

Subject Reference                      Physics 3.6  
 Title                                      Demonstrate understanding of electrical systems  
 Level            3                      Credits            6                      Assessment            External  
 Subfield            Science  
 Domain            Physics  
 Registration date            20 October 2005                      Date version published            20 October 2005

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This achievement standard involves knowledge and understanding of phenomena, concepts, principles and/or relationships related to direct current (DC) circuits, capacitance, electromagnetic induction, alternating current (AC) circuits, and the use of appropriate methods to solve related problems.

Achievement Criteria

Achievement	Achievement with Merit	Achievement with Excellence
<ul style="list-style-type: none"> <li>Identify or describe aspects of phenomena, concepts or principles.</li> <li>Solve straightforward problems.</li> </ul>	<ul style="list-style-type: none"> <li>Give descriptions or explanations in terms of phenomena, concepts, principles and/or relationships.</li> <li>Solve problems.</li> </ul>	<ul style="list-style-type: none"> <li>Give explanations that show clear understanding in terms of phenomena, concepts, principles and/or relationships.</li> <li>Solve complex problems.</li> </ul>

Explanatory Notes

1 This achievement standard is derived from Physics in the New Zealand Curriculum, Learning Media, Ministry of Education, 1994; Level 8, achievement objectives, p. 32.

2 Assessment will be limited to a selection from the following:

Phenomena, concepts and principles of electrical systems:

#### DC Circuits and Capacitance

Internal resistance; simple application of Kirchhoff's Laws; parallel plate capacitor; capacitance; dielectrics; series and parallel capacitors; charge/discharge characteristics of capacitors in DC RC circuits; voltage/time and current/time graphs for a capacitor; time constant; energy stored in a capacitor.

#### Electromagnetic Induction and AC Circuits

Magnetic flux; magnetic flux density; Faraday's Law; Lenz's Law; voltage/time and current/time graphs for an inductor; time constant; self inductance; the inductor; energy stored in an inductor; mutual inductance; the transformer; the comparison of the energy dissipation in a resistor carrying direct current and alternating current; peak and rms voltage and current; phase; phasors in AC; reactance and impedance and their frequency dependence in a series circuit; voltage and current and their phase relationship in LR and CR series circuits; resonance in LCR circuits.

Relationships:

$$\begin{array}{lllll} E = \frac{1}{2} QV & Q = CV & C = \frac{\epsilon_0 \epsilon_r A}{d} & C_T = C_1 + C_2 + \dots & \tau = RC \\ \frac{1}{C_T} = \frac{1}{C_1} + \frac{1}{C_2} + \dots & & \phi = BA & \epsilon = -L \frac{\Delta I}{\Delta t} & \epsilon = -\frac{\Delta \phi}{\Delta t} \\ \epsilon = -M \frac{\Delta I}{\Delta t} & \frac{N_p}{N_s} = \frac{V_p}{V_s} & E = \frac{1}{2} LI^2 & & \tau = \frac{L}{R} \\ I = I_{MAX} \sin \omega t & V = V_{MAX} \sin \omega t & I_{MAX} = \sqrt{2} I_{rms} & & \\ V_{MAX} = \sqrt{2} V_{rms} & X_C = \frac{1}{\omega C} & & & \\ X_L = \omega L & V = IZ & \omega = 2\pi f & & \end{array}$$

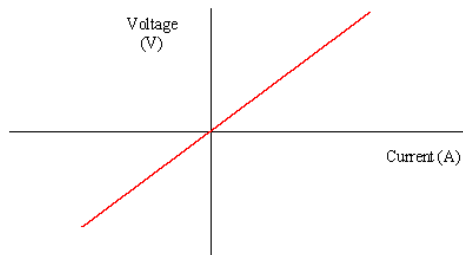
## KEY POINTS

The model of free electrons moving in a sea of ions in a uniform field can explain:

