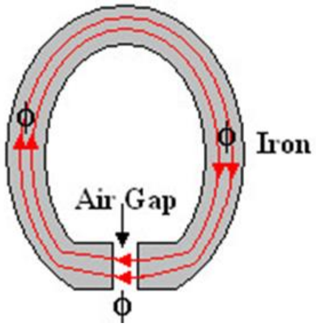
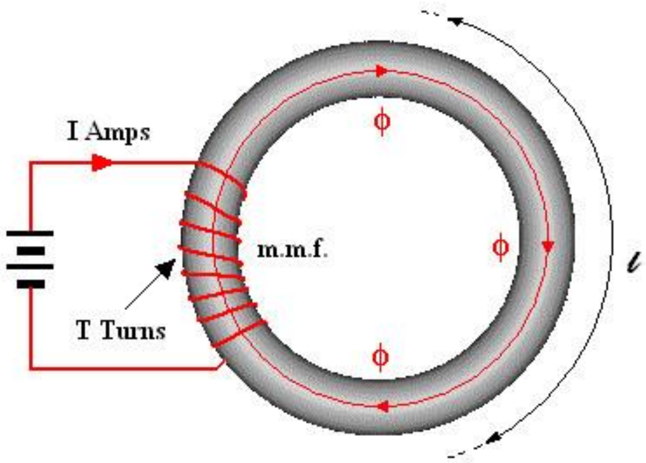
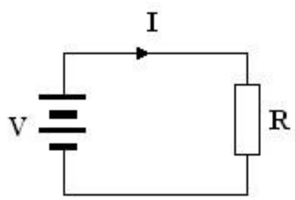
City&Guilds

UNIT 428 ELECTRICAL PRINCIPLES FOR MECHANICAL ENGINEERING

Lesson 1: Magnetic theory revision		**Suggested Teaching Time:** 2 hours
Learning Outcome 1: Understand the electromagnetic theory of transformers		
Topic	**Suggested Teaching**	**Suggested Resources**
Revision of **magnetism** Relationship between **common electromagnetic units of measurement** (AC 1.1)	Tutor to note that the learner will need the following underpinning knowledge: • Lenz's law • Faraday's laws • Fleming's rules • Mutual induction • Self-induction • Frequency • Sine waves • Amplitude • Root mean square values • Peak-to-peak values • Basic semiconductor theory of a p-n junction. They may need to recap certain areas of knowledge throughout the course Whole-class discussion and practical experiment session, tutor to lead a discussion on the basic principles of magnetism and to demonstrate using lab equipment. Tutor to cover: • Current convention, magnetic fields around a conductor (corkscrew rule) • How this can be used in an electromagnet • Use of electromagnets in a solenoid.	**Books:** Patrick, Dale R., and Fardo, Dale R., *Electricity and Electronics Fundamentals*, The Fairmont Press, Inc., 2008, ISBN 0881736023, 9780881736021 Jiles, David C., *Introduction to Magnetism and Magnetic Materials*, Second Edition, CRC Press, 1998, ISBN-10: 0412798603, ISBN-13: 9780412798603 **Practical Equipment:** Bar magnets, horseshoe magnets, electromagnets, solenoids paper iron filings(or similar magnetic powder) **Software:** http://phet.colorado.edu/en/simulation/faraday http://www.infolytica.com/en/products/magnet/

	Demonstrating practically where possible Whole-class teaching: tutor to convey the fact that magnetic field is correctly known as flux (ϕ or Φ) it is measured in Weber (Wb) In the iron core part of a simple bar magnet the flux (Φ) flows through a cross-section of area A; the flux density (B) is Φ/A	**Websites:** http://hyperphysics.phy-astr.gsu.edu/hbase/emcon.html
	Whole-class teaching: tutor to explain that the flux is assumed to have a direction North to South on the outside but South to North on the inside. The poles of a magnet are Red for North and Blue for South. The flux flowing on the outside has an indeterminate cross section and length but flux flowing in a magnetic core has a definite cross sectional area and length and this is important in the next section.  Tutor to demonstrate (practically if possible) how, in the horseshoe magnet, the flux runs through the iron and then jumps across the air gap and how the flux is concentrated in the gap. Demonstrate that the gap has a definite cross sectional area and length. For the horseshoe magnet shown the cross sectional area of the gap is 200 mm2and the flux flowing through it is 0.16 Wb. $\mathrm{B} = {}^{\Phi}/_{\mathrm{A}} = {}^{0.16}/_{200 \times 10^{-6}} = 800 \text{ Tesla}$	

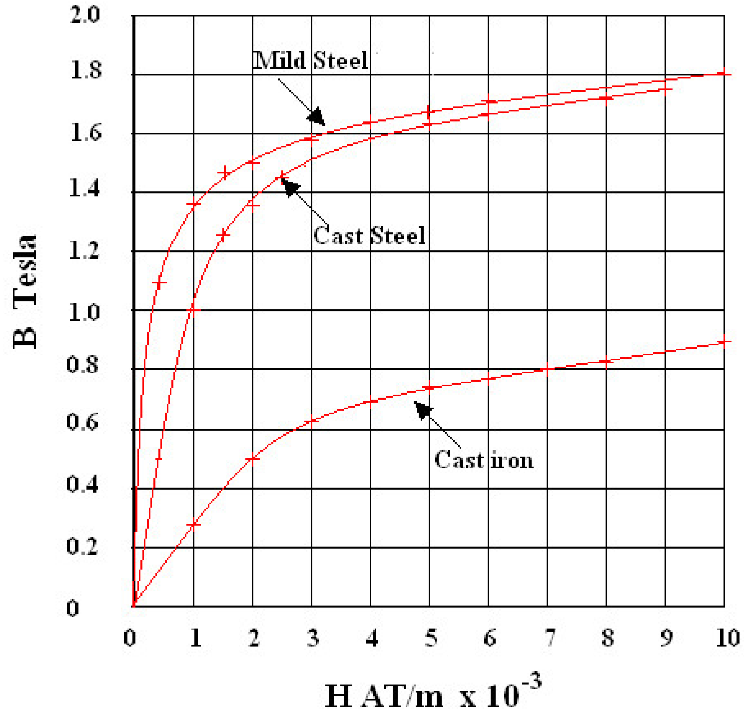
Lesson 2: Electromagnetism		**Suggested Teaching Time:** 4 hours
Learning Outcome 1: Understand the electromagnetic theory of transformers		
Topic	**Suggested Teaching**	**Suggested Resources**
Electromagnetism Relationship between **common electromagnetic units of measurement** (AC 1.1)	  Tutor to explain that in the following work, it is useful to think of a magnetic flux created by a coil wound on a ring (toroid) of magnetic material as shown. Demonstrate this practically if possible. This ring forms a complete circuit of uniform cross sectional area A and length l . The tutor may find that it is also beneficial to get the students to compare the circuit with an electrical circuit. In a simple electric circuit the current flowing I depends on the voltage V and the resistance R. In the magnetic circuit, a flux ϕ flows. The strength of the flux depends on the	**Books:** Jiles, David C., *Introduction to Magnetism and Magnetic Materials*, Second Edition, CRC Press, 1998, ISBN-10: 0412798603, ISBN-13: 9780412798603 **Practical Equipment:** Lab equipment to demonstrate electromagnets and the effect on number of coils etc **Software:** http://phet.colorado.edu/en/simulation/faraday http://www.infolytica.com/en/products/magnet/ **Websites:** http://hyperphysics.phyastr.gsu.edu/hbase/emcon.html

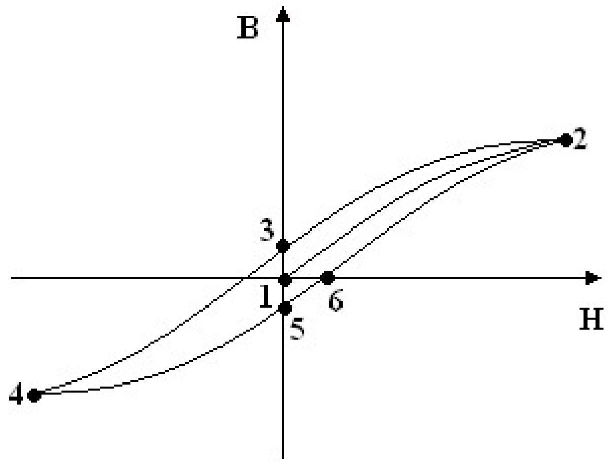
	coil and this property is called the magneto motive force (MMF) (see below). Tutor to explain that it therefore follows that we need a property equivalent to resistance to describe how easy it is for the flux to flow. This property is called 'reluctance'. In electric circuits resistance depends on a property of the material called the conductivity (or resistivity). Tutor to explain that it therefore follows that in the same way, the reluctance of a material depends on a property called the 'permeability'. The amount of magnetisation left behind in a magnetic material (such as iron) after an external magnetic field is removed is known as the 'remanence'. Split class into smaller groups and get students to carry out experiments using different materials, coil sizes etc. Tutor to circulate and assist where required, encouraging students to discuss their findings with each other and how they relate to the subjects learned so far.	

Topic	Suggested Teaching	Suggested Resources
Relationship between **common electromagnetic units of measurement** (AC 1.1)	Whole-class teaching to cover the following points: **Magneto Motive Force (MMF)** Tutor to explain: how MMF is created by the current flowing in the coil; how it is directly proportional to the current 'I' and the number of turns of the coil 'T'. $\mathrm{MMF} = \mathrm{I\,T}$. The units are ampere turns (AT). Tutor to explain how permanent magnets have a theoretical MMF to explain the permanent flux. **Magnetising Force (H)** Tutor to explain using the toroid used in the previous section, discussing how it formed a complete ring of uniform cross section. Where the length l is the mean circumference of the ring. The H is defined as the MMF divided by l $\mathrm{H} = {}^{\mathrm{I\,T}}/_{l}$ The units are AT per metre. *Tutor to demonstrate formula by use of an example such as* A coil is wound on a toroid core 50 mm mean diameter. There are 500 turns. Calculate the MMF and the H when a current of 2A is applied. **Solution** $\mathrm{MMF} = \mathrm{I\,T} = 2 \times 500 = 1000$ AT l = circumference $= \pi \mathrm{D} = \pi \times 0.05 = 0.157\mathrm{m}$ $\mathrm{H} = {}^{\mathrm{MMF}}/_{l} = {}^{1000}/_{0.157} = 6366.2\ \mathrm{AT/m}$	**Books:** Jiles, David C., *Introduction to Magnetism and Magnetic Materials*, Second Edition, CRC Press, 1998, ISBN-10: 0412798603, ISBN-13: 9780412798603 **Practical Equipment:** Lab equipment to demonstrate electromagnets and the effect on number of coils etc. **Software:** http://phet.colorado.edu/en/simulation/faraday http://www.infolytica.com/en/products/magnet/ **Websites:** http://hyperphysics.phy-astr.gsu.edu/hbase/emcon.html

Lesson 3: Electromagnetism (continued)		**Suggested Teaching Time: 4** hours
Learning Outcome 1: Understand the electromagnetic theory of transformers		
Topic	**Suggested Teaching**	**Suggested Resources**
Relationship between **common electromagnetic units of measurement** (AC 1.1)	**Relationship between B and H** Tutor to explain/demonstrate using the example of toroid used earlier. The toroid has a uniform cross sectional area A so the flux density is simply B = ϕ/A. The flux and hence flux density depends on the MMF and hence the magnetising force. For any coil it is found that B/H = constant. It has been found that for a simple coil with no core at all (a complete vacuum), the constant is 12.566 x 10^{-7} and this is called the 'absolute permeability of free space' and has a symbol μ_o. Tutor to demonstrate that if a magnetic material such as iron is placed inside the coil, the constant increases. The ratio by which the constant increases is called the 'relative permeability' and has a symbol μ_r. It therefore follows that: B/H = $\mu_o\mu_r$ Tutor to explain/demonstrate how it is difficult to apply this to a simple coil as the length of the magnetic circuit is not obvious unless the coil is wound on a magnetic material to produce a circuit. Tutor to explain/demonstrate using the example of the simple toroid circuit again. Tutor to discuss that for the electric analogy we have Ohm's law $\frac{V}{I} = R$	**Books:** Jiles, David C., *Introduction to Magnetism and Magnetic Materials*, Second Edition, CRC Press, 1998, ISBN-10: 0412798603, ISBN-13: 9780412798603 **Practical Equipment:** Lab equipment to demonstrate electromagnets and the effect of using different coils and to show the different properties discussed in lesson **Software:** http://phet.colorado.edu/en/simulation/faraday http://www.infolytica.com/en/products/magnet/ **Websites:** http://hyperphysics.phy-astr.gsu.edu/hbase/emcon.html

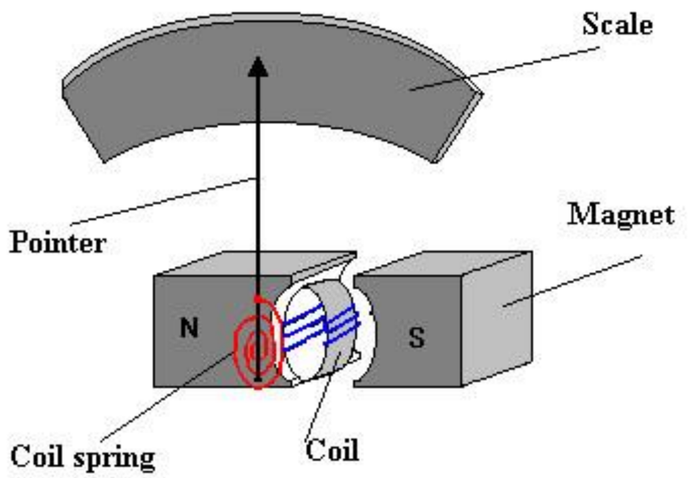
	Therefore by analogy, in the magnetic circuit $^{MMF}/_{\phi}$ = reluctance. Tutor to show that by substituting $B = {}^{\phi}/_{A}$ and $H = {}^{MMF}/_{l}$ into this equation we get $^{\phi l}/_{(A\ MMF)} = \mu_o \mu_r$ and that by rearranging it we get $^{MMF}/_{\phi} = {}^{l}/_{(A\mu_o\mu_r)}$ = Reluctance Reluctance = $^{l}/_{(A\mu_o\mu_r)}$ The units are AT/Wb Tutor to split students into smaller groups and hand out a series of questions based on the subject learned so far including questions based on the formula. Tutor to circulate and assist where required.	

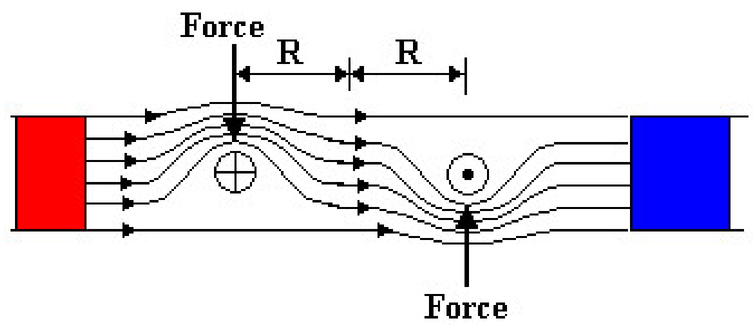
Topic	Suggested Teaching	Suggested Resources
B-H Graphs Relationship between common electromagnetic units of measurement (AC 1.1)	Tutor to demonstrate practically where possible how B-H graphs are created and allow students to conduct experiments to create their own graphs for various materials.  Tutor then to get students to discuss their findings. Tutor-led discussion towards a conclusion that for magnetic materials, the relative permeability μr is not constant as implied previously and B is not directly proportional to H. This then go on to explain that this is not a major problem as manufacturers produce the information in the form of a B-H graph and we can find the values of one if the other is known. Tutor to add that for non-magnetic materials μr is always about 1.0 In a typical graph (shown), the value of B increase directly with H when the values of I are small but when the values of H become large, B becomes constant. When B is constant, the magnetic core is said to be 'Saturated'.	**Books:** Jiles, David C., *Introduction to Magnetism and Magnetic Materials*, Second Edition, CRC Press, 1998, ISBN-10: 0412798603, ISBN-13: 9780412798603 **Practical Equipment:** Lab equipment to demonstrate electromagnets and the effect of using different coils and to show the different properties discussed in lesson and the effect of reversing the current **Software:** http://phet.colorado.edu/en/simulation/faraday http://www.infolytica.com/en/products/magnet/ **Websites:** http://hyperphysics.phy-astr.gsu.edu/hbase/emcon.html

Lesson 4: Hysterisis		**Suggested Teaching Time: 2** hour
Learning Outcome 1: Understand the electromagnetic theory of transformers		
Topic	**Suggested Teaching**	**Suggested Resources**
Changes in magnetic properties of a soft iron core undergoing cyclic magnetisation (AC 1.2)	Whole-class teaching, tutor to demonstrate, practically where possible, the phenomenon associated with magnetic materials that are capable of being permanently magnetised which is known as 'hysteresis'.  Tutor to demonstrate with a simple electromagnet how magnetic flux is created by a coil carrying a direct current and that the material becomes permanently magnetised. They should then reverse the current and show the effect Whole-class discussion to cover what happens when the current is alternating so that it reverses at regular intervals (50 times a second for mains frequency). Tutor to talk students through cycle while demonstrating practically and showing the B-H curve. A current is applied and a flux is produced. If the current is gradually	

	increased and the values of B are plotted against H we get a B-H graph from 1 to 2. At point 2, a further increase in current does not produce an increase in B and the core is said to be **saturated**. If the current is switched off at this point the iron core will remain magnetised and form a permanent magnet. If the current is gradually reduced from its maximum value and we continue to plot B against H we will get the graph 2 to 3. At point 3 the current is zero but we now have a flux because the core is magnetised in one direction and forms a permanent magnet. In order to reduce the magnetic flux to zero, we must apply a negative current and this takes the graph to point 4. Continuing to increase the current in the negative direction increases the flux in a negative direction (N and S poles are reversed) and the graph 4 to 5 is obtained (this resistance to demagnetisation is called the 'Coercivity' of the material). At this point the iron is magnetised in the opposite direction to before. If the current is reduced back to zero the graph 5 to 6 is obtained and at point 6 the current is again zero but there is a permanent flux opposite in direction to before. If the current is now increased in the positive direction again the flux will be reduced to zero at point 7 and then increases positively back to point 2. If we continue to alternate the current plus and minus (i.e. apply A.C.) the B-H graph will follow the loop 2, 3, 4, 5, 6, 7, 2 over and over again. Tutor to discuss the fact that this loop illustrates the 'hysteresis effect'.	

