordingly.

A major difference with this type of transformer is that the output voltage IS CONNECTED electrically to the applied voltage. It is NOT an 'Isolating Transformer'. Transformers like this are often used to transform the 240V.AC as used in Australia to say 110V.AC as used in America when an American machine must be used from Australian mains power.

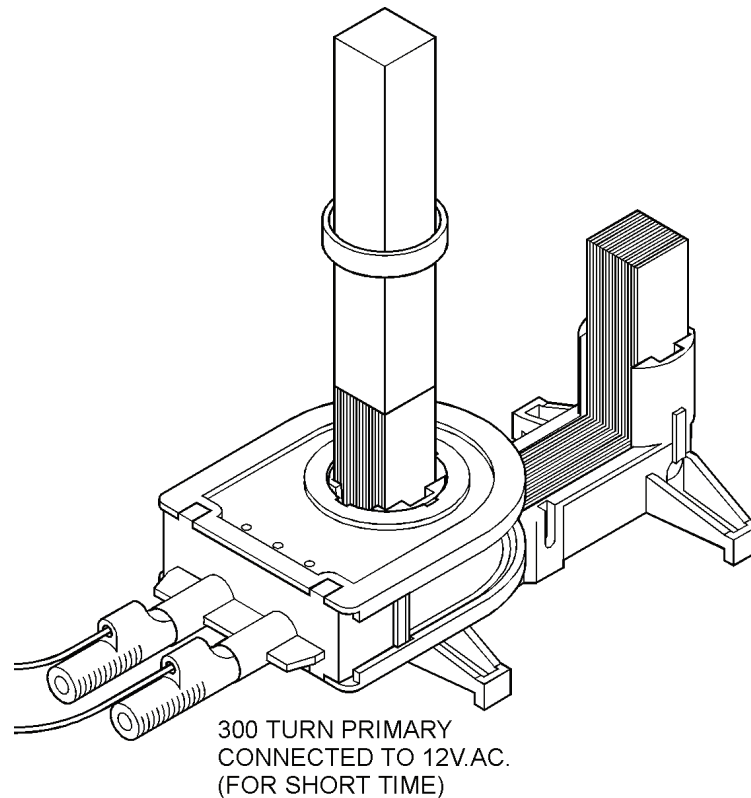
THOMPSON'S RING EXPERIMENT:

Place the 'U' core on the table with the primary coil fitted to one leg. Stand the long iron bar on the SAME leg so it is extended vertically upwards.

Place the 'Thompson's Ring' over the core so it rests on the top face on the primary coil bobbin.

Apply 12V.AC to the primary coil and watch the ring. Try different voltages.

Try DC instead of AC and see what happens. Explain.



When AC is used, the ring jumps upwards and floats in the magnetic field. **WHY ?**

The ring behaves as a secondary coil with only one turn that is **short circuited** and therefore carries a very high current. This current creates a strong magnetic field around the ring in opposition to the applied field in the primary coil. This force pushes the ring away from the coil until the force balances against the weight of the ring. When the weight and the force equals, the ring 'hovers' in the field.

CAUTION:

- 1) The large current in the ring can make the metal ring very hot. Be careful not to burn your fingers on the ring.
- 2) The primary coil is running without a closed magnetic core and you know this causes a very high magnetising current. If run for too long, the coil winding will get very hot.