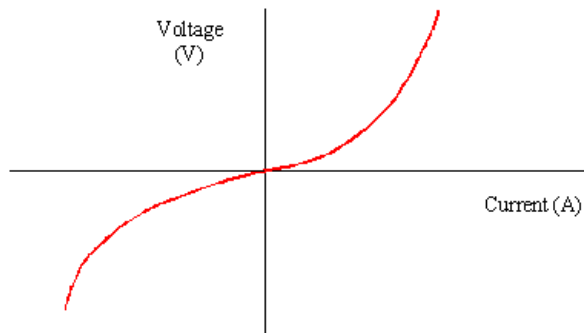
- resistance
- transfer of energy from electrical energy to kinetic energy to heat

The conducting properties and current/voltage relationships for:

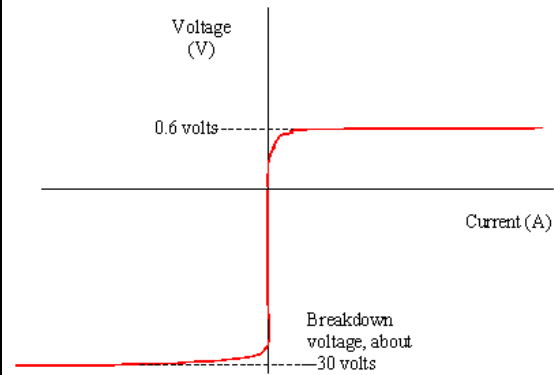
- metals and ohmic conductors



- non-ohmic conductors



- semiconductors, diodes



are different to each other

## KEY POINTS

Problems can be solved involving series, parallel and complex circuits.

This normally involves the use of this formula  $R = V/I$  to calculate resistances

Where  $R$  = resistance ( $\Omega$ ), Voltage (V), Current (A)

The individual resistances in a circuit can be calculated using:

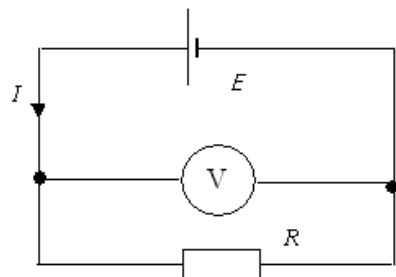
$$R_T = R_1 + R_2 + \dots \text{ (series)}$$

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \dots \text{ (parallel)}$$

## KEY POINTS

The internal resistance,  $r$ , of a power source also affects circuits.

The internal resistance of the power source should be included in any voltage or current calculations (At Level 3 this will be requested if required).



$E = V + Ir$  where  $E = \text{EMF}$ ,  $V = \text{Terminal p.d.}$  and  $Ir$  is the lost volts.

It is possible to analyse voltage/current graphs for a circuit to determine the internal resistance of a power source

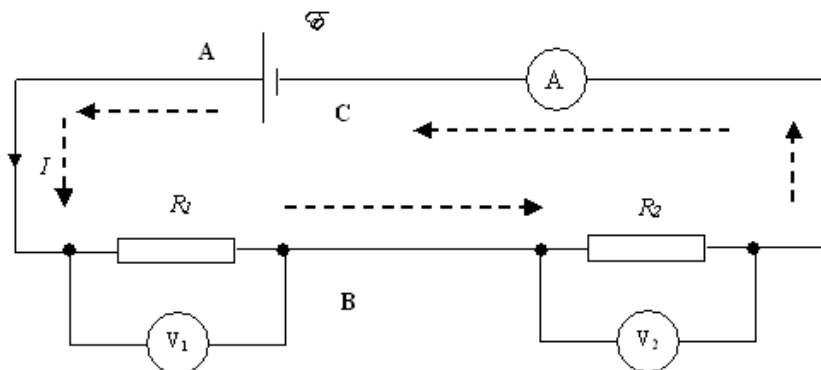
The effect of  $r$  on the circuit depends on the external resistance,  $R$ , in the circuit.