Lesson 5: Applied magnetism		**Suggested Teaching Time: 1** hour
Learning Outcome 2: Understand the principles of DC machines		
Topic	**Suggested Teaching**	**Suggested Resources**
Force on a conductor, AC 2.2	Tutor to recap creating and destroying a magnet and basic application of an electromagnet in a solenoid. Whole-class discussion on where we can find magnets and for what they are used. Lead if necessary towards electromagnets for moving things, solenoids, motors and transformers. Tutor-led experiment: The students set up a horseshoe magnet in a clamp, hold a wire between the ends of the magnet and then cause a current to flow through the wire. Whole-class discussion on the results to cover: a major discovery leading to the invention of the electric motor was that a conductor placed in a magnetic field experiences a force when current flows in it. Tutor to draw a diagram to show a conductor placed in a gap between the poles of a magnet. then to show that when current passes through the conductor, we have two magnetic fields, the circular lines around the conductor and the parallel lines between the poles. The lines of magnetism between the north and south poles would rather pass over the top of the conductor because both lines are in the same direction on top. The lines behave like elastic bands and force the conductor down. If the direction of either the current or the magnetic field is	**Books:** Jiles, David C., *Introduction to Magnetism and Magnetic Materials*, Second Edition, CRC Press, 1998, ISBN-10: 0412798603, ISBN-13: 9780412798603 **Practical Equipment:** Lab equipment to demonstrate electric motors. E.g. magnets, coils, wire and power source **Software:** http://phet.colorado.edu/en/simulation/faraday http://www.infolytica.com/en/products/magnet/ **Websites:** http://hyperphysics.phy-astr.gsu.edu/hbase/emcon.html

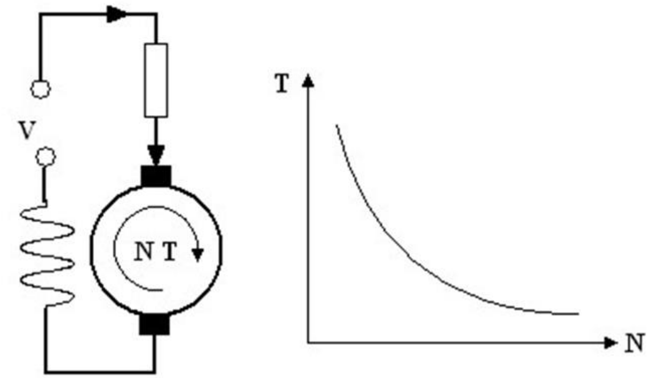
	reversed, the force will act up. Tutor to explain Fleming's left-hand rule Tutor to discuss how the force on the conductor is directly proportional to the current 'I' , the magnetic flux density 'B' and the length 'l' of the conductor within the flux. Emphasise that this is an important equation: The force on a conductor $\boldsymbol{F = B\ l\ I}$	
	Tutor then to get the students to set up a simple electric loop within a magnetic field Tutor to demonstrate how this produces a downwards force on one side and an upwards force on the other at a radius R. This  produces a torque on the coil of T = F R. This will make the loop rotate. Tutor to discuss a practical application of this principle with the moving coil meter. The loop or coil rotates only 90^o and rotation is governed by a spring. The loop is connected to a pointer which moves on a scale. The movement is directly proportional to current in the coil. $\boldsymbol{F = BlI}$	**Books:** Hughes, Austin, *Electric Motors and Drives: Fundamentals, Types and Applications*, 4th edition, Newnes, 2013, ISBN-10: 0080983324, ISBN-13: 978-0080983325 **Practical Equipment:** Lab equipment to test various electric motors, including moving coil meter **Websites:** http://www.animations.physics.unsw.edu.au/downloads.htm#electric

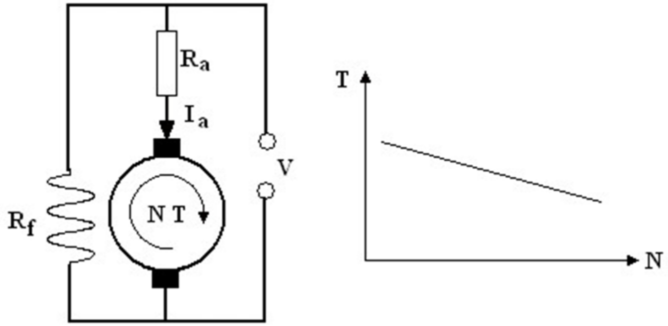
Lesson 6: DC motors		**Suggested Teaching Time:** 2 hours
Learning Outcome 2: Understand the principles of DC machines		
Topic	**Suggested Teaching**	**Suggested Resources**
	Tutor to develop ideas learned in last lesson aiming towards a practical DC motor. Return class's attention to the basic motor and discuss the flaw with this design in so far as when it turns 90º the radius is zero and the torque is zero so it will stop. Get students to discuss how we can overcome this. If we reverse the current as it passes the 90º position the torque will continue to make it rotate. Switching the direction of the current every half rotation will produce continuous rotation. This can be done with a split ring  Get students to elaborate on this and to come up with improvements such as by using several loops and switching the current to the one in the horizontal position all the time. The split ring becomes a commutator with many segments. Each pair of segments is connected to a loop and each pair in turn becomes connected to the brushes as it rotates.	**Books:** Hughes, Austin, *Electric Motors and Drives: Fundamentals, Types and Applications*, 4th edition, Newnes, 2013, ISBN-10: 0080983324, ISBN-13: 978-0080983325 **Practical Equipment:** Lab equipment to test various electric motors, including DC Series, shunt and Compound **Websites:** http://www.electrical4u.com/lap-winding-simplex-and-duplex-lap-winding/

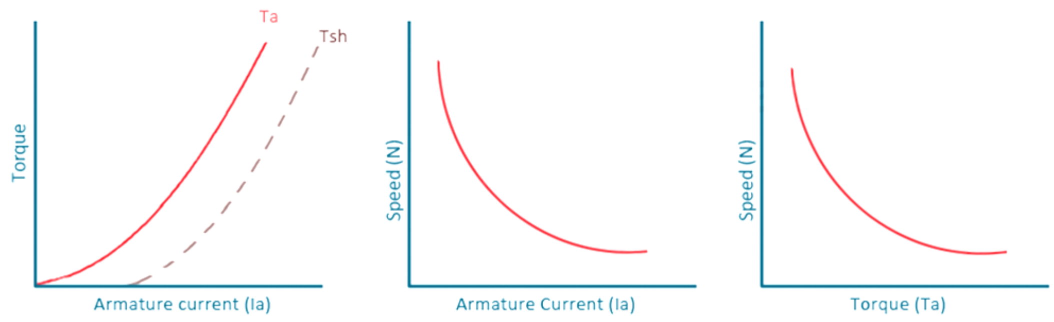
Lap and wave windings	Tutor to develop idea of multiple windings to discover how armatures are wound. Show practical examples where possible Tutor to explain that armature windings are mainly of two types: 1. Lap winding 2. Wave winding **Lap** winding is the winding in which successive coils overlap each other. It is named lap winding because it doubles or laps back with its succeeding coils.in this winding the finishing end of one coil is connected to one commutator segment and the starting end of the next coil situated under the same pole and connected with same commutator segment A winding in which the number of parallel path between the brushes is equal to the number of poles is called simplex lap winding. A winding in which the number of parallel path between the brushes is twice the number of poles is called duplex lap winding. Advantages of lap winding • This winding is necessarily required for large electric current application because it has more parallel paths. • It is suitable for low voltage and high electric current generators. Disadvantages of lap winding • It gives less emf compared to wave winding. This winding requires a higher number of conductors to give the same emf, resulting in higher winding cost. • It has less efficient utilisation of space in the armature slots.	

	With wave windings the number of parallel paths between conductors A is always equal to 2 irrespective of the number of poles. In this winding the end of one coil is connected to the starting of another coil of the same polarity as that of the first coil. In this type of winding the coil side (A-B) progress forward around the armature to another coil side and goes on successively passing through N and S pole till it returns to a conductor (A_1-B_1) lying under the starting pole. This winding forms a wave with its coil. That's why it is named as wave winding. It is also called series winding because its coils are connected in series. If after one round of the armature the coil falls in a slot right of its starting slot the winging is called progressive wave winding. If after one round of the armature the coil falls in a slot left of its starting slot the wiring is called 'retrogressive wave winding'.	

Topic	Suggested Teaching	Suggested Resources
	Tutor to discuss characteristics and advantage of simplex wave winding. In this winding only two brushes are required but more parallel brushes can be added to make it equal to the no. of poles. If one or more brushes set poor contacts with the commutator, satisfactory operation is still possible. This winding gives sparkles commutation. The reason behind that it has two parallel paths irrespective of no of poles of the machine. The conductors in each of the two parallel path distributed around the armature in the entire circumference. Number of conductors in each path = Z/2 , Z is the total number of conductors. Generated emf = average emf induced in each path X Z/2 For a given number of poles and armature conductors it gives more emf than that of lap winding. Hence wave winding is used in high voltage and low electric current machines This winding is suitable for small generators circuit with voltage rating 500-600V. Current flowing through each conductor $= \frac{\text{Current per path } (I_a)}{2}$ $I_a$is the armature current. Current per path for this kind of winding must not be exceeded 250A. Resultant emf around the entire circuit is zero. **Disadvantage of simplex wave winding** Wave winding cannot be used in the machines having higher electric current rating because it has only two parallel paths.	**Books:** Hughes, Austin, *Electric Motors and Drives: Fundamentals, Types and Applications*, 4th edition, Newnes, 2013, ISBN-10: 0080983324, ISBN-13: 978-0080983325 **Practical Equipment:** Lab equipment to test various electric motors, including DC Series, shunt and Compound **Websites:** http://www.electrical4u.com/lap-winding-simplex-and-duplex-lap-winding/

Lesson 7: DC motors (continued)		**Suggested Teaching Time:** 1 hour
Learning Outcome 2: Understand the principles of DC machines		
Topic	**Suggested Teaching**	**Suggested Resources**
Field windings and **armature arrangements**	Whole-class teaching: tutor to show that there are various ways of arranging the windings but the two most common ways are in series and as a shunt.	**Books:** Hughes, Austin, *Electric Motors and Drives: Fundamentals, Types and Applications*, 4th edition, Newnes, 2013, ISBN-10: 0080983324, ISBN-13: 978-0080983325 **Practical Equipment:** Lab equipment to test various electric motors, including DC Series, shunt and Compound **Websites:** http://www.electrical4u.com/lap-winding-simplex-and-duplex-lap-winding/
Series motor	Tutor to demonstrate, practically where possible, how, in a series motor, the field winding is in series with the armature. And that the same current flows through the armature and the field winding. The mechanical power of any rotor is $P = 2\pi NT$ The electric power of any rotor is ideally $P = E_a I_a$  SERIES MOTOR Equating and rearranging we see that $T = {E_a I_a}/{2\pi N}$ If the electric power is constant, $E_a I_a$ are constant so T = Constant/N This means that for a constant electrical power the speed would increase as the load is removed and decrease as the load increases as shown by the graph.	

	Advantage At low speed there is a high torque (starting torque) which is ideal for servo applications. **Disadvantage** At low torque (no load conditions) the motor is liable to over speed and become damaged.	
Shunt motor	In this case the field winding is connected in parallel with the armature as shown. The field current is constant so flux cannot be changed except by changing the supply voltage.  SHUNT MOTOR $E_a = V = I_a R_a$ It can be shown that $T = C_1 - C_2 N$ C_1 and C_2 are constants. This shows that at zero speed the starting torque is C_1 and as speed increases, the torque drops off. The ideal torque-speed characteristic is as shown. In reality the line is curved down due to other effects not considered.	

Lesson 8: DC motors (continued)		**Suggested Teaching Time: 6** hours
Learning Outcome 2: Understand the principles of DC machines		
Topic	**Suggested Teaching**	**Suggested Resources**
Represent the characteristic curves of the different types of **DC motors** in a diagram (AC 2.4) Evaluate the relative characteristics of different types of DC motors (AC 2.5)	Whole-class teaching with practical demonstrations/student participation in testing where possible Tutor to get student to carry out practical activities to record the data required for each of the following characteristics and to discuss the results  Characteristics of DC series motor **DC series motor** **Torque vs. armature current (Ta-Ia)** This characteristic is also known as electrical characteristic. We know that torque is directly proportional to armature current and flux, $T_a \propto \Phi \times I_a$. In DC series motors, field winding is connected in series with armature. Thus, before magnetic saturation of the field, flux Φ is directly proportional to Ia. Therefore,	**Books:** Hughes, Austin, *Electric Motors and Drives: Fundamentals, Types and Applications*, 4th edition, Newnes, 2013, ISBN-10: 0080983324, ISBN-13: 978-0080983325 **Practical Equipment:** Lab equipment to test various electric motors, including DC Series, shunt and Compound **Websites:** http://www.electrical4u.com/lap-winding-simplex-and-duplex-lap-winding/

	before magnetic saturation Ta ∝ Ia2. At light loads, Ia as well as Φ is small and hence the torque increases as the square of the armature current. Therefore, the Ta-Ia curve is parabola for smaller values of Ia. After magnetic saturation of the field winding, flux Φ is independent of armature current Ia. Therefore, the torque varies proportional to Ia only, T ∝ Ia. Therefore, after magnetic saturation, Ta-Ia curve becomes straight line. The shaft torque (Tsh) is less than armature torque (Ta) due to stray losses. In DC series motors, (prior to magnetic saturation) torque increases as the square of armature current, these motors are used where high starting torque is required **Speed vs. armature current (N-Ia)** We know the relation, N ∝ Eb/Φ For a small load current (and hence for small armature current) the change in back emf Eb is small and it may be neglected. Thus, for small currents, speed is inversely proportional to Φ. As we know, flux is directly proportional to Ia, speed is also inversely proportional to Ia. When armature current is very small the speed becomes dangerously high. That is why a series motor should never be started without some mechanical load. But, at heavy loads, armature current Ia is large. And hence speed is low which results in decreased back emf Eb. Due to decreased Eb, more armature current is allowed **Speed vs. torque (N-Ta)** This characteristic is also called as mechanical characteristic. From the above two characteristics of a DC series motor, it can be found that when speed is high, torque is low and vice versa.	

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<tr><th>Topic</th><th>Suggested Teaching</th><th>Suggested Resources</th></tr>
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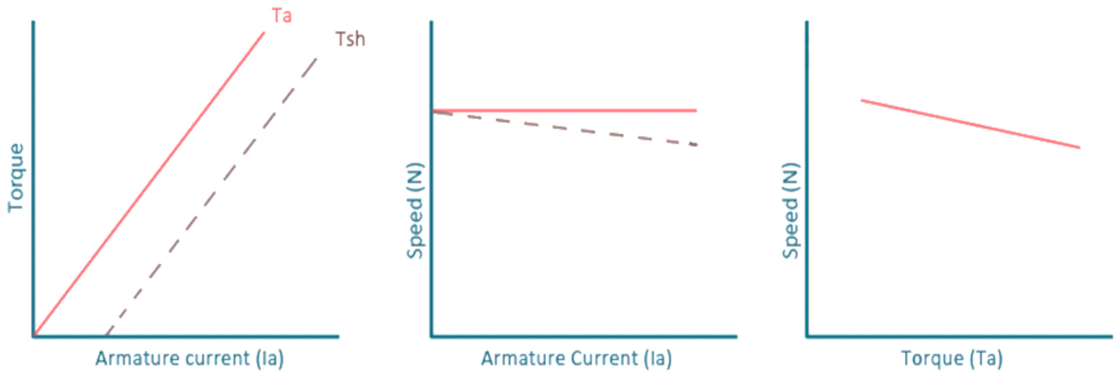
<td>Represent the characteristic curves of the different types of DC motors in a diagram

(AC 2.4)

Evaluate the relative characteristics of different types of DC motors

(AC 2.5)</td>
<td>

Characteristics of DC shunt motor

DC shunt motors

Torque vs. armature current (T_a-I_a)

In case of DC shunt motors we can assume the field flux Φ to be constant. Though at heavy loads, Φ decreases in a small amount due to increased armature reaction. But as we are neglecting the change in the flux Φ, we can say that torque is proportional to armature current. Hence the T_a-I_a characteristic for a DC shunt motor will be a straight line through origin.

Since, heavy starting load needs heavy starting current, shunt motor should never be started on a heavy load.</td>
<td>Books:

Hughes, Austin, Electric Motors and Drives: Fundamentals, Types and Applications, 4^{th} edition, Newnes, 2013, ISBN-10: 0080983324, ISBN-13: 978-0080983325

Practical Equipment:

Lab equipment to test various electric motors, including DC series, shunt and compound

Websites:

http://www.electrical4u.com/lap-winding-simplex-and-duplex-lap-winding/</td>
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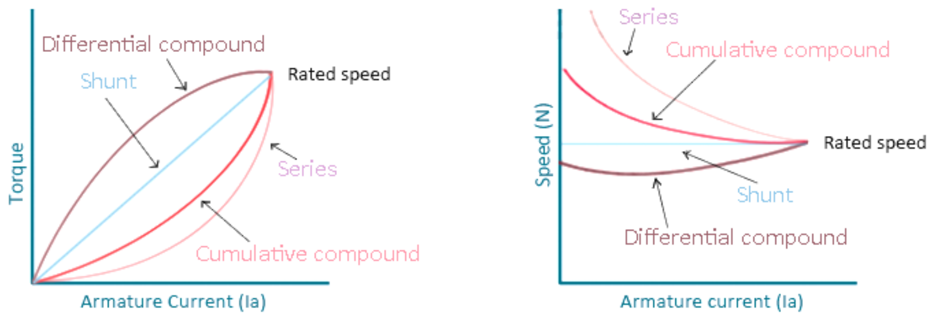
Speed vs. armature current (N-I_a)

As flux Φ is assumed constant, we can say N ∝ E_b. But, back emf is also almost constant, the speed remains constant. But practically, Φ as well as E_b decreases with increase in load. But, the E_b decreases slightly more than Φ, and hence the speed decreases slightly. Generally, the speed decreases by 5 to 15% of full load speed only. And hence, a shunt motor can be assumed as a constant speed motor.