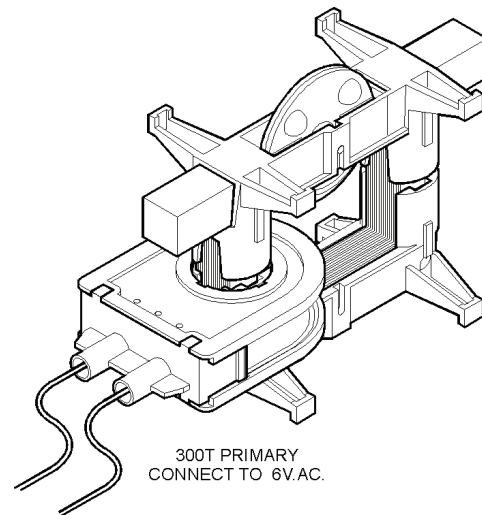
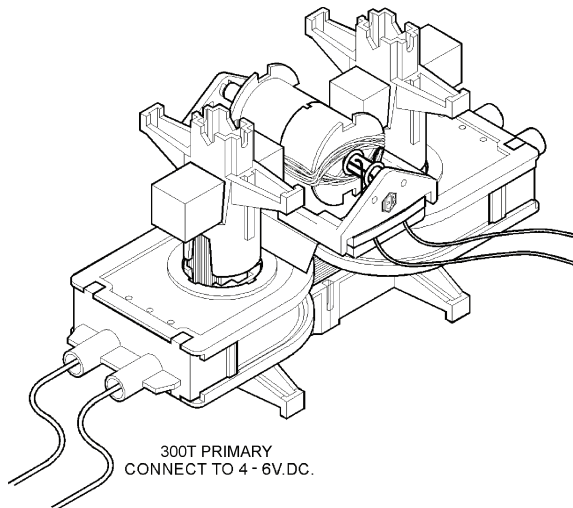
Try rings made from copper wire or pieces of metal tube. Try different metals and explain the effects.

Wind a secondary coil with just a few turns and short circuit the coil (twist the Start and Finish together tightly). Place it on top of the primary coil. Be careful of any heat generated in the winding.

Try thicker wire and see if you can make the coils deflect apart.

ELECTRIC MOTORS:

A SIMPLE DC MOTOR: IEC manufactures a small DC 'Hodson' Electric Motor Kit that can be made by students. It is supplied in a pack of 2x motors in screw top jars (cat: EM2193-201). This motor kit allows students to wind their own rotor and make their own brushes. It is supplied with magnets, wire and all the parts required. This 'Hodson' Induction Kit permits the 'Hodson' DC Motor to be mounted and to use the iron core to provide the DC magnetic field to run the motor. A small aluminium plate is part of the Induction Kit to position the 'Hodson' motor correctly between the poles of the 'U' core. See left illustration below.



A SIMPLE AC MOTOR: See right hand illustration above. Take the pair of 'spinner discs' and position the two small bar magnets in the recesses provided. Take the compass and check that one magnet has its north pole facing outwards and the other magnet has its south pole facing outwards. Take the second disc and locate one to the other and press them together with the magnets inside.

Take the empty plastic frame and slide the assembled 'spinner disc' down the grooves provided so it 'clicks' into place and check that it can spin easily and freely in the plastic frame.

Position the plastic frame on the 'U' core with a short iron bar held at each end. Fit the elastic bands (not shown in the illustration) to hold the short bars tightly to the tips of the 'U' core. Position the two bars so they nearly touch the 'spinner disc' (say 2 or 3mm away). The magnets inside the disc will probably pull the disc around to attract to the iron core.

Apply a few volts AC to the primary coil and, with the finger, flick the edge of the disc to make it spin. It might take several tries before it continues to spin as a motor. As the AC field reverses in the poles, the magnets in the spinner attract to the opposite pole and so on. When the flick to the spinner is the correct force, the disc will **synchronise** with the reversing AC field and the disc will continue to spin as a motor.

This type of motor is called a 'Synchronous Motor' because the speed is exactly synchronised with the frequency of the AC power. If the frequency rises it will spin faster, if reduced it will spin slower to always synchronise exactly. Motors of this type are used in clocks where the speed must be always exact. If it is slowed down with the finger so it cannot synchronise, it will immediately stop.

NOTE When flicking the rotor to start the motor, it must be flicked hard enough to be sufficiently close to the 'synchronous speed' so its rotation can 'lock-in' with the 50Hz AC field.

If an IEC **Stroboscope** is available, follow the instructions with the Stroboscope and measure the speed and compare it to the frequency of 50Hz. 50Hz (50 cycles per second) is the same as 3000 pulses per minute. The motor speed should be exactly a multiple of this speed (maybe 1500 turns or revolutions per minute).

AN INDUCTION MOTOR: The 'Induction Motor' uses the principle of magnetic induction to run. An AC field is passed through an iron rotor which has a number of high conductivity metal bars embedded inside the iron. These bars are all joined in parallel by rings at each end of the rotor.