- When  $R$  is very large,  $r$  has no effect and  $V = E$
- When  $R$  is very small,  $r$  has effect and  $V < E$
- When  $R = r$ , this is impedance matching and the maximum power is gained from the voltage source

## KEY POINTS

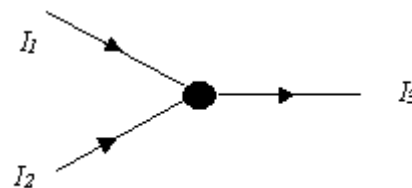
Calculation of voltages and currents in one- and two-loop circuits, which may include DC voltage sources and resistors must be done by using Kirchoff's laws:

- The sum of the potential differences in any loop is zero



$$IR_1 + IR_2 + -\mathcal{E} = 0$$

- The sum of the currents entering a junction = The sum of the currents leaving a junction



## KEY POINTS

Understand that a **capacitor** in a DC circuit stores charge – charge gathers on one plate and is repelled from the other plate – charges never move between the plates inside a capacitor.  $Q = CV$

Where  $Q$  = charge(C),  $C$  = capacitance (F) and  $V$  = Voltage (V)

Understand the parallel plate capacitor by using the formula below:

$$C = \frac{\epsilon_0 \epsilon_r A}{d}$$

Where  $C$  = Capacitance (F),  $\epsilon_0$  = absolute permittivity (Fm),  $\epsilon_r$  = dielectric constant (A.K.A relative permittivity),  $A$  = overlap area of plates ( $m^2$ ),  $d$  = distance between plates

TABLE 7-1. Dielectric Constants for Common Materials.

MATERIAL	CONSTANT
Vacuum	1.0000
Air	1.0006
Paraffin paper	2.5 - 3.5
Transformer oil	4
Glass	5 - 10
Mica	3 - 6
Rubber	2.5 - 35
Wood	2.5 - 8
Porcelain	6
Glycerine (15 C)	56
Petroleum	2
Pure water	81

### CAPACITOR RATING

To make a capacitor smaller, most capacitors are rolled up.

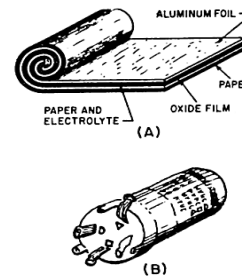


FIGURE 7-11. Construction of an Electrolytic Capacitor.

## KEY POINTS

The total capacitance for series and parallel capacitor combinations can be calculated:

$C_T = C_1 + C_2 + \dots$  for capacitors in parallel

$\frac{1}{C_T} = \frac{1}{C_1} + \frac{1}{C_2} + \dots$   
for capacitors in series

The energy stored in a capacitor can be calculated by:

$$E = \frac{1}{2} QV$$

Where E = energy (J), Q = charge(C) and V = Voltage (V)

Note: A capacitor in a d.c. circuit is only 50% efficient (Energy supplied E = QV)

## KEY POINTS

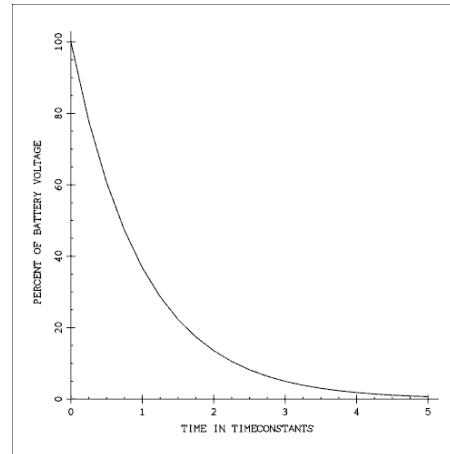
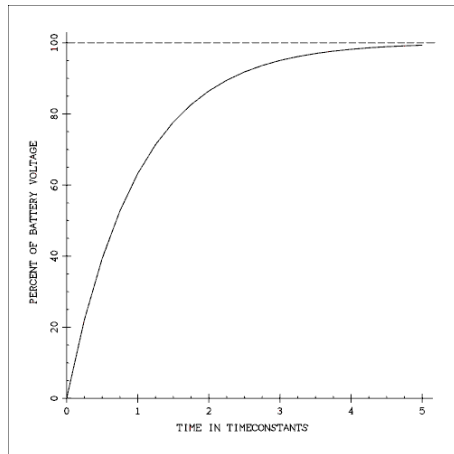
Capacitors can charge up (gain charge) and discharge (lose charge).