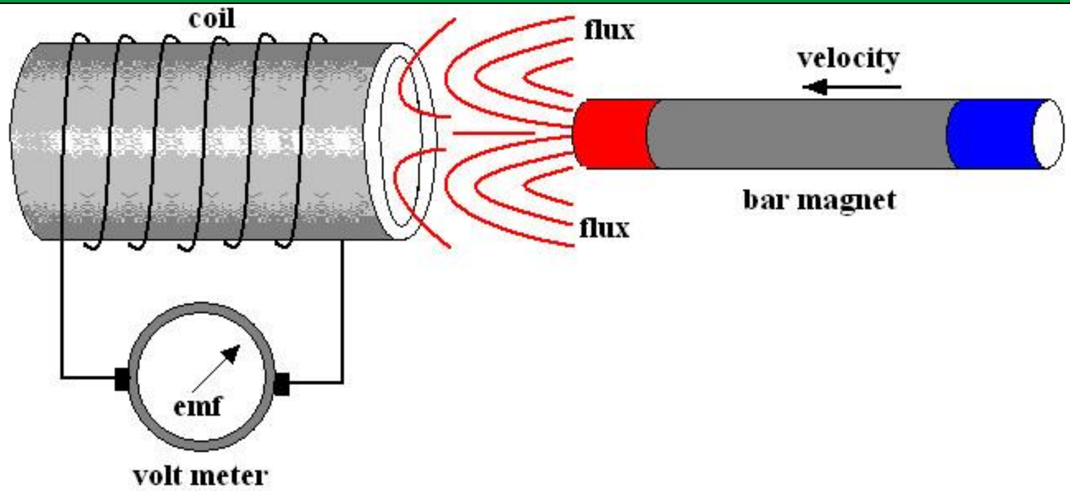


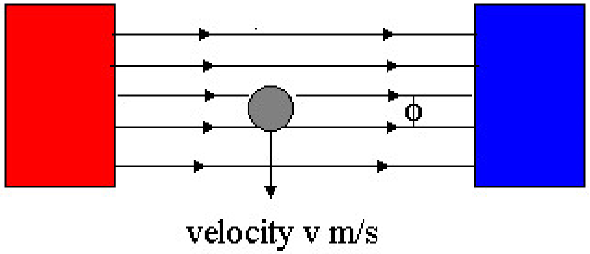
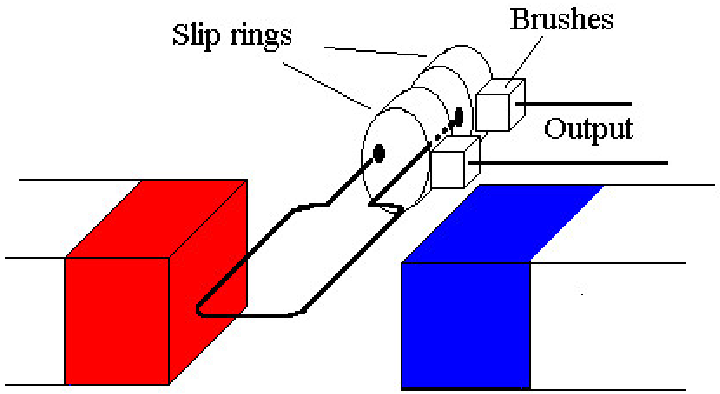
Characteristics of DC compound motor

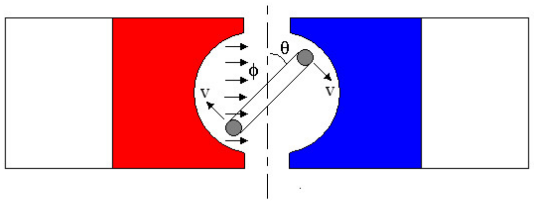
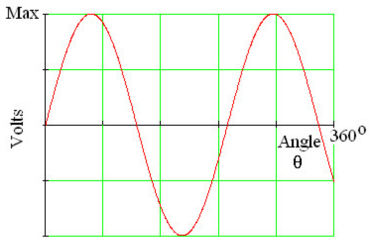
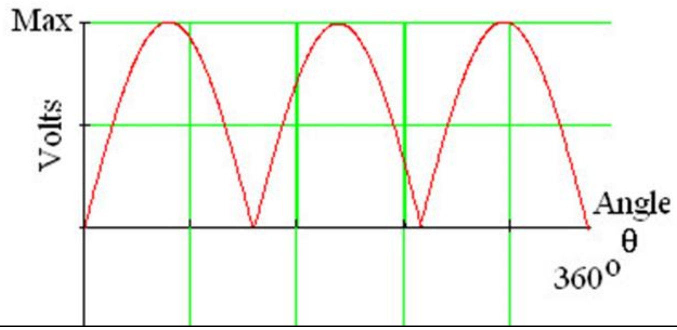
DC compound motor

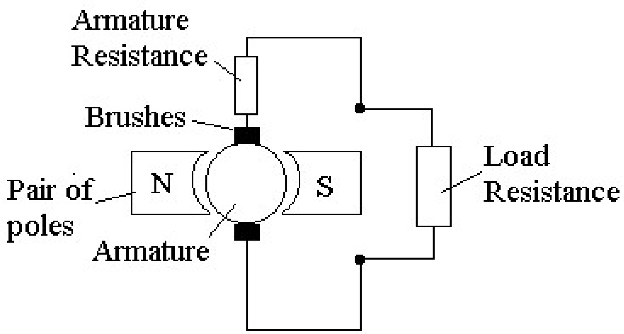
DC compound motors have both series as well as shunt windings. In a compound motor series and shunt windings are connected such that series flux is in direction with shunt flux then the motor is said to be cumulatively compounded. And if series flux is opposite direction as that of the shunt flux, then the motor is said to be differentially compounded.

	Cumulative compound motors These are used where series characteristics are required but the load is likely to be removed completely. Series winding takes care of the heavy load, whereas the shunt winding prevents the motor from running at dangerously high speed when the load is suddenly removed. These motors are generally employed in systems using a flywheel, where sudden and temporary loads are applied like in rolling mills.	
	Differential compound motors Since in differential field motors, series flux opposes shunt flux, the total flux decreases with increase in load. Due to this, the speed remains almost constant or even it may increase slightly with increase in load. Differential compound motors are not commonly use, but they find limited applications in experimental and research work.	
	Tutor to split students into smaller groups and hand out a series of questions based on the subject learned so far including questions based on the formula. Tutor to circulate and assist where required	

Lesson 9: Electromagnetic induction		**Suggested Teaching Time:** 1 hour
Learning Outcome 1: **Understand the electromagnetic theory of transformers**		
Topic	**Suggested Teaching**	**Suggested Resources**
Electromagnetic Induction **(AC 1.4)**	 Whole-class discussion and or practical experiments to cover the Generator Principle. Students to discover by practical experiment that by inserting a magnet into a coil as shown all the flux cuts across the turns of the conductor at 90º and induces an emf Tutor to emphasise that an emf is generated only when the magnet is moved. Changing the direction of movement changes the polarity of the emf Tutor to explain Fleming's right hand rule Student to get students to conduct a series of experiments using various sized magnets and coils and to record their findings. Tutor then to lead a discussion on the findings; lead students towards the fact that the emf is directly proportional to the flux density B, the velocity v and the length of the conductor	**Books:** Bhandari, N. S., *Together with Physics: 12 Cbse Syllabus*, Rachna Sagar, 2009, ISBN 818741412X, 9788187414124 **Practical Equipment:** Lab equipment for generating electricity and demonstrating principles **Websites:** http://www.learnabout-electronics.org/index.php

	within the flux l. Tutor to then reason with students that It therefore follows that the emf is given by: $\boldsymbol{e} = \boldsymbol{B}\,\boldsymbol{l}\,\boldsymbol{v}$ (the generator equation)  	
	Whole-class discussion to cover the similarity between a DC motor and the generator. However, instead of passing current into the loop, the loop is made to rotate and a voltage is generated across the end of the loop. Tutor to explain how the current flowing from the terminals is governed by the resistance connected between them (e.g. the resistance of a light bulb).  	

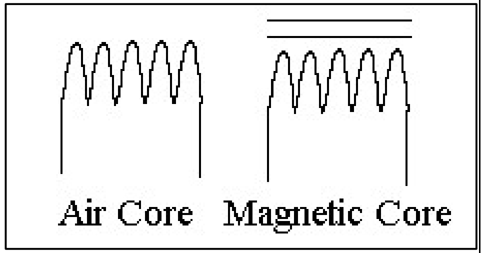
Lesson 10: Electricity generation		**Suggested Teaching Time:** 2 hour
Learning Outcome 1: **Understand the electromagnetic theory of transformers**		
Topic	**Suggested Teaching**	**Suggested Resources**
Electricity generation	Tutor-led discussion to conclude that the voltage generated is directly proportional to the angle of the loop to the flux 'θ'. The output voltage is given by $\boldsymbol{V = Vmax\ Sin}\ \theta$ V max is the maximum voltage and θ is the angle of rotation.  Student to get students to conduct a series of experiments using simple generators and oscilloscopes and to record their findings Tutor-led discussion to conclude that the simple generator produces alternating current which is sinusoidal in form. Students then to conduct the same experiment but in this case the coil is connected to a split ring, and record their results. 	**Books:** Patrick, Dale R., and Fardo, Dale R., *Electricity and Electronics Fundamentals*, The Fairmont Press, Inc., 2008, ISBN 0881736023, 9780881736021 Jiles, David C., *Introduction to Magnetism and Magnetic Materials*, Second Edition, CRC Press, 1998, ISBN-10: 0412798603, ISBN-13: 9780412798603 **Equipment:** Adaptable simple generator and an oscilloscope **Websites:** http://www.freestudy.co.uk/eep5/outcome3.pdf

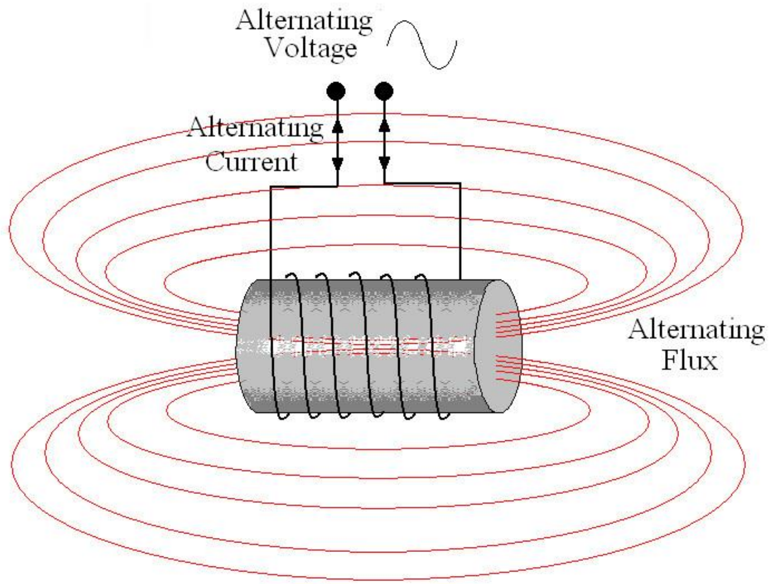
	Whole-class discussion to conclude that the polarity is reversed every half revolution and the output is a direct current consisting of half sinusoidal waves. Tutor to discuss how the emf is generated in the armature and that the current is tapped off through brushes. Tutor-led discussion to come up with ways to improve this simple design – for example If many coils are used with a commutator, the output can be made into a constant DC form. Tutor to get the students to set up a circuit as shown here The armature resistance represents the resistance of the coil. Students to operate the generator and record their results for current voltage and resistance.  Whole-class discussion to conclude that the ideal voltage generated is E but when a current I flows, the terminal voltage is given by $\boldsymbol{V = E - I\,R_a}$ Tutor to give the students a series of questions on the topics covered so far, example questions can be found at http://www.freestudy.co.uk/eep5/outcome3.pdf	

Lesson 11: Electromagnetic induction revisited

Suggested Teaching Time: 2 hours

Learning Outcome 1: **Understand the electromagnetic theory of transformers**

Topic	Suggested Teaching	Suggested Resources
Principles of induction revisited	Whole-class discussion to recap induction, including the effect of changing the number of turns and the relative velocity of the magnet to the coil. When a current flows in a coil, a magnetic flux is generated. If we generate a current we also generate a magnetic field in the coil and this will produce a force of repulsion between the magnet and the coil so that mechanical work has to be done to move the magnet. This is the source of the energy produced in the current  Emphasise that any coil of wire can generate a current flow when exposed to a magnetic field. However, a coil made specifically for an electric circuit is called an inductor. Tutor to show symbols for both air core and magnetic core. Tutor to explain that an ideal Inductor has no effect on direct current. However in reality they have a small resistance in the copper wire. Tutor to recap that when alternating current is applied to a coil, electro-magnetic induction produces a reaction. Inductors and capacitors are examples of 'reactive' components because their properties are affected by the frequency of the current flowing through it. Resistors are not affected and are called 'passive'.	**Books:** Patrick, Dale R., and Fardo, Dale R., *Electricity and Electronics Fundamentals*, The Fairmont Press, Inc., 2008, ISBN 0881736023, 9780881736021 Jiles, David C., *Introduction to Magnetism and Magnetic Materials*, Second Edition, CRC Press, 1998, ISBN-10: 0412798603, ISBN-13: 9780412798603 **Equipment:** Induction coils **Websites:** http://www.freestudy.co.uk/eep5/outcome3.pdf Example questions given at: http://www.freestudy.co.uk/eep5/outcome3.pdf

Topic	Suggested Teaching	Suggested Resources
	Split class into smaller groups and get them to conduct a series of experiments using an inductor through which AC current flows, tutor to then lead a discussion to conclude that the current  produces an alternating magnetic flux. The alternating flux cuts across the coil and generates an emf that is opposite in sense to the applied voltage. This is called the back emf. This opposes the flow of the applied current (Lenz's law) and a minus sign is used in Faraday's law. The back emf is hence: $e = -n \times rate\ of\ change\ of\ flux$ The applied voltage must be equal and opposite. This means that even though there is no resistance in the coil, a voltage is required to make	Patrick, Dale R., and Fardo, Dale R., *Electricity and Electronics Fundamentals*, The Fairmont Press, Inc., 2008, ISBN 0881736023, 9780881736021 Jiles, David C., *Introduction to Magnetism and Magnetic Materials*, Second Edition, CRC Press, 1998, ISBN-10: 0412798603, ISBN-13: 9780412798603 **Equipment:** Induction coils **Websites:** http://www.freestudy.co.uk/eep5/outcome3.pdf

	alternating current flow. This voltage depends on the rate of change and hence the frequency. This is not resistance it is called 'Reactance'. it can be shown that: $\mathrm{e} = -\mathrm{L} \times \text{rate of change of current}$ L is a property called the Inductance and the units are called Henries (H). The base unit is very large and mH or μH is more common. It can further be shown that: $\mathrm{L} = {}^{\mu_o \mu_r \mathrm{A} n^2}/_{l}$ This is a theoretical formula for the inductance of a coil. Where A is the cross sectional area of the core and l is the length of the inductor. Tutor to explain how the problem with a coil as shown above is that half of the flux is in the core and half in the air outside so we cannot calculate L easily unless the core is a ring. Tutor then to discuss the following: Suppose the current in an inductor is increased uniformly from 0 to I amps in time t seconds. The rate of change of current is constant and equal to I/t. The emf required is LI/t Remember that: • Electric power is volts x current • Power grows from $P = 0$ to $P = VI$ in time t • Energy stored is the mean power x time and the mean is half the maximum • $\text{Energy} = VIt/2$ Substitute $V = LI/t$ and the energy stored is $\boldsymbol{Energy = LI^2/2}$	

Lesson 12: Transformers		**Suggested Teaching Time:** 2 hour
Learning Outcome 1: **Understand the electromagnetic theory of transformers**		
Topic	**Suggested Teaching**	**Suggested Resources**
How transformers work (AC 1.5 and 1.12)	Whole-class discussion to recap how electromagnets work and how generators work, tutor to lead discussion towards a transformer where an electromagnet excites a core which is shared with an induction coil. Split class into smaller groups that construct a simple transformer with two coils (one with more turns than the other) placed in close proximity to each other sharing a common core. Students to apply an AC current to one of the coils and to take voltage readings off the other. Then get the students to swap which coil receives the power and record the readings again. Whole-class discussion to cover how when an alternating voltage is applied to one of the coils, called the primary winding, this produces an alternating magnetic flux Φ. The flux cuts the turns of the second coil (called the secondary winding) and generates an emf at the same frequency. Discuss the effect of changing over the power supply to the other coil had on the voltage measured. Discuss the fact that the ratio of the voltages is in direct proportion to the number of turns on each winding such that: $\boldsymbol{V_1/V_2 = N_1/N_2}$ In the ideal transformer, the electric power going in at the primary would be the same as the power coming out of the secondary. In this case: $\boldsymbol{P_1 = V_1 I_1 = P_2 = V_2 I_2}$ Hence $\boldsymbol{V_1/V_2 = I_2/I_1 = N_1/N_2}$ Note that If the secondary voltage is smaller than the primary we have a 'step down' transformer and if the voltage is larger we have a 'step up' transformer**.** Tutor to also emphasise the fact that if the voltage is stepped up, the current is stepped down and vice versa.	**Books:** Patrick, Dale R., and Fardo, Dale R., *Electricity and Electronics Fundamentals*, The Fairmont Press, Inc., 2008, ISBN 0881736023, 9780881736021 Jiles, David C., *Introduction to Magnetism and Magnetic Materials*, Second Edition, CRC Press, 1998, ISBN-10: 0412798603, ISBN-13: 9780412798603 **Equipment:** Adaptable simple transformer and an oscilloscope and/or multimeter **Websites:** http://www.freestudy.co.uk/eep5/outcome3.pdf http://www.electronics-tutorials.ws/category/transformer