As the AC field reverses back and forth, there are large circulating currents created inside these rotor bars. These currents create their own AC magnetic fields which opposes the applied AC field. The bars are then repelled from the applied field and, because they are inside the iron rotor, they carry the rotor with them so that the rotor spins inside the applied field.

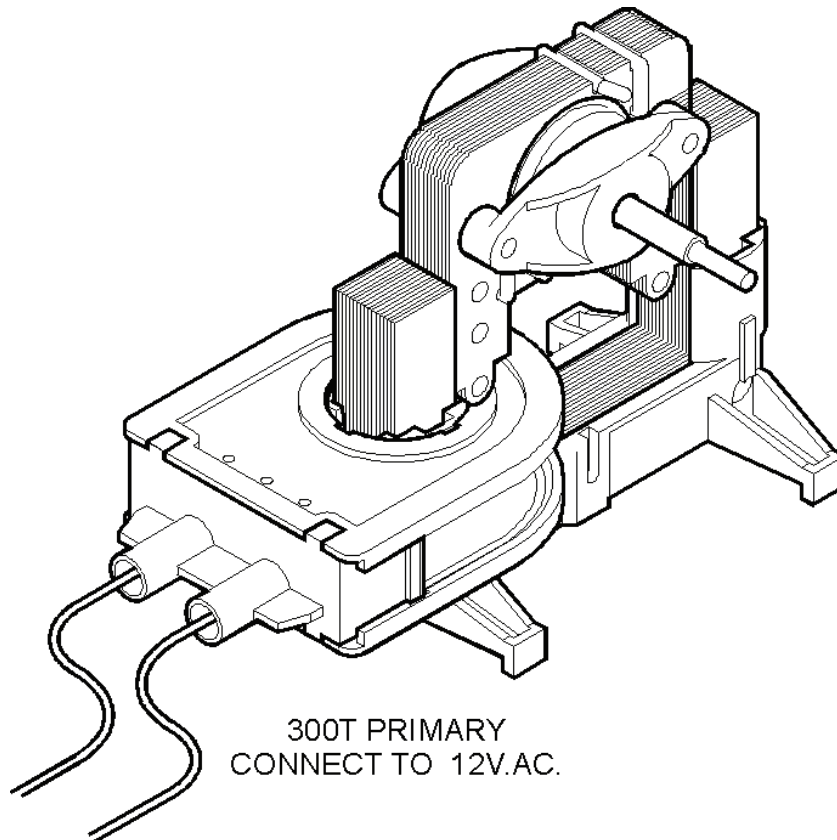
Stand the 'U core on the table and place the 300 turn primary coil on one leg. Use any other bobbin on the other leg of the 'U' core to help support the motor. Take the induction motor from the kit and place it between the 2 legs of the 'U' core as seen in the illustration below. It should just fit neatly between the legs of the core. The motor is supplied without screws for ease of dismantling, so be sure the motor is properly pushed together and will not fall to pieces.

Apply 12V.AC. to the 300 turn primary coil and watch the motor turn. Feel the motor power by holding the motor shaft between the fingers.

Remove AC power from the coil and remove the induction motor and examine its construction. Pull off the bearing holders (called 'end shields') and observe the ball race bearings and the rotor that contains the bars. See if you can see any indication of the bars inside the rotor iron.

If the iron was not there, the bars would form a sort of barrel or cage made from bars. It would look like the little wheel that mice or squirrels run inside to get exercise. Sometimes these mouse exercise cages can be seen in pet shops. This is why this type of motor is called a '**squirrel cage**' motor.

Notice the copper loops fitted to the iron core of the motor. These are called 'shading rings' and they make the motor begin to turn in a particular direction. To reverse the motor direction, it must be re-assembled with the shading rings on the opposite sides of the rotor. This is done by reversing the direction of the rotor in the stator. So, re-assemble the rotor with the shaft protruding from the opposite side and notice that the motor runs in the opposite direction.





The '**Hodson**' Induction Kit can be used for many other useful experiments not mentioned in this booklet.

If more experiments are discovered by users over time, IEC is always ready to accept good ideas to improve the product and to advise educators of more uses for the equipment. In addition any ideas for improvements that we can make to this booklet would be gratefully accepted.

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