This **charging and discharging** is non-linear.

Capacitor charge/discharge curves (Voltage/time and current/time) can be explained using all the formulas covered so far and the additional formula of

$$Q = It$$

Where  $Q$  = Charge(C),  $I$  = current (A),  $t$  = time (s)



The time constant for a DC RC circuit is given by:

$$\tau = RC$$

Where  $\tau$  = time constant(s),  $R$  = resistance ( $\Omega$ ) and  $C$  = capacitance (F)

The time constant is the physical time for a change of 63% to occur. A capacitor is regarded to be fully charged or fully discharged after  $5 \times \tau$  (although theoretically a capacitor never fully charges or discharges)

## KEY POINTS

Magnetic fields can be described in terms of magnetic flux,  $\Phi$  (Wb), and magnetic field strength, B (T).

They are linked by the equation  $\Phi = B A$

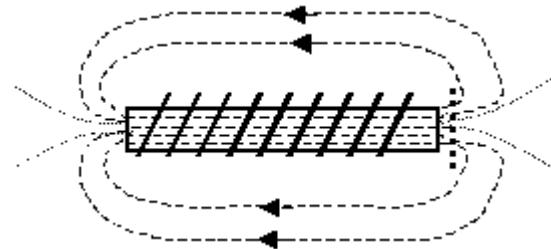
Where A = area ( $m^2$ )

Magnetic fields are found outside and inside magnets (and are strongest at the poles).

A solenoid also behaves like a magnet since a moving current produces a magnetic field

Magnetic fields can be produced by:

- single wire
- coil (solenoid)



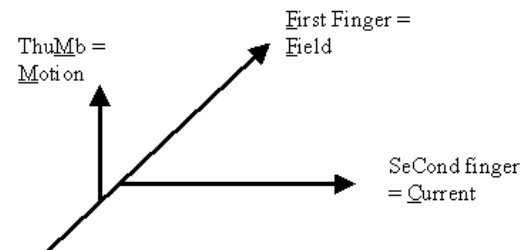
Electromagnetic induction:

When 2 of the following 3 exist at an angle to each other ( $90^\circ$  is the optimum angle) the third is induced:

**Movement**

**Magnetic Field**

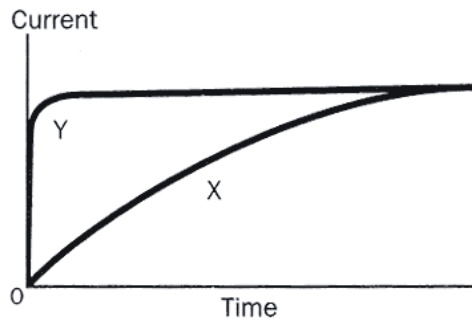
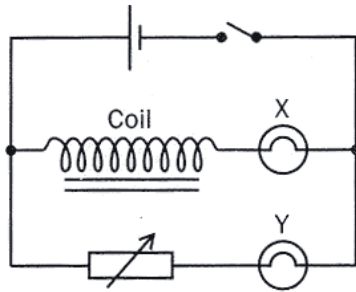
**Current**



## KEY POINTS

Inductors can produce magnetic fields when current is changing within the coil. They oppose any change in current (either an increase or a decrease).

This **opposition** is non-linear (just like Capacitors)



Inductors charge/discharge curves (Voltage/time and current/time) can be explained using all the formulas covered so far and the additional formula of

$$\varepsilon = -L \frac{\Delta I}{\Delta t}$$

Where  $\varepsilon$  = EMF(V),  $L$  = inductance (H),  $\Delta I / \Delta t$  = rate of change of current ( $\text{As}^{-1}$ )

The time constant for a DC RL circuit is given by:

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

Where  $\tau$  = time constant(s),  $R$  = resistance ( $\Omega$ ) and  $L$  = inductance (H)

The time constant is the physical time for a change of 63% to occur. An inductor is regarded to have a stable magnetic field or no magnetic field after  $5 \times \tau$  (although theoretically a this never happens)