Lesson 13: Transformer losses		**Suggested Teaching Time: 1** hour
Learning Outcome 1: **Understand the electromagnetic theory of transformers**		
Topic	**Suggested Teaching**	**Suggested Resources**
Transformer losses **(AC 1.11)**	Whole-class discussion to cover the real world and transformers and how real transformers are affected by energy losses. These fall into two main groups – 'Core Loss' and 'Coil Loss' **Core Loss** Large power transformers have iron cores and these become hot and lose energy because of hysteresis and 'eddy currents'. The core losses are near constant and are not affected by the current flowing in the coils. Hysteresis (explained earlier) heats up the iron core of a transformer and this is an energy lost. **Eddy Currents** The alternating flux generates electricity in the magnetic core material. As this is a short circuit, random currents flow in the material and dissipate energy as heat due to the electrical resistance. In order to reduce this, larger transformers have cores made from laminate iron sheets and each layer is insulated from each other. **Coil Losses** **Resistance** The losses in the primary and secondary coils are due to the Ohmic resistance of the copper windings. Energy is lost in the form of heat. These	**Books:** Patrick, Dale R., and Fardo, Dale R., *Electricity and Electronics Fundamentals*, The Fairmont Press, Inc., 2008, ISBN 0881736023, 9780881736021 Jiles, David C., *Introduction to Magnetism and Magnetic Materials*, Second Edition, CRC Press, 1998, ISBN-10: 0412798603, ISBN-13: 9780412798603 **Equipment:** Adaptable transformer an oscilloscope and multi-meter **Websites:** http://www.freestudy.co.uk/eep5/outcome3.pdf http://www.electronics-tutorials.ws/category/transformer

	losses are best calculated with the formula I^2R and so they increase as the square of the current. **Efficiency** η In simple terms the efficiency of a transformer is the ratio of the power in top the power out but this is complicated by the power factor of the load. The primary coil is referred to as 1 and the secondary coil as 2. $\eta = \frac{Power\ Out}{Power\ In} = \frac{P_2}{P_1} = \frac{P_2}{P_2 + \text{copper loss} + \text{core loss}} = \frac{I_2^2R_2}{(I_2^2R_2 \times PF) + \text{copper loss} + \text{core loss}}$ Example questions can be found at http://www.freestudy.co.uk/eep5/outcome3.pdf	

UNIT 428 ELECTRICAL PRINCIPLES FOR MECHANICAL ENGINEERING

Lesson 14: Three-phase transformers (part 1)		**Suggested Teaching Time:** 2 hour
Learning Outcome 1: **Understand the electromagnetic theory of transformers**		
Topic	**Suggested Teaching**	**Suggested Resources**
AC theory	Students may need a refresher on three-phase theory here: http://www.freestudy.co.uk/further%20elprinc%20unit67/outcome4t1.pdf provides a usefull handout and exercise sheet	http://www.freestudy.co.uk/further%20elprinc%20unit67/outcome4t1.pdf

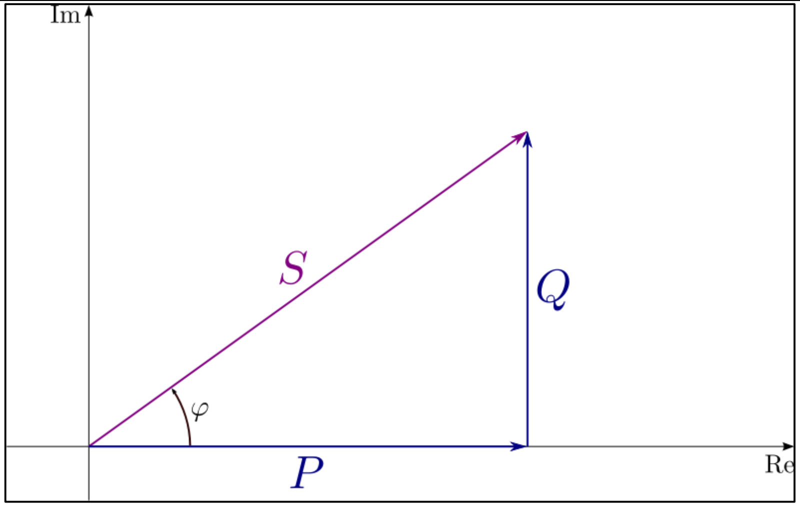
Lesson 15: Three-phase transformers (part 2)		**Suggested Teaching Time: 2** hour
Learning Outcome 1: Understand the electromagnetic theory of transformers		
Topic	**Suggested Teaching**	**Suggested Resources**
Construction of a **five limb core three-phase power transformer** Evaluate the use of **three-phase power transformers** (AC 1.8 and 1.9)	Tutor to recap previous theory and how a single-phase, two-winding voltage transformer works including step up and step down transformers. This is to develop into how voltage transformers can also be constructed for connection to not only one single phase, but also for three-phases (among others) Tutor to explain how a three-phase transformer can be constructed • Either by connecting together three single-phase transformers, thereby forming a so-called three-phase transformer bank, • Or by using one pre-assembled and balanced three-phase transformer which consists of three pairs of single-phase windings mounted onto one single laminated core. Lead whole-class discussion towards the advantages of building a single three-phase transformer e.g. for the same kVA rating it will be smaller, cheaper and lighter than three individual single-phase transformers connected together because the copper and iron core are used more effectively. The three-limb core-type three-phase transformer is the most common method of three-phase transformer construction allowing the phases to be magnetically linked. Flux of each limb uses the other two limbs for its return path with the three magnetic fluxes in the core generated by the line voltages differing in time-	**Books:** Robertson, Christopher R., *Fundamental Electrical and Electronic Principles*, Routledge, 2008, ISBN 0750687371, 9780750687379 **Practical Equipment:** Assorted three-phase transformers and measuring equipment: **Websites:** http://www.electronics-tutorials.ws/transformer/three-phase-transformer.html

	phase by 120 degrees. Thus the flux in the core remains nearly sinusoidal, producing a sinusoidal secondary supply voltage. The shell-type five-limb type three-phase transformer construction is heavier and more expensive to build than the core-type. Five-limb cores are generally used for very large power transformers as they can be made with reduced height. A shell-type transformers core materials, electrical windings, steel enclosure and cooling are much the same as for the larger single-phase types.	

Lesson 16: Power in AC circuits		**Suggested Teaching Time:** 2 hour
Learning Outcome 1: Understand the electromagnetic theory of transformers		
Topic	**Suggested Teaching**	**Suggested Resources**
Relationship between true power and apparent power in a reactive circuit (AC 1.10)	Whole-class teaching to cover how Engineers use the following terms to describe energy flow in a system (and assign each of them a different unit to differentiate between them): Real power, P, or active power — watt — (W) Reactive power, Q — volt ampere reactive — (var) Complex power, S — volt ampere — (VA) Apparent power, |S| the magnitude of complex power S — volt ampere — (VA) Phase of voltage relative to current, current lagging voltage (quadrant I vector), current leading voltage (quadrant IV vector) — the angle of difference (in degrees) between current and voltage — φ: Generally speaking, power in an electric circuit is the rate of flow of energy past a given point of the circuit. In alternating current circuits, energy storage elements such as inductors and capacitors may result in periodic reversals of the direction of energy flow. The portion of power that averaged over a complete cycle of the AC waveform, results in net transfer of energy in one direction is known as **real power**. The portion of power due to stored energy, which returns to the source in each	**Books:** Patrick, Dale R., and Fardo, Dale R., *Electricity and Electronics Fundamentals*, The Fairmont Press, Inc., 2008, ISBN 0881736023, 9780881736021 Jiles, David C., *Introduction to Magnetism and Magnetic Materials*, Second Edition, CRC Press, 1998, ISBN-10: 0412798603, ISBN-13: 9780412798603 **Websites:** http://www.freestudy.co.uk/eep5/outcome3.pdf http://www.electronics-tutorials.ws/transformer/three-phase-transformer.html

	cycle, is known as reactive power. If the load is purely **resistive**, the two quantities reverse their polarity at the same time. At every instant the product of voltage and current is positive, indicating that the direction of energy flow does not reverse. In this case, only real power is transferred. If the loads are purely **reactive**, then the voltage and current are 90 degrees out of phase. For half of each cycle, the product of voltage and current is positive, but on the other half of the cycle, the product is negative, indicating that on average, exactly as much energy flows toward the load as flows back. There is no net energy flow over one cycle. In this case, only **reactive** energy flows—there is no net transfer of energy to the load Practical loads have resistance, inductance, and capacitance, so both real and reactive power will flow to real loads. Power engineers measure apparent power as the magnitude of the vector sum of real and reactive power. Apparent power is the product of the root-mean-square of voltage and current Even though the current associated with reactive power does no work at the load, it heats the wires, wasting energy. Conductors, transformers and generators must be sized to carry the total current, not just the current that does useful work	

Topic	Suggested Teaching	Suggested Resources
Calculating the power factor of a transformer (AC 1.12)	In electrical engineering, the power factor of an AC electrical power system is defined as the ratio of the real power flowing to the load, to the apparent power in the circuit, and is a dimensionless number between -1 and 1. When power factor is equal to 0, the energy flow is entirely reactive, and stored energy in the load returns to the source on each cycle. When the power factor is 1, all the energy supplied by the source is consumed by the load. Power factors are usually stated as 'leading' or 'lagging' to show the sign of the phase angle. Capacitive loads are leading (current leads voltage), and inductive loads are lagging (current lags voltage). For example, to get 1kW of real power, if the power factor is unity, 1 kVA of apparent power needs to be transferred (1 kW ÷ 1 = 1 kVA). At low values of power factor, more apparent power needs to be transferred to get the same real power. To get 1kW of real power at 0.2 power factor, 5 kVA of apparent power needs to be transferred (1kW ÷ 0.2 = 5 kVA). Electrical loads consuming alternating current power consume both real power and reactive power. The vector sum of real and reactive power is the apparent power. The presence of reactive power causes the real power to be less than the apparent power, and so, the electric load has a power factor of less than 1. Where the waveforms are purely sinusoidal, the power factor is the cosine of the phase angle (φ) between the current and voltage sinusoid waveforms. Example: The real power is 700 W and the phase angle between voltage and current is 45.6°. The power factor is cos(45.6°) = 0.700. The apparent power is then: 700 W / cos(45.6°) = 1000 VA	**Books:** Patrick, Dale R., and Fardo, Dale R., *Electricity and Electronics Fundamentals*, The Fairmont Press, Inc., 2008, ISBN 0881736023, 9780881736021 Jiles, David C., *Introduction to Magnetism and Magnetic Materials*, Second Edition, CRC Press, 1998, ISBN-10: 0412798603, ISBN-13: 9780412798603 **Websites:** http://www.freestudy.co.uk/eep5/outcome3.pdf http://www.electronics-tutorials.ws/transformer/three-phase-transformer.html

	 In the diagram, P is the real power, Q is the reactive power (in this case positive), S is the complex power and the length of S is the apparent power. Reactive power does not do any work, so it is represented as the imaginary axis of the vector diagram. Real power does do work, so it is the real axis. In the diagram *P* is the real power, *Q* is the reactive power (in this case positive), *S* is the complex power and the length of *S* is the apparent power. Reactive power does not do any work, so it is represented as the imaginary axis of the vector diagram. Real power does do work, so it is the real axis. Understanding the relationship among these three quantities lies at the heart of understanding power engineering. The mathematical relationship among them can be represented by vectors or expressed using complex numbers, S = P + jQ (where j is the imaginary unit).	

Lesson 17: AC motors		**Suggested Teaching Time:** 8 hours
Learning Outcome 3: Understand the principles of three-phase induction motors		
Topic	**Suggested Teaching**	**Suggested Resources**
Analysing the operating principles of **three-phase synchronous induction motors** for different rotor types	Tutor-led discussion to recap on DC motors and how the current is applied to the conductors on the rotor so that the magnetic field interacts with the constant flux. This can then lead on to discussing the differences between an AC and DC motor, with the main one being that the magnetic flux is produced by AC in the coils and an alternating magnetic flux produced. In a three-phase induction motor there are three set of coils. Each one is connected to a phase. This results in a magnetic flux that varies from maximum to minimum at any point and the point of maximum flux moves around the stator. In other words a rotating magnetic flux is produced. You can see an animated demonstration of the principle at this location http://www.youtube.com/watch?v=LtJoJBUSe28 Tutor to recap using Faraday's law how an emf induced in any circuit is due to the rate of change of magnetic flux linkage through the circuit. As the rotor windings in an induction motor are either closed through an external resistance or directly shorted by end ring, and cut the stator rotating magnetic field, an emf is induced in the rotor copper bar and due to this emf an electric current flows through the same rotor conductor. Here it is the relative velocity between the rotating flux and the static rotor conductor that is the cause of electric current generation; hence as per Lenz's law the rotor will rotate in the same direction to reduce the cause i.e. the	**Books:** Hughes, Austin, *Electric Motors and Drives: Fundamentals, Types and Applications*, 4th edition, Newnes, 2013, ISBN-10: 0080983324, ISBN-13: 978-0080983325 **Practical Equipment:** Three-phase motor and test equipment **Websites:** http://www.electrical4u.com/lap-winding-simplex-and-duplex-lap-winding/

	relative velocity. Thus from the working principle of three-phase induction motor it may observed that the rotor speed should not reach the synchronous speed produced by the stator. If the speeds equals, there would be no such relative velocity, so no emf induction in the rotor, and no electric current would be flowing, and therefore no torque would be generated. Consequently the rotor cannot reach the synchronous speed. The difference between the stator (synchronous speed) and rotor speeds is called the slip. The rotation of the magnetic field in an induction motor has the advantage that no electrical connections need to be made to the rotor. Thus the three-phase induction motor is: • Self-starting • Less armature reaction and brush sparking because of the absence of commutators and brushes that may cause sparks • Robust in construction • Economical • Easier to maintain One disadvantage is that when starting large motors, very high currents are drawn in the windings Tutor to explain how a change of rotation can be achieved in a three-phase induction motor	

UNIT 428 ELECTRICAL PRINCIPLES FOR MECHANICAL ENGINEERING

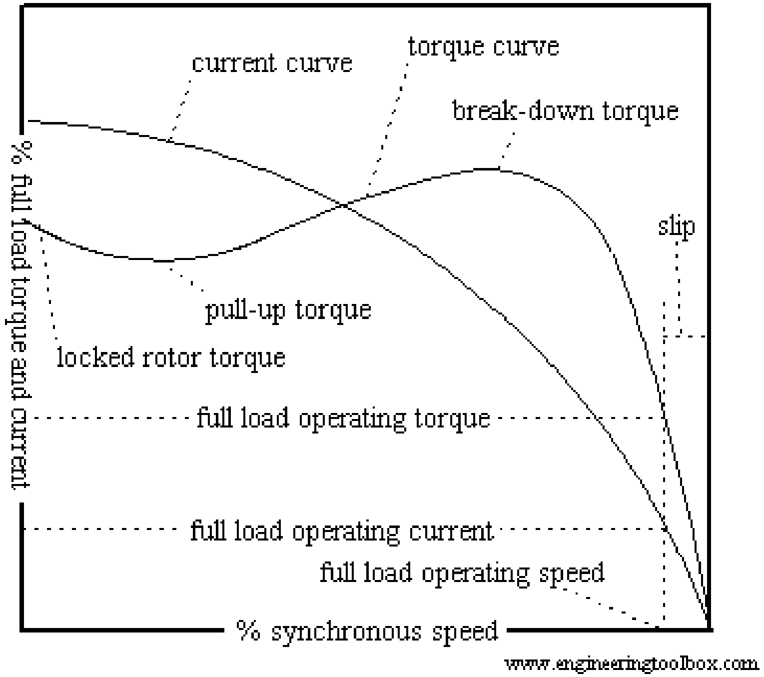
Topic	Suggested Teaching	Suggested Resources
Squirrel cage rotors (AC 3.1 and 3.3)	The current and flux induced in the rotor conductors reacts with the rotating field and the rotor is dragged around with the flux. The speed of rotation of the magnetic field is known as the synchronous speed and this depends on the frequency of the power supply. In the UK this is normally 50 Hz and the synchronous speed is 3,000 rev/min. When the motor is initially switched on and the rotor is stationary, the effect is at its strongest. This gives it an advantage over other types because it has a high starting torque. In reality, the coils in the stator overlap. The stator is made from soft iron laminations to prevent eddy currents being generated in the iron and causing losses. In the three-phase induction motor, the conductors on the rotor are essentially short circuits. Most commonly they are arranged like a cage, often referred to as a squirrel cage. These slot into the rotor which is made up of laminated iron sections to reduce losses. In squirrel-cage motors, the motor speed is determined by the load it drives and by the number of poles generating a magnetic field in the stator. This layout produces a compact, robust, simple motor that is relatively low cost.	**Books:** Hughes, Austin, *Electric Motors and Drives: Fundamentals, Types and Applications*, 4th edition, Newnes, 2013, ISBN-10: 0080983324, ISBN-13: 978-0080983325 **Practical Equipment:** Three-phase motor and test equipment **Websites:** http://www.electrical4u.com/lap-winding-simplex-and-duplex-lap-winding/
Wound rotor (AC 3.1)	An alternate design, called the wound rotor, is used when variable speed is required. In this case, the rotor has the same number of poles as the stator and the windings are made of wire, connected to slip rings on the shaft. Carbon brushes connect the slip rings to a controller such as a variable resistor that allows changing the motor's slip rate.	

	In certain high-power variable speed wound-rotor drives, the slip-frequency energy is captured, rectified and returned to the power supply through an inverter. With bi-directionally controlled power, the wound-rotor becomes an active participant in the energy conversion process with the wound-rotor doubly fed configuration showing twice the power density. Compared to squirrel-cage rotors, wound rotor motors are expensive and require maintenance of the slip rings and brushes, but they were the standard form for variable speed control before the advent of compact power electronic devices. Transistorised inverters with variable-frequency drive can now be used for speed control, and wound rotor motors are becoming less common. This type of motor is becoming more common in traction applications such as locomotives, where it is known as the asynchronous traction motor.	

UNIT 428 ELECTRICAL PRINCIPLES FOR MECHANICAL ENGINEERING

Topic	Suggested Teaching	Suggested Resources
Relationship between **torque and slip of three-phase induction motors** (A.C.3.2)	If the rotor of a squirrel-cage motor runs at the true synchronous speed, the flux in the rotor at any given place on the rotor would not change, and no current would be created in the squirrel cage. For this reason, ordinary squirrel-cage motors run at some tens of RPM slower than synchronous speed. Because the rotating field (or equivalent pulsating field) effectively rotates faster than the rotor, it could be said to slip past the surface of the rotor. The difference between synchronous speed and actual speed is called slip, and loading the motor increases the amount of slip as the motor slows down slightly. Even with no load, internal mechanical losses prevent the slip from being zero. The speed of the AC motor is determined primarily by the frequency of the AC supply and the number of poles in the stator winding, according to the relation: N_{s} = 120F/p where Ns = synchronous speed, in revolutions per minute F = AC power frequency p = Number of poles per phase winding Actual RPM for an induction motor will be less than this calculated synchronous speed by an amount known as slip, that increases with the torque produced. With no load, the speed will be very close to synchronous. When loaded, standard motors have between 2-3% slip, special motors may have up to 7% slip, and a class of motors known as torque motors are rated to operate at 100% slip (0 RPM/full stall).	**Books:** Hughes, Austin, *Electric Motors and Drives: Fundamentals, Types and Applications*, 4th edition, Newnes, 2013, ISBN-10: 0080983324, ISBN-13: 978-0080983325 **Practical Equipment:** Three-phase motor and test equipment **Websites:** http://www.electrical4u.com/lap-winding-simplex-and-duplex-lap-winding/

	The slip of the AC motor is calculated by: $S = (N_{s} - N_{r})/N_{s}$ where Nr = Rotational speed, in revolutions per minute. S = Normalised Slip, 0 to 1. As an example, a typical four-pole motor running on 60 Hz might have a nameplate rating of 1725 RPM at full load, while its calculated speed is 1800 RPM. The speed in this type of motor has traditionally been altered by having additional sets of coils or poles in the motor that can be switched on and off to change the speed of magnetic field rotation. However, developments in power electronics mean that the frequency of the power supply can also now be varied to provide a smoother control of the motor speed. This kind of rotor is the basic hardware for induction regulators, which is an exception of the use of rotating magnetic field as pure electrical (not electromechanical) application.	

Topic	Suggested Teaching	Suggested Resources
Torque	Torque is the turning force through a radius and the units is rated in –*Nm* in the SI-system and in *-lb ft*- in the imperial system. The torque developed by asynchronous induction motors varies with the speed of the motor when it is accelerated from full stop or zero speed, to maximum operating speed.  **Locked rotor or starting torque** The locked rotor torque or starting torque is the torque the electrical motor develop when its starts at rest or zero speed. A high starting torque is more important for application or machines hard to start - as positive displacement pumps, cranes etc. A lower starting torque can be accepted in applications as centrifugal fans or pumps where the start load is low or close to zero.	**Books:** Hughes, Austin, *Electric Motors and Drives: Fundamentals, Types and Applications*, 4th edition, Newnes, 2013, ISBN-10: 0080983324, ISBN-13: 978-0080983325 **Practical Equipment:** Three-phase motor and test equipment **Websites:** http://www.electrical4u.com/lap-winding-simplex-and-duplex-lap-winding/ http://www.engineeringtoolbox.com/electrical-motors-torques-d_651.html

	Pull-up torque The pull-up torque is the minimum torque developed by the electrical motor when it runs from zero to full-load speed (before it reaches the break-down torque point) When the motor starts and begins to accelerate the torque in general decrease until it reach a low point at a certain speed (the pull-up torque) before the torque increases until it reach the highest torque at a higher speed (the break-down torque) point. The pull-up torque may be critical for applications that needs power to go through some temporary barriers achieving the working conditions. **Break-down torque** The break-down torque is the highest torque available before the torque decreases when the machine continues to accelerate to the working conditions. **Full-load (rated) torque or braking torque** The full-load torque is the torque required to produce the rated power of the electrical motor at full-load speed. Full-load (rated) torque can be expressed as $T = 9550 P_{kW}/n_r$ where T = rated torque (Nm) P_{kW} = rated power (kW) n_r = rated rotational speed (rpm) **Accelerating torque** Accelerating torque = available motor torque - load torque	

Lesson 18: Synchronous AC motors		**Suggested Teaching Time:** 4 hours
Learning Outcome 4: Understand the principles of three-phase synchronous induction motors		
Topic	**Suggested Teaching**	**Suggested Resources**
Synchronous motors (AC 4.2, 4.3 & 4.4)	The synchronous motor and induction motor are the most widely used types of AC motor. The difference between the two types is that the synchronous motor rotates in exact synchronism with the line frequency. Therefore small synchronous motors are used in timing applications such as in synchronous clocks, timers in appliances, tape recorders and precision servomechanisms in which the motor must operate at a precise speed	**Books:** Hughes, Austin, *Electric Motors and Drives: Fundamentals, Types and Applications*, 4th edition, Newnes, 2013, ISBN-10: 0080983324, ISBN-13: 978-0080983325 **Practical Equipment:** Three-phase motor and test equipment **Websites:** http://www.electrical4u.com
	DC-excited motors Usually made in larger sizes (larger than about 1 horsepower or 1 kilowatt) these motors require direct current supplied to the rotor for excitation. This is most straightforwardly supplied through slip rings, but a brushless AC induction and rectifier arrangement may also be used. The direct current may be supplied from a separate DC source or from a DC generator directly connected to the motor shaft Three-phase synchronous motors have an additional coil on the rotor that is supplied with DC. This produces a constant magnetic field. The motor accelerates to the synchronous speed because the north and south poles of the rotor magnet locks to the south and north poles of the rotating stator field. The rotor of a synchronous motor will usually include a squirrel-cage winding	

	which is used to start the motor rotation and then the DC coil is connected to lock it at the synchronous speed. The squirrel cage has no effect at synchronous speeds as no induction takes place	
	In non-excited motors, the rotor is made of steel. At synchronous speed it rotates in step with the rotating magnetic field of the stator, so it has an almost-constant magnetic field through it. The external stator field magnetizes the rotor, inducing the magnetic poles needed to turn it. The rotor is made of a high-retentivity steel such as cobalt steel. These are manufactured in **permanent magnet, reluctance and hysteresis designs**:	
	Permanent magnet motors Some synchronous motors use permanent magnets embedded in the steel rotor to create a constant magnetic field. At synchronous speed these poles lock to the rotating magnetic field. They are not self-starting. Because of the constant magnetic field in the rotor these cannot use induction windings for starting. (Permanent-magnet synchronous motors are not to be confused with the other kind of permanent-magnet electric motor that requires DC current to rotate.	

Topic	Suggested Teaching	Suggested Resources
	Reluctance motors These have a rotor consisting of a solid steel casting with projecting (salient) toothed poles, typically less than the stator poles to minimise torque ripple and prevents the poles from all aligning simultaneously—a position which cannot generate torque. The size of the air gap in the magnetic circuit and thus the reluctance is minimum when the poles are aligned with the (rotating) magnetic field of the stator, and increases with the angle between them. This creates a torque pulling the rotor into alignment with the nearest pole of the stator field. Thus at synchronous speed the rotor is 'locked' to the rotating stator field. This cannot start the motor, so the rotor poles usually have squirrel-cage windings embedded in them, to provide torque below synchronous speed. The machine starts as an induction motor until it approaches synchronous speed, when the rotor 'pulls in' and locks to the rotating stator field.	**Books:** Hughes, Austin, *Electric Motors and Drives: Fundamentals, Types and Applications*, 4th edition, Newnes, 2013, ISBN-10: 0080983324, ISBN-13: 978-0080983325 **Practical Equipment:** Three-phase motor and test equipment **Websites:** http://www.electrical4u.com http://en.wikipedia.org/wiki/Synchronous_motor
	Hysteresis motors These have a solid smooth cylindrical rotor, cast of a high coercivity magnetically 'hard' cobalt steel. This material has a wide hysteresis loop (high coercivity), meaning once it is magnetised in a given direction; it requires a large reverse magnetic field to reverse the magnetisation. The rotating stator field causes each small volume of the rotor to experience a reversing magnetic field. Because of hysteresis the phase of the magnetisation	

	lags behind the phase of the applied field. The result of this is that the axis of the magnetic field induced in the rotor lags behind the axis of the stator field by a constant angle δ, producing a torque as the rotor tries to 'catch up' with the stator field. As long as the rotor is below synchronous speed, each particle of the rotor experiences a reversing magnetic field at the 'slip' frequency which drives it around its hysteresis loop, causing the rotor field to lag and create torque. There is a 2-pole low reluctance bar structure in the rotor.[4] As the rotor approaches synchronous speed and slip goes to zero, this magnetises and aligns with the stator field, causing the rotor to 'lock' to the rotating stator field. A major advantage of the hysteresis motor is that since the lag angle δ is independent of speed, it develops constant torque from start up to synchronous speed. Therefore it is self-starting and doesn't need an induction winding to start it, although many designs do have a squirrel-cage conductive winding structure embedded in the rotor to provide extra torque at start-up. Hysteresis motors are manufactured in sub-fractional horsepower ratings, primarily as servomotors and timing motors. More expensive than the reluctance type, hysteresis motors are used where precise constant speed is required	

Topic	Suggested Teaching	Suggested Resources
	In salient pole type of rotor consist of large number of projected poles (salient poles) mounted on a magnetic wheel, the projected poles are made up from laminations of steel. The rotor winding is provided on these poles and it is supported by pole shoes. Salient pole rotors have large diameter and shorter axial length. They are generally used in lower speed electrical machines, say 100 RPM to 1500 RPM. As the rotor speed is lower, more number of poles are required to attain the required frequency ($N_s = 120f/P$ therefore, $f = N_sP/120$ i.e. frequency is proportional to number of poles). Typically the number of salient poles is 4 to 60. Flux distribution is relatively poor than non-salient pole rotor, hence the generated emf waveform is not as good as cylindrical rotor. Salient pole rotors generally need damper windings to prevent rotor oscillations during operation	**Books:** Hughes, Austin, *Electric Motors and Drives: Fundamentals, Types and Applications*, 4th edition, Newnes, 2013, ISBN-10: 0080983324, ISBN-13: 978-0080983325 **Practical Equipment:** Three-phase motor and test equipment **Websites:** http://www.electrical4u.com http://www.electricaleasy.com/2014/03/salient-pole-rotor-vs-non-salient-pole.html
Synchronous speed	The synchronous speed N_S (in RPM) of a synchronous motor is given by $N_S = \frac{120f}{P}$ where, f is the frequency of the AC supply current in Hz. and P is the number of poles per phase. Synchronous speed can also be expressed in terms of angular speed, $\omega_s = \frac{4\pi f}{P}$ Here, ω_s is the angular speed expressed in rad s−1 and in difference with the previous formula for number of turns per a minute, P is the number of ‘pair of poles’ per phase.	

Lesson 19: Power factors revisited		**Suggested Teaching Time:** 4 hours
Learning Outcome 4: Understand the principles of three-phase synchronous induction motors		
Topic	**Suggested Teaching**	**Suggested Resources**
Calculating overall **power factor correction of an industrial plant** (AC 4.5)	Whole-class teaching to cover how to calculate overall power factor correction of an industrial plant: see link for further information	**Websites:** http://www.eaton.com/ecm/groups/public/@pub/@electrical/documents/content/sa02607001e.pdf

Lesson 20: Semi-conductors		**Suggested Teaching Time:** 2 hour
Learning Outcome 5: Understand the properties, principles and applications of basic analogue components used in electrical machine control		
Topic	**Suggested Teaching**	**Suggested Resources**
	Tutor to note that a recap on electron theory may be useful at this point	

Semiconductors
(AC 5.1)
	There are a group of natural materials that are neither good conductors nor good insulators. These are called semiconductors such as silicon and germanium. Tutor to cover band theory including:
	• The **Valence** band
	• The **Conduction** band
	Tutor to also cover how:
	• Band theory supposes that a fixed amount of energy is required to make an electron jump from the valence shell into the conduction band.
	  ○ This is called the energy gap.
	• In the case of semiconductors like silicon the resistance goes down.
	  ○ Natural semiconductors are called **Intrinsic**.
	  ○ When they are modified by a manufacturing process to give them enhanced properties, they are then called **Extrinsic.**
	    ▪ Extrinsic semiconductors are produced by doping them to enhance their conductivity.
	  ○ The conductivity of semiconductors such as silicon can be increased by adding small, controlled amounts of impurities that have roughly the same atomic size, but more or fewer valence electrons than the semimetal. This is known as **doping**
		Books:
		Patrick, Dale R., and Fardo, Dale R., *Electricity and Electronics Fundamentals*, The Fairmont Press, Inc., 2008, ISBN 0881736023, 9780881736021
		Jiles, David C., *Introduction to Magnetism and Magnetic Materials*, Second Edition, CRC Press, 1998, ISBN-10: 0412798603, ISBN-13: 9780412798603
		Websites:
		https://www.designsoft.biz/orders/order.php
		http://www.allaboutcircuits.com/vol_3/chpt_3/1.html
		http://www.youspice.com/ys/spicebasesoftware.3sp

P-type semiconductors	An impurity with fewer valence electrons such as boron, aluminium or indium takes up space in the solid structure, but contributes fewer electrons to the valence band, thus generating an electron deficit and making the atoms more positively charged. This type of doping creates a hole in the valence band making it possible for the electrons in the valence band to move from one atom to another within this band and so increases the conductivity. Such doped semiconductors are known as ***p-type*** because the atoms are more positively charged	
N-type semiconductors	Alternately, an impurity with more valence electrons such as phosphorus, antimony or arsenic contributes extra electrons to the band. Since the valence band is already filled by the semimetal, the extra electrons must go into the conduction band. This also improves the conductivity. Such dopes semiconductors are known as ***n-type*** because the enrichment of electrons makes it more negatively charged.	

Lesson 21: Diodes		**Suggested Teaching Time:** 2 hour
Learning Outcome 5: Understand the properties, principles and applications of basic analogue components used in electrical machine control		
Topic	**Suggested Teaching**	**Suggested Resources**
Diode		**Books:** Patrick, Dale R., and Fardo, Dale R., *Electricity and Electronics Fundamentals*, The Fairmont Press, Inc., 2008, ISBN 0881736023, 9780881736021 Jiles, David C., *Introduction to Magnetism and Magnetic Materials*, Second Edition, CRC Press, 1998, ISBN-10: 0412798603, ISBN-13: 9780412798603 Singh, Yaduvir, and Agnihotri, Swarajya, *Semiconductor Devices*, I. K. International Pvt Ltd, 2009, ISBN-10 9380026129, ISBN-13: 9789380026121 **Website:** http://www.allaboutcircuits.com/worksheets/zener.html http://en.wikipedia.org/wiki/Zener_diode http://simple.wikipedia.org/wiki/Diode
Types of diodes and their uses (AC 5.2)	**Zener Diode** A zener diode is like a normal diode, but instead of being destroyed by a big reverse voltage, it lets electricity through. The voltage needed for this is called the breakdown voltage or Zener voltage. Because it can be built with a known breakdown voltage, it can be used to accurately measure voltage.	
	Schottky diode The symbol of this is the diode symbol, with an ‘S’ at the peak. Instead of both sides being a semiconductor (like silicon), one side is metal, like aluminum or nickel. This reduces the cut-in voltage to about 0.3 volt. This is about half of the threshold voltage of a usual diode. It can react faster, it also creates less heat and is more efficient. But it does has some current leakage with reverse voltage. When a diode switches from moving current to not moving current, this is known as switching. It takes dozens of nanoseconds in a typical diode; this creates some radio noise, which temporarily degrades radio signals. The Schottky diode switches in a small fraction of that time, less than a nanosecond.	
	Tunnel diode In the symbol of the tunnel diode there´s a kind of additional square bracket at the end of the usual symbol. A tunnel diode consists of a highly doped p-n	

	junction. Because of this high doping, there is only a very narrow gap where the electrons are able to pass through. This tunnel-effect appears in both directions. After a certain amount of electrons have passed, the current through the gap decreases, until the normal current through the diode at the threshold voltage begins. This causes an area of a negative resistance. These diodes are used to deal with really high frequencies (100 GHz). It's also resistant to radiation, so they are used in spacecraft. They are also used in microwaves and refrigerators.	

Lesson 22: Diode applications		**Suggested Teaching Time:** 4 hours
Learning Outcome 5: Understand the properties, principles and applications of basic analogue components used in electrical machine control		
Topic	**Suggested Teaching**	**Suggested Resources**
Processing diodes **Rectifiers** **Voltage regulation** (AC 5.2)	Tutor to discuss how we can use a diode to change AC power to DC power. Tutor to cover half-wave and full-wave bridge rectification and three-phase full-wave bridge rectifier circuit	**Books:** Patrick, Dale R., and Fardo, Dale R., *Electricity and Electronics Fundamentals*, The Fairmont Press, Inc., 2008, ISBN 0881736023, 9780881736021 Jiles, David C., *Introduction to Magnetism and Magnetic Materials*, Second Edition, CRC Press, 1998, ISBN-10: 0412798603, ISBN-13: 9780412798603 Singh, Yaduvir, and Agnihotri, Swarajya, *Semiconductor Devices*, I. K. International Pvt Ltd, 2009, ISBN-10 9380026129, ISBN-13: 9789380026121 **Websites:** http://www.allaboutcircuits.com/
	Tutor to discuss how a diode has a voltage drop and how we can exploit this for Voltage regulation applications. Suppose we were building some kind of circuit which could not tolerate variations in power supply voltage, but needed to be powered by a chemical battery, whose voltage changes over its lifetime. We could form a circuit with a silicon diode and a resistor, connect the circuit requiring steady voltage across the diode, where it would receive an unchanging 0.7 volts. This would certainly work, but most practical circuits of any kind require a power supply voltage in excess of 0.7 volts to properly function. One way we could increase our voltage regulation point would be to connect multiple diodes in series, so that their individual forward voltage drops of 0.7 volts each would add to create a larger total. For instance, if we had ten diodes in series, the regulated voltage would be ten times 0.7, or 7 volts	
	Zener diodes are frequently used as voltage regulating devices, because they act to clamp the voltage drop across themselves at a predetermined level. Whatever excess voltage is supplied by the power source becomes dropped across the series resistor. However, it is important to note that a zener diode cannot make up for a deficiency in source voltage. For instance, this 12-volt	

Voltage reference	zener diode does not drop 12 volts when the power source is only 6 volts strong. It is helpful to think of a zener diode as a voltage limiter: establishing a maximum voltage drop, but not a minimum voltage drop. Try experiment shown at http://www.allaboutcircuits.com/vol_6/chpt_5/7.html	
	A voltage reference is an electronic device that produces a fixed (constant) voltage irrespective of the loading on the device, power supply variations, temperature changes, and the passage of time. Voltage references are used in power supplies, analogue-to-digital converters, digital-to-analogue converters, and other measurement and control systems. Voltage references vary widely in performance; a regulator for a computer power supply may only hold its value to within a few per cent of the nominal value, whereas laboratory voltage standards have precisions and stability measured in parts per million. These all use Diodes to perform the required corrections. The most common voltage reference circuit used in integrated circuits is the bandgap voltage reference	
Varicap or varactor diodes	A variable capacitance diode is known as a varicap diode or as a varactor. If a diode is reverse biased, an insulating depletion region forms between the two semiconductive layers. In many diodes the width of the depletion region may be changed by varying the reverse bias. This varies the capacitance. This effect is accentuated in varicap diodes	
Constant-current diodes	A constant-current diode, also known as a current-limiting diode, or current-regulating diode, does exactly what its name implies: it regulates current through it to some maximum level. The constant current diode is a two terminal version of a JFET. If we try to force more current through a constant-current diode than its current-regulation point, it simply ‘fights back’ by dropping more voltage	