The energy stored in an inductor is given by:

$$E = \frac{1}{2} LI^2$$

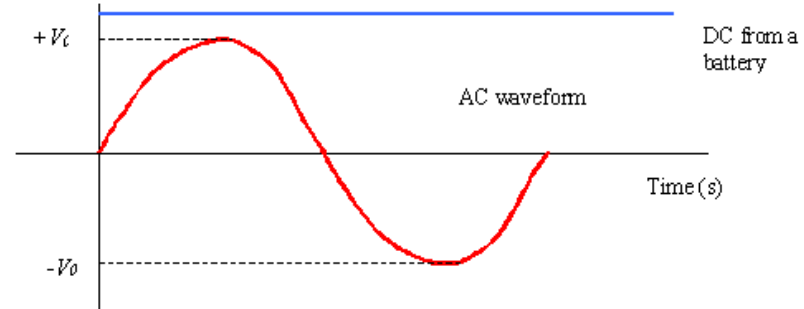
## KEY POINTS

Electricity can be generated by a coil rotating with a constant angular velocity in a uniform magnetic field – This is what happens in nearly all power stations worldwide.

$$V = V_{MAX} \sin \omega t$$

$$I = I_{MAX} \sin \omega t$$

are consequences of a coil rotating with constant angular velocity where  $\omega$  is the angular frequency of the coil ( $s^{-1}$ ) and  $t$  is the instantaneous time (s).  $I_{MAX}$  and  $V_{MAX}$  are the maximum values of the current produced when the movement of the coils is  $90^\circ$  to the magnetic field.



The Voltage can be calculated by using Faraday's law:

$$\varepsilon = - \frac{\Delta \phi}{\Delta t}$$

Where  $\varepsilon$  = EMF(V),  $L$  = inductance (H),  $\Delta I / \Delta t$  = rate of change of current ( $As^{-1}$ )

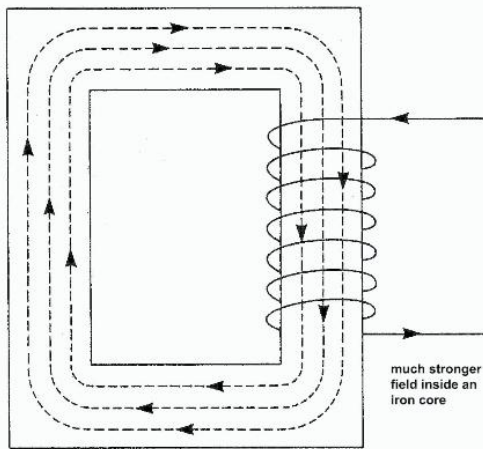
## KEY POINTS

Mains electricity in New Zealand is 240 V 50Hz.

However, due to energy losses at medium to high currents, electricity is converted to 330,000 Volts for transmission around NZ.

Two inductors are used as shown by the formula:

$$\varepsilon = -M \frac{\Delta I}{\Delta t}$$



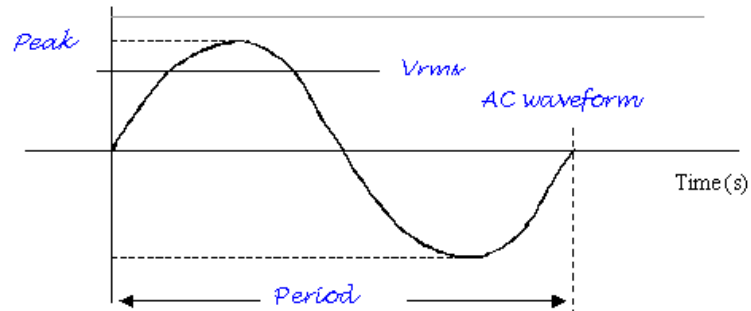
Where  $\varepsilon$  = EMF(V),  $M$ = mutual inductance (H),  $\Delta I / \Delta t$  = rate of change of current ( $\text{As}^{-1}$ ). These two inductors linked by a common magnetic field are more commonly called a transformer.

$$\frac{N_p}{N_s} = \frac{V_p}{V_s}$$

Where  $N_p$  = number of turns on primary,  $N_s$  = number of turns on secondary,  $V_p$  = voltage supplied to primary and  $V_s$  = voltage induced on secondary. Transformers can step up or step down Voltages with high efficiency.