UNIT 428 ELECTRICAL PRINCIPLES FOR MECHANICAL ENGINEERING

Topic	Suggested Teaching	Suggested Resources
Light-emitting diodes (AC 5.2)	Tutor to describe how diodes, like all semiconductor devices, are governed by the principles described in quantum physics. One of these principles is the emission of specific-frequency radiant energy whenever electrons fall from a higher energy level to a lower energy level. Each chemical element has its own 'signature' emission of radiant energy when its electrons 'jump' between different, quantised energy levels. Hydrogen gas, for example, glows red when ionised; mercury vapour glows blue. Electrons flowing through a p-n junction experience similar transitions in energy level, and emit radiant energy as they do so. The frequency of this radiant energy is determined by the crystal structure of the semiconductor material, and the elements comprising it. Some emit radiant energy within the spectrum of visible light as the electrons change energy levels. Simply put, these junctions glow when forward biased. A diode intentionally designed to glow like a lamp is called a light-emitting diode, or LED. Diodes made from a combination of the elements gallium, arsenic, and phosphorus (called gallium-arsenide-phosphide) glow bright red, and are some of the most common LEDs manufactured. By altering the chemical constituency of the p-n junction, different colours may be obtained. Because LEDs do not have to warmup to produce light they can switch on and off very quickly. For this reason LEDs are used to transmit digital (on/off) information as pulses of light, conducted in empty space or through fibre-optic cable, at very high rates of speed (millions of pulses per second)	**Books:** Schubert, E. Fred, *Light-Emitting Diodes*, 2nd edition, Cambridge University Press, 2006, ISBN 9780521865388 (hardback), 9780521865387 (paperback) *Proceedings of SPIE - The International Society for Optical Engineering* vol 4996 **Equipment:** LEDs, and circuit to power them **Websites:** http://www.allaboutcircuits.com/vol_3/chpt_3/12.html

Photodiode	A photodiode is a diode optimised to produce an electron current flow in response to irradiation by ultraviolet, visible, or infrared light. Silicon is most often used to fabricate photodiodes, but germanium, gallium arsenide can be used. The junction through which light enters the semiconductor must be thin enough to pass most of the light on to the active region (depletion region) where light is converted to electron hole pairs. These photodiodes can be used to convert sunlight into electricity (as in a solar panel) or can be used as switches that react to light such as those used to receive signals from a fibre-optic cable (millions of pulses per second).	**Books:** Patrick, Dale R., and Fardo, Dale R., *Electricity and Electronics Fundamentals*, The Fairmont Press, Inc., 2008, ISBN 0881736023, 9780881736021 **Equipment:** Photo diodes, varicap diodes and constant current diodes Voltage/current measuring equipment **Website:** http://www.allaboutcircuits.com/vol_3/chpt_3/12.html

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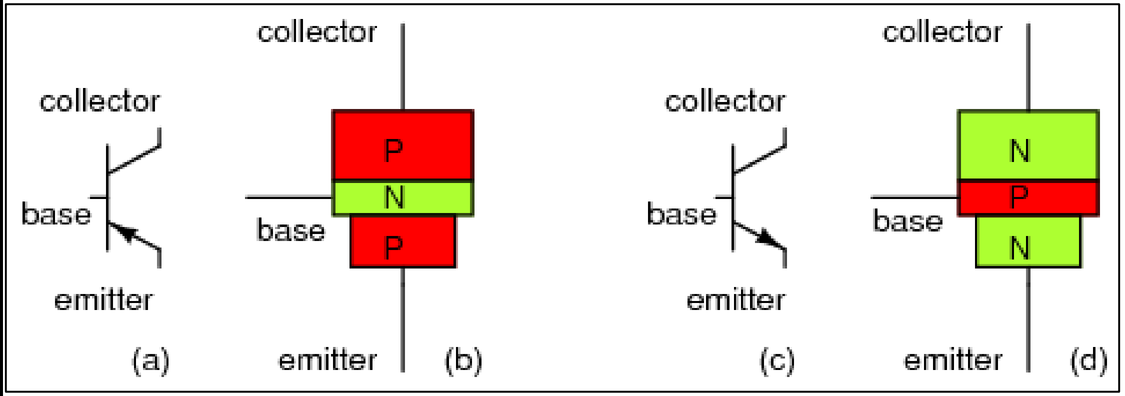
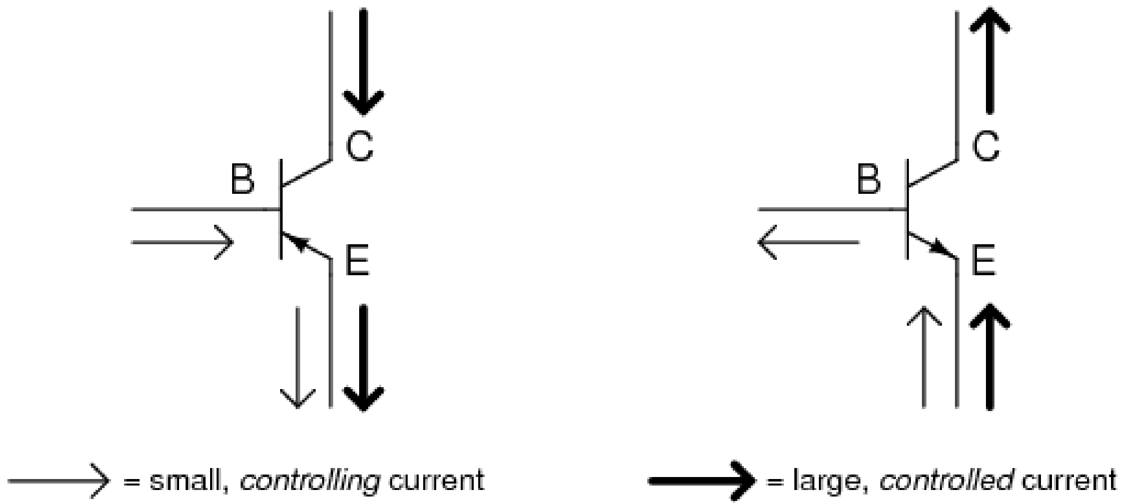
Topic	Suggested Teaching	Suggested Resources
High-voltage uses	Avalanche diodes are a type of high-voltage diode that can handle large amounts of power. An avalanche effect is caused when a charge begins to increase in a diode without a subsequent increase in outside power. This effect will destroy normal diodes, but an avalanche diode will continue operation until the outer voltage catches up or the system equalises. A transient voltage suppression diode is a diode that protects systems from high-voltage overloads. This diode has a very large p-n junction, which discourages the transmission of power through the system. When large power spikes hit the system, this high-voltage diode will take on the additional power and move the surge to the ground system. Often, this is the only function for one of these diodes—when not conducting surplus power to ground, it transmits no power at all. The last common high-voltage diode is one that operates differently than nearly any other diode. The zener diode can actually transmit power backward through its system. When power reaches a certain level, the diode’s specially-doped p-n junction begins to let power move backward through the system, creating a temporary bottleneck. This blocks power from moving for long enough for the voltage to stabilise without hurting the device. Afterward, the p-n junction goes back to operating like a normal diode.	**Books:** Patrick, Dale R., and Fardo, Dale R., *Electricity and Electronics Fundamentals*, The Fairmont Press, Inc., 2008, ISBN 0881736023, 9780881736021 **Website:** http://www.wisegeek.com/what-is-a-high-voltage-diode.htm

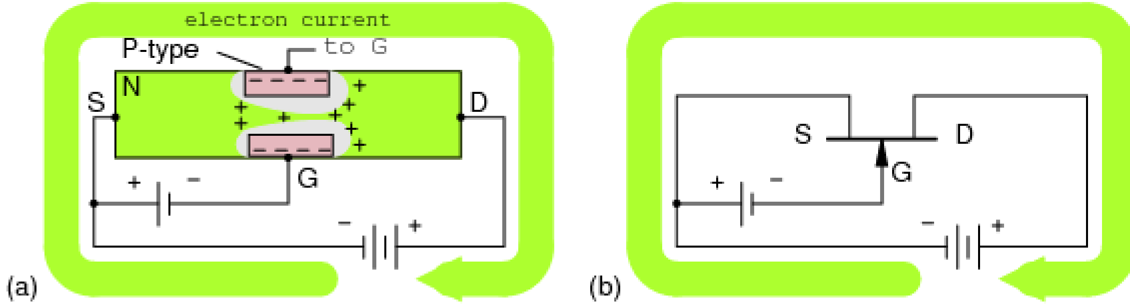
Lesson 23: Bipolar junction transistors		**Suggested Teaching Time:** 2 hour
Learning Outcome 5: Understand the properties, principles and applications of basic analogue components used in electrical machine control		
Topic	**Suggested Teaching**	**Suggested Resources**
Operation of **bipolar junction transistors** in terms of their construction (AC 5.3)	 Bipolar transistors are so named because the controlled current must go through two types of semiconductor material: P and N. A bipolar transistor consists of a three-layer 'sandwich' of doped (extrinsic) semiconductor materials, either P-N-P in diagram to right (b) or N-P-N at (d). The three leads of a bipolar transistor are called the emitter, base, and collector. The schematic symbols are shown in diagram to right (a) and (d). Bipolar transistors work as current-controlled current regulators. In other words, transistors restrict the amount of current passed according to a smaller,	**Books:** Patrick, Dale R., and Fardo, Dale R., *Electricity and Electronics Fundamentals*, The Fairmont Press, Inc., 2008, ISBN 0881736023, 9780881736021 Jiles, David C., *Introduction to Magnetism and Magnetic Materials*, Second Edition, CRC Press, 1998, ISBN-10: 0412798603, ISBN-13: 9780412798603 Singh, Yaduvir, and Agnihotri, Swarajya, *Semiconductor Devices*, I. K. International Pvt Ltd, 2009, ISBN-10 9380026129, ISBN-13: 9789380026121 **Websites:** http://www.allaboutcircuits.com/vol_3/chpt_4/1.html https://www.examtime.com/en/p/203657-untitled-notes

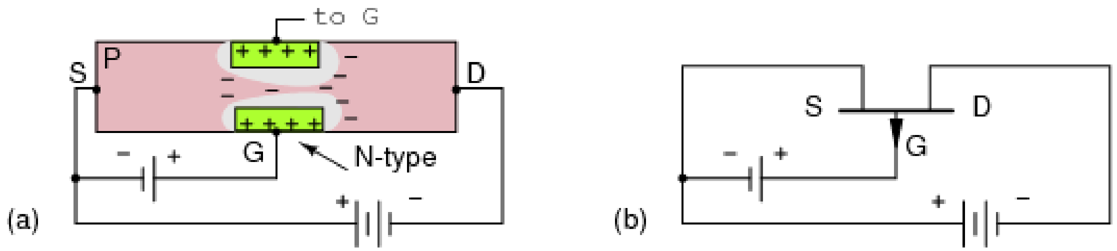
controlling current. The main current that is controlled goes from collector to emitter, or from emitter to collector, depending on the type of transistor it is (PNP or NPN, respectively). The small current that controls the main current goes from base to emitter, or from emitter to base, once again depending on the kind of transistor it is (PNP or NPN, respectively). According to the standards of semiconductor symbology, the arrow always points against the direction of electron flow

In order for a transistor to properly function as a current regulator, the controlling (base) current and the controlled (collector) currents must be going in the proper directions: meshing additively at the emitter and going against the emitter arrow symbol.



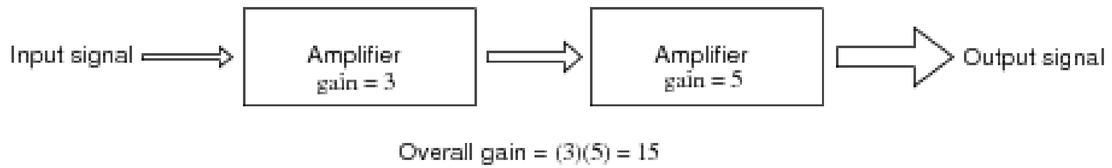
Lesson 24: Field-effect transistors		**Suggested Teaching Time:** 4 hour
Learning Outcome 5: Understand the properties, principles and applications of basic analogue components used in electrical machine control		
Topic	**Suggested Teaching**	**Suggested Resources**
Operation of **field-effect transistors** (FET) in terms of their construction (AC 5.4)	A field-effect transistor (FET) is a unipolar device, conducting a current using only one kind of charge carrier. If based on an N-type slab of semiconductor, the carriers are electrons. Conversely, a P-type based device uses only holes. At the circuit level, field-effect transistor operation is simple. A voltage applied to the gate, input element, controls the resistance of the channel, the unipolar region between the gate regions. In an N-channel device, this is a lightly doped N-type slab of silicon with terminals at the ends. The source and drain terminals are analogous to the emitter and collector, respectively, of a BJT. In an N-channel device, a heavy P-type region on both sides of the centre of the slab serves as a control electrode, the gate. The gate is analogous to the base of a bipolar transistor. The source and drain are interchangeable, and the source to drain current may flow in either direction for low level drain battery voltage (< 0.6 V). That is, the drain battery may be replaced by a low voltage AC source. For a high drain power supply voltage, the polarity must be as indicated in Figure a (*below*). This drain power supply, distorts the depletion region, enlarging it on the drain side of the gate. Figure b (*below*) shows the schematic symbol for an N-channel field-effect transistor compared to the silicon cross-section at (a). The gate arrow points in the same direction as a junction diode. The 'pointing' arrow and 'non-	**Books:** Patrick, Dale R., and Fardo, Dale R., *Electricity and Electronics Fundamentals*, The Fairmont Press, Inc., 2008, ISBN 0881736023, 9780881736021 Jiles, David C., *Introduction to Magnetism and Magnetic Materials*, Second Edition, CRC Press, 1998, ISBN-10: 0412798603, ISBN-13: 9780412798603 Singh, Yaduvir, and Agnihotri, Swarajya, *Semiconductor Devices*, I. K. International Pvt Ltd, 2009, ISBN-10 9380026129, ISBN-13: 9789380026121 **Websites:** http://www.allaboutcircuits.com/vol_3/chpt_2/9.html

	pointing' bar correspond to P and N-type semiconductors, respectively.  **N-channel JFET electron current flow from source to drain in (a) cross-section, (b) schematic symbol.** Figure above shows a large electron current flow from (-) battery terminal, to FET source, out the drain, returning to the (+) battery terminal. This current flow may be controlled by varying the gate voltage.	

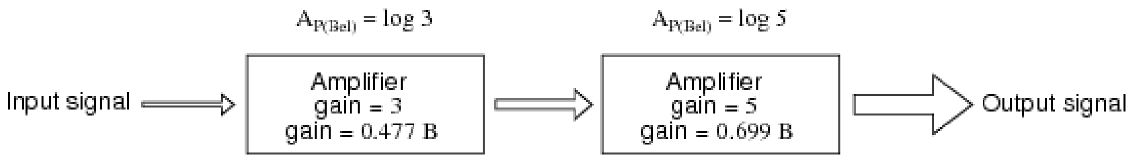
Topic	Suggested Teaching	Suggested Resources
	P-channel field-effect transistors are also available. The channel is made of P-type material. The gate is a heavily doped N-type region. All the voltage sources are reversed in the P-channel circuit (Figure below) as compared with the more popular N-channel device. Also note, the arrow points out of the gate of the schematic symbol (b) of the P-channel field-effect transistor. As the positive gate bias voltage is increased, the resistance of the P-channel increases, decreasing the current flow in the drain circuit  P-channel JFET: (a) N-type gate, P-type channel, reversed voltage sources compared with N-channel device. (b) Note reversed gate arrow and voltage sources on schematic.	**Books:** Patrick, Dale R., and Fardo, Dale R., *Electricity and Electronics Fundamentals*, The Fairmont Press, Inc., 2008, ISBN 0881736023, 9780881736021 Jiles, David C., *Introduction to Magnetism and Magnetic Materials*, Second Edition, CRC Press, 1998, ISBN-10: 0412798603, ISBN-13: 9780412798603 Singh, Yaduvir, and Agnihotri, Swarajya, *Semiconductor Devices*, I. K. International Pvt Ltd, 2009, ISBN-10 9380026129, ISBN-13: 9789380026121 **Websites:** http://www.allaboutcircuits.com/vol_3/chpt_2/9.html

Lesson 25: Amplifiers		**Suggested Teaching Time:** 8 hour
Learning Outcome 5: Understand the properties, principles and applications of basic analogue components used in electrical machine control		
Topic	**Suggested Teaching**	**Suggested Resources**
Amplifiers (AC 5.5)	The practical benefit of active devices is their amplifying ability. Whether the device in question be voltage-controlled or current-controlled, the amount of power required of the controlling signal is typically far less than the amount of power available in the controlled current. In other words, an active device doesn't just allow electricity to control electricity; it allows a small amount of electricity to control a large amount of electricity. Because of this disparity between controlling and controlled powers, active devices may be employed to govern a large amount of power (controlled) by the application of a small amount of power (controlling). This behaviour is known as **amplification**. The law of conservation of energy is not violated because the additional power is supplied by an external source, usually a DC battery or equivalent. The amplifier neither creates nor destroys energy, but merely reshapes it into the waveform desired. There are many forms of electronic circuits classed as amplifiers, from operational amplifiers and small signal amplifiers up to large signal and power amplifiers. The classification of an amplifier depends upon the size of the signal, large or small, its physical configuration and how it processes the input signal, the relationship between the input signal and the current flowing in the load.	**Books:** Patrick, Dale R., and Fardo, Dale R., *Electricity and Electronics Fundamentals*, The Fairmont Press, Inc., 2008, ISBN 0881736023, 9780881736021 Jiles, David C., *Introduction to Magnetism and Magnetic Materials*, Second Edition, CRC Press, 1998, ISBN-10: 0412798603, ISBN-13: 9780412798603 Singh, Yaduvir, and Agnihotri, Swarajya, *Semiconductor Devices*, I. K. International Pvt Ltd, 2009, ISBN-10 9380026129, ISBN-13: 9789380026121 **Websites:** http://www.allaboutcircuits.com/vol_3/chpt_1/5.html

Gain (AC 5.5)	Because amplifiers have the ability to increase the magnitude of an input signal, it is useful to be able to rate an amplifier's amplifying ability in terms of an output/input ratio. The technical term for an amplifier's output/input magnitude ratio is gain. As a ratio of equal units (power out / power in, voltage out / voltage in, or current out / current in), gain is naturally a unit less measurement. Mathematically, gain is symbolised by the capital letter 'A'. DC gains / AC gains Voltage: DC $A_V = \frac{V_{output}}{V_{input}}$; AC $A_V = \frac{\Delta V_{output}}{\Delta V_{input}}$ Current: DC $A_I = \frac{I_{output}}{I_{input}}$; AC $A_I = \frac{\Delta I_{output}}{\Delta I_{input}}$ Power: DC $A_P = \frac{P_{output}}{P_{input}}$; AC $A_P = \frac{(\Delta V_{output})(\Delta I_{output})}{(\Delta V_{input})(\Delta I_{input})}$ $A_P = (A_V)(A_I)$ *Δ = "change in . . ."* Electrical amplifier gains may be expressed in terms of voltage, current, and/or power, in both AC and DC. A summary of gain definitions is as follows. The triangle-shaped 'delta' symbol (Δ) represents change in mathematics, so 'ΔVoutput / ΔVinput' means 'change in output voltage divided by change in input voltage,' or more simply, 'AC output voltage divided by AC input voltage':	

Topic	Suggested Teaching	Suggested Resources
Units of measurement (AC 5.5)	In its simplest form, an amplifier's gain is a ratio of output over input. Like all ratios, this form of gain is unit less. However, there is an actual unit intended to represent gain, and it is called the bel. Originally, the bel represented the amount of signal power loss due to resistance over a standard length of electrical cable. Now, it is defined in terms of the common (base 10) logarithm of a power ratio (output power divided by input power): $A_{P(ratio)} = \frac{P_{output}}{P_{input}}$ $A_{P(Bel)} = \log \frac{P_{output}}{P_{input}}$ Another reason for the adoption of the bel as a unit for gain is for simple expression of system gains and losses. Where two amplifiers are connected in tandem to amplify a signal. The respective gain for each amplifier is expressed as a ratio, and the overall gain for the system will be the product (multiplication) of those two ratios:  If these figures represented power gains, we could directly apply the unit of bels to the task of representing the gain of each amplifier, and of the system altogether	**Books:** Dale R Patrick, Dale R., and Fardo, Dale R., *Electricity and Electronics Fundamentals*, The Fairmont Press, Inc., 2008, ISBN 0881736023, 9780881736021 Jiles, David C., *Introduction to Magnetism and Magnetic Materials*, Second Edition, CRC Press, 1998, ISBN-10: 0412798603, ISBN-13: 9780412798603 Singh, Yaduvir, and Agnihotri, Swarajya, *Semiconductor Devices*, I. K. International Pvt Ltd, 2009, ISBN-10 9380026129, ISBN-13: 9789380026121 **Websites:** http://www.allaboutcircuits.com/vol_3/chpt_1/5.html http://www3.eng.cam.ac.uk/DesignOffice/mdp/electric_web/Semi/SEMI_1.html

$$A_{P(Bel)} = \log A_{P(ratio)}$$



Overall gain = (3)(5) = 15

Overall $\text{gain}_{(Bel)} = \log 15 = 1.176$ B

Close inspection of these gain figures in the unit of bel yields a discovery: they're additive. In this example: 0.477 B + 0.699 B = 1.176 B. Ratio gain figures are multiplicative for staged amplifiers, but gains expressed in bels add rather than multiply to equal the overall system gain.

Because the bel is fundamentally a unit of power gain or loss in a system, voltage or current gains and losses don't convert to bels or dB in quite the same way. When using bels or decibels to express a gain other than power, be it voltage or current, we must perform the calculation in terms of how much power gain there would be for that amount of voltage or current gain. For a constant load impedance, a voltage or current gain of 2 equates to a power gain of 4 (22); a voltage or current gain of 3 equates to a power gain of 9 (32). If we multiply either voltage or current by a given factor, then the power gain incurred by that multiplication will be the square of that factor. This relates back to the forms of Joule's law where power was calculated from either voltage or current, and resistance:

$P = \frac{E^2}{R}$ $P = I^2R$ Power is proportional to the square of either voltage or current

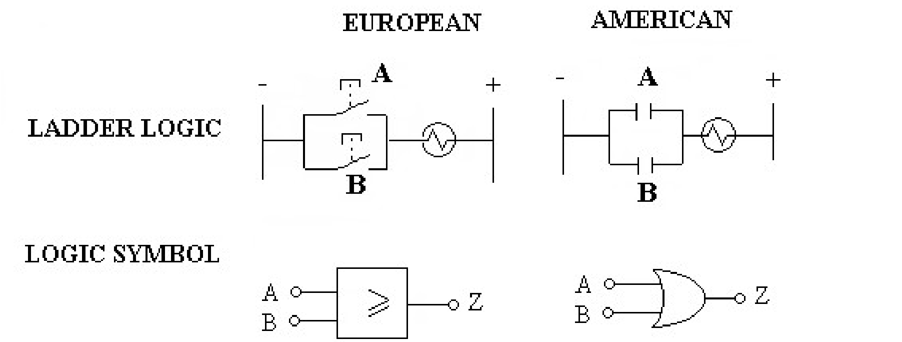
Topic	Suggested Teaching	Suggested Resources
Impedence (AC 5.5)	Impedance is a comprehensive expression of any and all forms of opposition to electron flow, including both resistance and reactance. It is present in all circuits, and in all components. When alternating current goes through an impedance, a voltage drop is produced that is somewhere between 0o and 90o out of phase with the current. Impedance is mathematically symbolised by the letter 'Z' and is measured in the unit of ohms (Ω), in complex form. Input Impedance, Z_{in} or input resistance as it is also called, is an important parameter in the design of a transistor amplifier and as such allows amplifiers to be characterised according to their effective input and output impedances as well as their power and current ratings. An amplifiers impedance value is particularly important for analysis especially when cascading individual amplifier stages together one after another to minimise distortion of the signal. The input impedance of an amplifier is the input impedance 'seen' by the source driving the input of the amplifier. If it is too low, it can have an adverse loading effect on the previous stage and possibly affecting the frequency response and output signal level of that stage. But in most applications, common emitter and common collector amplifier circuits generally have high input impedances. Some types of amplifier designs, such as the common collector amplifier circuit automatically have high input impedance and low output impedance by the very nature of their design. In addition to voltage amplification (A_V), an amplifier circuit must also have current amplification (A_I). Power amplification (A_P) can also be expected from an	**Books:** Patrick, Dale R., and Fardo, Dale R., *Electricity and Electronics Fundamentals*, The Fairmont Press, Inc., 2008, ISBN 0881736023, 9780881736021 Jiles, David C., *Introduction to Magnetism and Magnetic Materials*, Second Edition, CRC Press, 1998, ISBN-10: 0412798603, ISBN-13: 9780412798603 Singh, Yaduvir, and Agnihotri, Swarajya, *Semiconductor Devices*, I. K. International Pvt Ltd, 2009, ISBN-10 9380026129, ISBN-13: 9789380026121 **Websites:** http://www.allaboutcircuits.com/vol_3/chpt_1/5.html http://www.electronics-tutorials.ws/amplifier/input-impedance-of-an-amplifier.html

	amplifier circuit. But as well as having these three important characteristics, an amplifier circuit must also have other characteristics like high input impedance (Z_{in}), low output impedance (Z_{out}) and some degree of bandwidth, (Bw). Either way, the 'perfect' amplifier will have infinite input impedance and zero output impedance.	
Attenuators (AC 5.5)	Attenuators are passive devices. Attenuators weaken or attenuate the high level output of a signal generator, for example, to provide a lower level signal for something like the antenna input of a sensitive radio receiver. (Figure below) The attenuator could be built into the signal generator, or be a stand-alone device. It could provide a fixed or adjustable amount of attenuation. An attenuator section can also provide isolation between a source and a troublesome load. Attenuator sections can be cascaded for more attenuation than may be available from a single section. For example two 10 dB attenuators may be cascaded to provide 20 dB of attenuation, the dB values being additive.	

Lesson 26: Electronic noise		**Suggested Teaching Time:** 4 hour
Learning Outcome 5: Understand the properties, principles and applications of basic analogue components used in electrical machine control		
Topic	**Suggested Teaching**	**Suggested Resources**
Thermal noise (AC 5.6)	Thermal noise is due to thermal agitation of electrons in a conductor. It is present in all electronic devices and transmission media and is a function of temperature. Thermal noise is uniformly distributed across the frequency spectrum and hence is often referred to as white noise; it cannot be eliminated	**Books:** Patrick, Dale R., and Fardo, Dale R., *Electricity and Electronics Fundamentals*, The Fairmont Press, Inc., 2008, ISBN 0881736023, 9780881736021 Jiles, David C., *Introduction to Magnetism and Magnetic Materials*, Second Edition, CRC Press, 1998, ISBN-10: 0412798603, ISBN-13: 9780412798603 Carter, Bruce, and Mancini, Roy, *Op Amps for Everyone*, Newnes (Elsevier) 2009, ISBN: 978-1-85617-505-0 Singh, Yaduvir, and Agnihotri, Swarajya, *Semiconductor Devices*, I. K. International Pvt Ltd, 2009, ISBN-10 9380026129, ISBN-13: 9789380026121 **Websites:** http://www.ti.com/lit/an/slva043b/slva043b.pdf
Intermediation noise	Intermediation noise is produced when there is some non-linearity in the transmitter, receiver, or intervening transmission system. Normally, these components behave as linear systems; that is, the output is equal to the input, times a constant. In a nonlinear system, the output is a more complex function of the input. Such non linearity can be caused by component malfunction or the use of excessive signal strength. It is under these circumstances that the sum and difference terms occur	
Shot noise	The name 'shot noise' is short for Schottky noise (or 'quantum noise'). This is caused by random fluctuations in the motion of charge carriers in a conductor. In other words, current flow is not a continuous effect. Current flow is electrons, charged particles that move in accordance with an applied potential. When the electrons encounter a barrier, potential energy builds until they have enough energy to cross that barrier. When they have enough potential energy, it is abruptly transformed into kinetic energy as they cross the barrier. As each electron randomly crosses a potential barrier, such as a p-n junction in a semiconductor, energy is stored and released as the electron encounters and then shoots across the barrier. Each electron contributes a little pop as its stored energy is released when it crosses the barrier	

Burst noise	Burst noise, also called popcorn noise, is related to imperfections in semiconductor material and heavy ion implants. It is characterised by discrete high-frequency pulses. The pulse rates may vary, but the amplitudes remain constant at several times the thermal noise amplitude. Burst noise makes a popping sound at rates below 100 Hz when played through a speaker; it sounds like popcorn popping, hence the name.	http://qooljaq.com/OpAmps.htm
Avalanche noise	Avalanche noise is created when a p-n junction is operated in the reverse breakdown mode. Under the influence of a strong reverse electric field within the junction's depletion region, electrons have enough kinetic energy that, when they collide with the atoms of the crystal lattice, additional electron-hole pairs are formed. These collisions are purely random and produce random current pulses similar to shot noise, but much more intense	

Topic	Suggested Teaching	Suggested Resources
Cross talk	Crosstalk has been experienced by anyone who, while using the telephone, has been able to hear another conversation. It is an unwanted coupling between signal paths. It can occur by electrical coupling between nearby twisted pair or, rarely, coax cable lines carrying multiple signals. Crosstalk can also occur when unwanted signals are picked up by microwave antennas; although highly directional, microwave energy does spread during propagation. Typically, crosstalk is of the same order of magnitude (or less) as thermal noise.	**Books:** Patrick, Dale R., and Fardo, Dale R., *Electricity and Electronics Fundamentals*, The Fairmont Press, Inc., 2008, ISBN 0881736023, 9780881736021 Jiles, David C., *Introduction to Magnetism and Magnetic Materials*, Second Edition, CRC Press, 1998, ISBN-10: 0412798603, ISBN-13: 9780412798603 Singh, Yaduvir, and Agnihotri, Swarajya, *Semiconductor Devices*, I. K. International Pvt Ltd, 2009, ISBN-10 9380026129, ISBN-13: 9789380026121 **Websites:** http://www.ti.com/lit/an/slva043b/slva043b.pdf http://www.engineersblogsite.com/thermal-noise.html
Impulse noise	Impulse noise is generally only a minor annoyance for analogue data. For example, voice transmission may be corrupted by short clicks and crackles with no loss of intelligibility. However, impulse noise is the primary source of error in digital data communication. For example, a sharp spike of energy of 0.01-second duration would not destroy any voice data, but would wash out about 50 bits of data being transmitted at 4800 bps	
Signal-to-noise ratio	The signal-to-noise ratio is defined as average signal power is divided by the average noise power $SNR = \frac{ASP}{ANP}$ where ASP = average signal power and ANP = average noise power. SNR is actually the ratio of what is not wanted (noise) because SNR is the ratio of power; it is often described in Decibel units. $SNR_{Db} = 10\log_{10} SNR10.$ **Example** If the power of a signal is 10mW and the noise is 1μW what are the values of SNR and SNR_{Db} ? **Solution** $SNR = \frac{10{,}000\mu W}{1\mu W} = 10{,}000 \;\; SNR_{Db} \;\; 10\log_{10} 10^4 = 40$	

<table>
<tr><td colspan="2">Lesson 27: Logic circuits</td><td>Suggested Teaching Time: 6 hour</td></tr>
<tr><td colspan="2">Learning Outcome 6: Understand the properties, principles and applications of basic logic devices used in electrical machine control</td><td></td></tr>
<tr><th>Topic</th><th>Suggested Teaching</th><th>Suggested Resources</th></tr>
<tr><td>Evaluating the function of logic gates (AC 6.1)</td><td>


A	B	Z
0	0	0
0	1	1
1	0	1
1	1	1

TRUTH TABLE

Tutor to draw a lamp circuit with two switches, where either of the switches will operate the lamp.

Tutor to get the students to discuss how they can turn a light on: lead towards answer that switch A **or** switch B will turn the light on.

Tutor to introduce concept of a truth table where a 0 represents off (or not true) and a 1 represents on (or true).

Tutor to get students to discuss and complete the truth table for this circuit.

Tutor to draw a circuit where both switches have to be made tutor to get the students to discuss how they can turn a light on: lead towards answer that both switch A **and** switch B need to be on to turn the light on.
</td><td>
Books:

Marcovitz, Alan B., *Introduction to Logic and Computer Design*, McGraw Hill HE, ISBN-13: 978-0071285988 ISBN-10: 0071285989

Websites:

http://www.tutorialspoint.com/computer_logical_organization/logic_gates.htm
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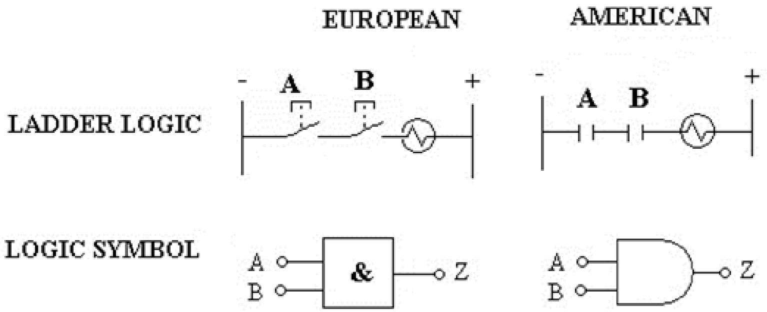
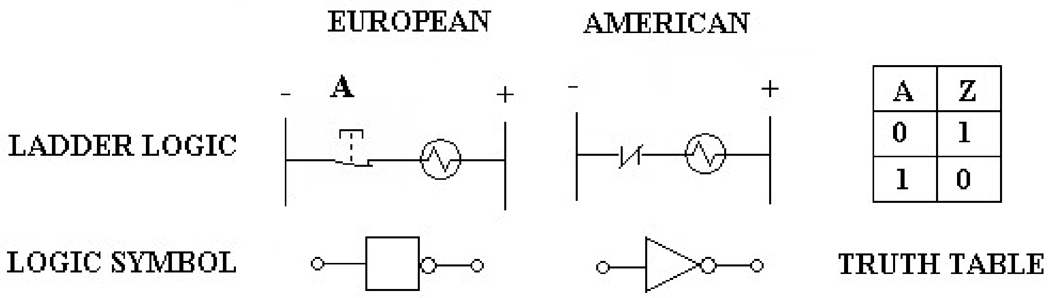
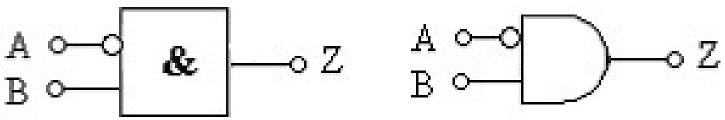
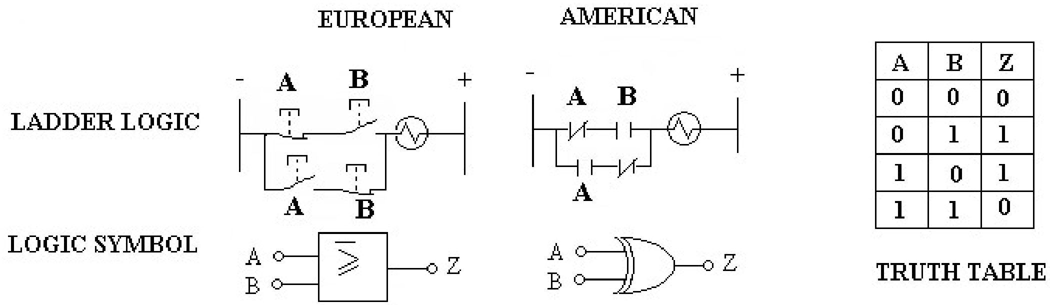
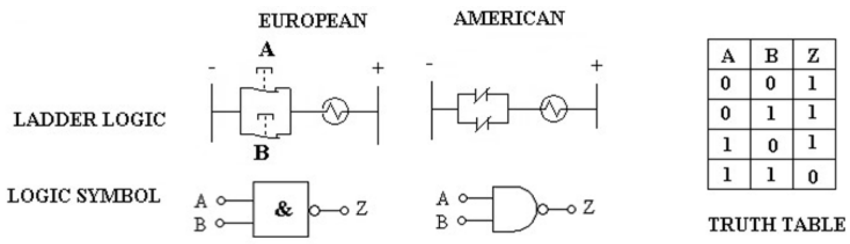


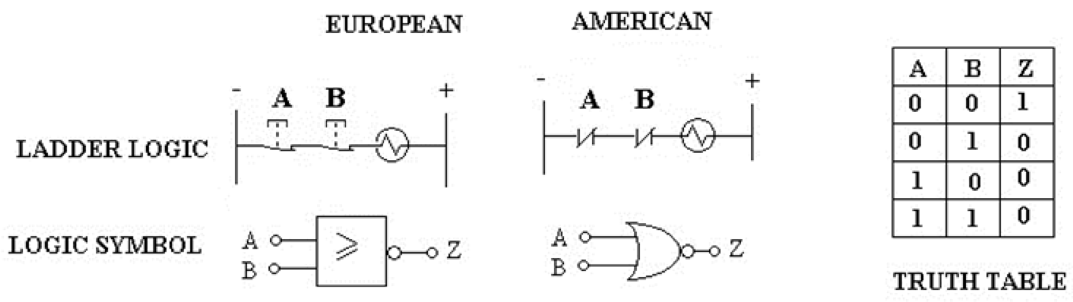
A	B	Z
0	0	0
0	1	0
1	0	0
1	1	1

TRUTH TABLE

	Tutor to get students to discuss and complete the truth table for this circuit. Tutor to introduce students to the concept of logic gates and explain how they have just seen an ‘OR’ gate and an ‘AND’ gate.	
	Tutor to introduce the concept of Boolean algebra. Which is a method of turning words into symbols.	
AND gate	Tutor to go back to the **AND** gate and show that if we say output Z is on, when either line A or B is on or A and B is on together. We write: Z = A + B + A.B The plus sign means OR and the dot means AND.	
OR gate	Tutor to go back to the **OR** gate and show that if we say output Z is on, when both line A and B are on. We write: Z = A.B meaning Z is on only when A and B are on.	

Topic	Suggested Teaching	Suggested Resources
NOT gate	 Tutor to draw a circuit with a spring loaded switch that is normally on and a lamp, Tutor to get the students to discuss what happens if we press the switch this time: the light goes out, get the students to complete a truth table for this circuit, tutor to explain that this is called a not gate The Boolean statement is either $Z = \overline{A}$ or $\overline{Z} = A$ The over score indicates low or off. An O added to any input terminal inverts that signal and makes it a not gate (i.e. normally on). 	**Books:** Marcovitz, Alan B., *Introduction to Logic and Computer Design*, McGraw Hill HE, ISBN-13: 978-0071285988 ISBN-10: 0071285989 **Websites:** http://www.tutorialspoint.com/computer_logical_organization/logic_gates.htm

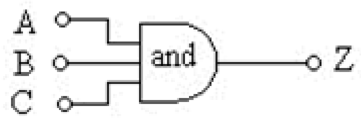
Exclusive OR (XOR)	 Tutor to draw a circuit where there are two parallel paths with switch A having a component in both lines one normally made and one normally open and switch B having the same layout but where A is normally open B must be normally closed. Tutor to get the students to discuss what happens if we press the switches this time. Lead them to the conclusion that the light is on when A or B is on but off when both are on; get the students to complete a truth table for this circuit The Boolean statement is: Z = A + B which means Z is on when A is on and B is off or when A is off and B is on (tutor to point out that there is no +A.B at the end like there was on the AND gate).	
NAND gate	Tutor to go back to the not gate and add a parallel path way with another 	

	normally on switch. Tutor to show similarity to an and switch. However this time the light is normally on until you press switch A and B together when it will go out: tutor to get the students to complete a truth table for this circuit. This is known as a NAND switch (not and) The Boolean statement is: $\bar{Z}$ = A.B meaning Z is Off when A and B are both on.	
Topic	**Suggested Teaching**	**Suggested Resources**
NOR gate	 Tutor to draw a lamp circuit with a pair of normally closed switches in series. Tutor to get the students to discuss what happens if we press the switches this time. If necessary help them reach the conclusion that the light is on until either switch A or B is pressed, get the students to complete a truth table for this circuit. The Boolean statement is: $Z = \bar{A} + \bar{B}$	**Books:** Marcovitz, Alan B., *Introduction to Logic and Computer Design*, McGraw Hill HE, ISBN-13: 978-0071285988 ISBN-10: 0071285989 **Websites:** http://www.tutorialspoint.com/computer_logical_organization/logic_gates.htm

Multile inputs

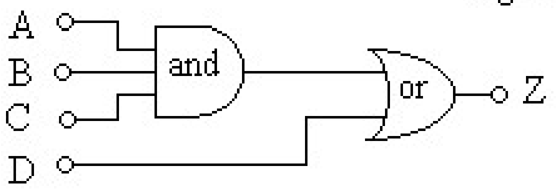
Tutor t introduce the concept that logic gates can have more than two inputs

This one has three inputs so the output Z is turned on when A and B and C is turned on



Combining logic gates – an introduction

Tutor to give a quick introduction as to how these gates could be used together in a more complex logic circuit is shown below with four inputs.



digital value	8	4	2	1	
	A	B	C	D	Z
	1	1	1	0	on
	0	0	0	1	on
	1	1	1	1	on

The truth table is shown with only the conditions for turning the output on.

The pattern of the inputs can be interpreted as a digital number.

There are three possible combinations that can turn the output on.

The three digital numbers that will turn the output on are hence 14, 1 and 15. (With A forming the most significant bit).

If A, B, C and D were connected to a computer data bus then the computer could switch the output on when it recognises these numbers.

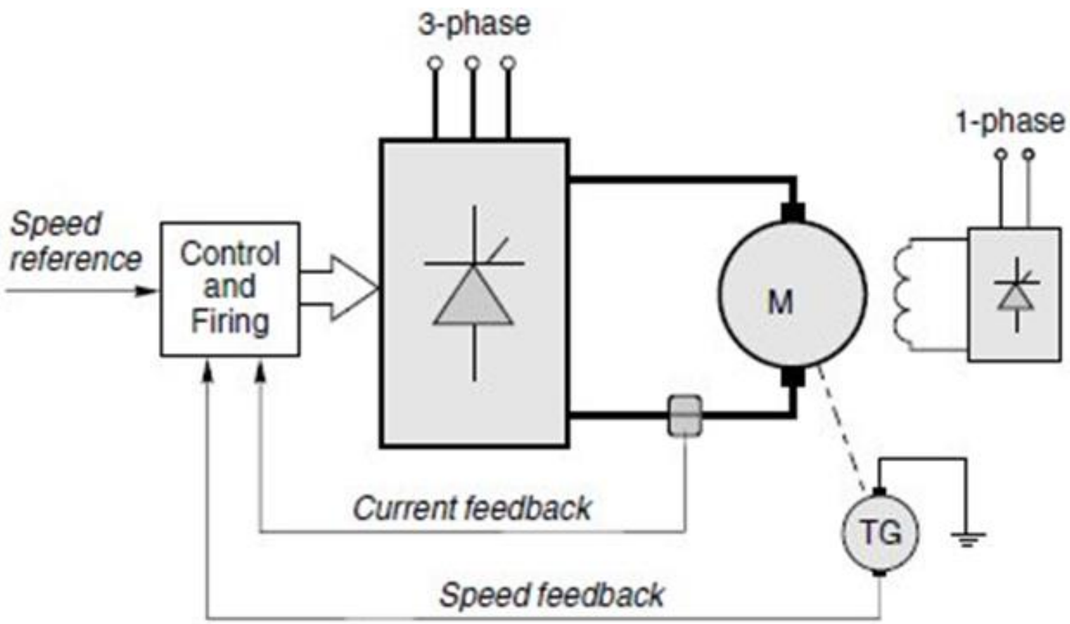
Lesson 28: Logic families		**Suggested Teaching Time: 1** hour
Learning Outcome 6: Understand the properties, principles and applications of basic logic devices used in electrical machine control		
Topic	**Suggested Teaching**	**Suggested Resources**
Evaluating the principal characteristics of different **logic families** (AC 6.2)	Tutor to get the students to do a research project on the different logic families Getting them to cover factors such as: • Speed • Power • Cost • Interface requirements (propagation delay). for the following types: • Complementary metal oxide – semiconductor (CMOS) • Transistor-transistor logic (TTL) • ECL • BiCMOS	**Books:** Marcovitz, Alan B., *Introduction to Logic and Computer Design*, McGraw Hill HE, ISBN-13: 978-0071285988, ISBN-10: 0071285989

Lesson 29: Logic families		**Suggested Teaching Time:** 8hour
Learning Outcome 6: Understand the properties, principles and applications of basic logic devices used in electrical machine control		
Topic	**Suggested Teaching**	**Suggested Resources**
Operation of combinational logic circuits (AC 6.3)	Whole-class discussion to recap the lessons learned about logic gates and how they can be combined. Tutor to demonstrate using Boolean expressions and truth tables how these gates work together. Explain the difference between: • Half adders and full adders • Multiplexers and demultiplexers • Half subtractors and full subtractors • Encoders and decoders Explain that a comparator is a device that compares two voltages or currents and outputs a digital signal indicating which is larger.	**Books:** Marcovitz, Alan B., *Introduction to Logic and Computer Design*, McGraw Hill HE, ISBN-13: 978-0071285988 ISBN-10: 0071285989 **Websites:** http://www.tutorialspoint.com/computer_logical_organization/logic_gates.htm http://www.tutorialspoint.com/computer_logical_organization/combinational_circuits.htm http://eshare.stust.edu.tw/EshareFile/2011_4/2011_4_d4f0ae35.pdf
	Tutor to discuss how it is important to check that data has been transmitted and received correctly and the use of parity checkers and generators.	

Lesson 30: Large electrical motors		**Suggested Teaching Time:** 1 hours
Learning Outcome 7: Understand the principles of controlling large industrial electric motors		
Topic	**Suggested Teaching**	**Suggested Resources**
Assess attributes of different types of **motor starters for three-phase squirrel-cage induction motors** (AC 7.1)	Tutor-led discussion to recap AC motors and to recap advantages and disadvantages of three-phase motors If the coils are connected in a star formation, the current flowing through them is the phase current. If the coils are connected in the delta formation, the current flowing through them is the line current. Suppose we had a three-phase motor supplied with 415 V and 17.3 A (line values). If the motor is connected in delta formation we have 17.3 A in each coil and 415 V over each. If we connect it in star formation we get $17.3/\sqrt{3} = 10$ A in each coil and $\sqrt{3} \times 415 = 240$ V over each. Three-phase motors running normally have their field coils connected in the DELTA fashion. Because of the high currents drawn on starting when the induction effect is greatest, the coils are connected in the star formation and then changed to the delta formation when it has accelerated close to its running speed. Note that the starting torque is also reduced in star formation but this is usually sufficient to run the motor up to speed. The change from Star to Delta is normally achieved by external switching and this is commonly referred to as a soft starter or a Star Delta starter. This is simply a number of contactors (switches) that connect the different leads together to form the required connection, i.e. Star or Delta. These use a specific starting sequence with timers to switch between Star and Delta.	**Books:** Hughes, Austin, *Electric Motors and Drives: Fundamentals, Types and Applications*, 4th edition, Newnes, 2013, ISBN-10: 0080983324, ISBN-13: 978-0080983325 **Practical Equipment:** Three-phase motor and test equipment **Websites:** http://www.electrical4u.com http://www.freestudy.co.uk/further%20elprinc%20unit67/outcome4t1.pdf

Lesson 31: Silicon controlled rectifiers		**Suggested Teaching Time:** 2 hours
Learning Outcome 7: Understand the principles of controlling large industrial electric motors		
Topic	**Suggested Teaching**	**Suggested Resources**
Operating principle of the **silicon controlled rectifier** SCR (AC 7.2)	A silicon controlled rectifier (SCR) works in a similar fashion to a typical diode, but is controlled similar to a bipolar transistor as far as connections go. It has three connection points: anode [A], cathode [K], and gate [G]. The SCR is made up of two p-n junctions with a gate attachment between them (a normal diode [power type semiconductor diode] has one p-n junction). The gate is connected between the two p-n junctions with a current waiting in the forward bias direction [+ to -] and the voltage is above 1-volt. A momentary pulse to the gate will cause the SCR to conduct and current will flow across the device until the value changes. If this happens, the gate needs to be pulsed again to cause conduction to resume; otherwise no current will flow across the device. If used on AC, the device needs to be triggered [fired] in relationship to the points on the sine wave that conduction is requested. Example: to chop a wave to be 1/2 peak, the SCR gate will need to be pulsed with either a high-logic pulse or a positive-voltage pulse until the AC wave reaches 50% of peak value in the positive flowing direction.	**Books:** Hughes, Austin, *Electric Motors and Drives: Fundamentals, Types and Applications*, 4th edition, Newnes, 2013, ISBN-10: 0080983324, ISBN-13: 978-0080983325 **Practical Equipment:** Electric motor, SCR and test equipment **Websites:** http://www.electrical4u.com

<table>
<tr><th>Topic</th><th>Suggested Teaching</th><th>Suggested Resources</th></tr>
<tr><td>How precise speed control of a DC motor can be achieved using an SCR and a suitable feedback signal

(A.C.7.3)</td><td>

When a SCR device is connected in series with load circuit, the load current will flow through the device from anode (A) to cathode (K), but this load current will be controlled by the gate (G) signal applied to the device externally.

A thyristor is an on-off switch which is used to control output power of an electrical circuit by switching on and off the load circuit periodically in a preset interval.

The main difference between thyristors and other digital and electronics switches is that a thyristor can handle more larger electric current and can withstand larger voltage than the others.</td><td>Books:

Hughes, Austin, Electric Motors and Drives: Fundamentals, Types and Applications, 4th edition, Newnes, 2013, ISBN-10: 0080983324, ISBN-13: 978-0080983325

Subrahmanyam, Vedam, Thyristor Control of Electric Drives, Tata McGraw-Hill Education, 1988, ISBN 0074603418, 9780074603413

Practical Equipment:

Electric motor, SCR and test equipment

Websites:

http://www.electrical4u.com/thyristor-silicon-controlled-rectifier/

http://www.eetimes.com/document.asp?doc_id=1274114</td></tr>
</table>

	The controlled (thyristor) rectifier provides a low-impedance adjustable DC voltage for the motor armature, thereby providing speed control. For motors up to a few kilowatts, the armature converter can be supplied from either single-phase or three-phase mains, but for larger motors three-phase is always used. A separate thyristor or diode rectifier is used to supply the field of the motor: the power is much less than the armature power, so the supply is often single-phase, as shown in the diagram of a DC-controlled motor-drive shown *above*. The arrangement shown is typical of the majority of DC drives and provides for closed-loop speed control. Low power control circuits are used to monitor the principal variables of interest (usually motor current and speed), and to generate appropriate firing pulses so that the motor maintains constant speed despite variations in the load. The 'speed reference' (diagram *above*) is typically an analogue voltage varying from 0 to 10 V, and obtained from a manual speed-setting potentiometer or from elsewhere in the plant.	

Lesson 32: Variable frequency drive		**Suggested Teaching Time:** 6 hours
Learning Outcome 7: Understand the principles of controlling large industrial electric motors		
Topic	**Suggested Teaching**	**Suggested Resources**
Speed control of a three-phase induction motor using a **variable frequency drive** (A.C.7.4)	A variable frequency drive (VFD) is a type of motor controller that drives an electric motor by varying the frequency and voltage supplied to the electric motor. Other names for a VFD are variable speed drive, adjustable speed drive, adjustable frequency drive, AC drive, microdrive, and inverter. Frequency (or hertz) is directly related to the motor's speed (RPMs). In other words, the faster the frequency, the faster the RPMs go. If an application does not require an electric motor to run at full speed, the VFD can be used to ramp down the frequency and voltage to meet the requirements of the electric motor's load. As the application's motor speed requirements change, the VFD can simply turn up or down the motor speed to meet the speed requirement.	**Books:** Hughes, Austin, *Electric Motors and Drives: Fundamentals, Types and Applications*, 4th edition, Newnes, 2013, ISBN-10: 0080983324, ISBN-13: 978-0080983325 **Websites:** http://www.vfds.com/blog/what-is-a-vfd
Effects of **solid-state speed control systems** on different types of motors (DC, ac) (A.C.7.5)	The AC electric motor used in a VFD system is usually a three-phase induction motor. Some types of single-phase motors can be used, but three-phase motors are usually preferred. Various types of synchronous motors offer advantages in some situations, but three-phase induction motors are suitable for most purposes and are generally the most economical motor choice. Motors that are designed for fixed-speed operation are often used. Elevated voltage stresses imposed on induction motors that are supplied by VFDs require that such motors be designed for definite-purpose inverter-fed duty.	**Books:** Hughes, Austin, *Electric Motors and Drives: Fundamentals, Types and Applications*, 4th edition, Newnes, 2013, ISBN-10: 0080983324, ISBN-13: 978-0080983325 **Websites:** http://en.wikipedia.org/wiki/Variable-frequency_drive

	Many fixed-speed motor load applications that are supplied direct from AC line power can save energy when they are operated at variable-speed, by means of VFD. Such energy cost savings are especially pronounced in variable-torque centrifugal fan and pump applications, where the loads' torque and power vary with the square and cube, respectively, of the speed. This change gives a large power reduction compared to fixed-speed operation for a relatively small reduction in speed. For example, at 63% speed a motor load consumes only 25% of its full speed power. **Load torque and power characteristics** Variable frequency drives are also categorised by the following load torque and power characteristics: • Variable torque, such as in centrifugal fan, pump and blower applications • Constant torque, such as in conveyor and positive displacement pump applications • Constant power, such as in machine tool and traction applications.	http://www.pacontrol.com/download/Adjustable-Speed-Drives-Tutorial.pdf

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Topic	Suggested Teaching	Suggested Resources
Effects of solid state speed control systems on different types of motors (DC, AC) (AC 7.5)	Tutor to discuss how adjustable speed drives have a number of advantages and disadvantages compared to other types of variable speed controls including: Advantages: • Energy savings • Improved process control • Reduced voltage starting • Lower system maintenance • Bypass capability • Multi-motor control Disadvantages: • Initial cost • Motor heating at low speeds • Maintenance4. Output harmonics • Induced power line harmonics	