## KEY POINTS

The energy dissipation of a resistor carrying DC and AC is identical as is bulb brightness (power) using AC and DC providing the root mean square(rms) value of the A.C. matches the D.C. value.



RMS values are a method of averaging sine waves that would otherwise be calculated as zero.

$$I_{MAX} = \sqrt{2} I_{rms}$$

$$V_{MAX} = \sqrt{2} V_{rms}$$

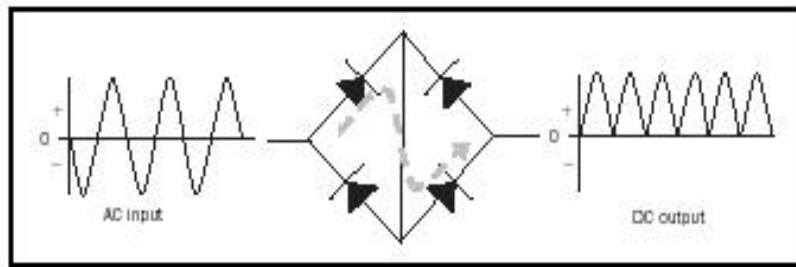
Mains electricity actually varies between + 340 V and – 340 V with 240 V being the rms value. (Mains current works in a similar way but the current depends on the resistance of the device).

A.C. electricity can be described by drawing a sine wave with time period 0.02 s – it is best drawn using phasors.

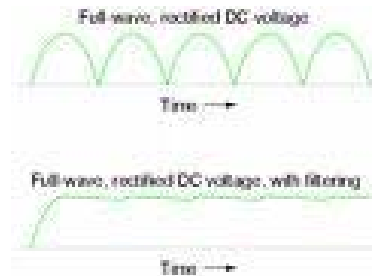
## KEY POINTS

A.C. is useful for transporting electricity but most electrical devices (particularly electronic ones) require D.C. electricity.

A.C. can be converted to DC by the use of bridge diode circuits to achieve full wave rectification.



To get constant DC a capacitor is used for smoothing.



## KEY POINTS

The current and voltage for a resistor in an AC circuit are in phase (resistors are passive in nature).

However:

current leads p.d by  $90^\circ$  in a capacitor in an RC circuit

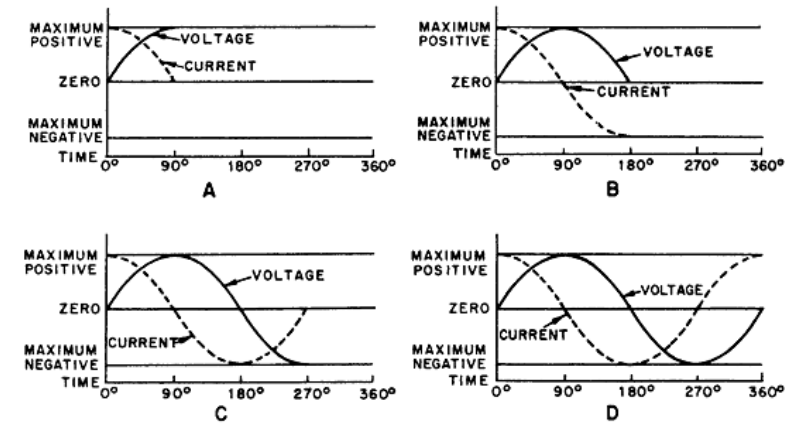
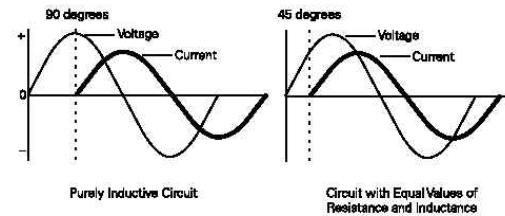


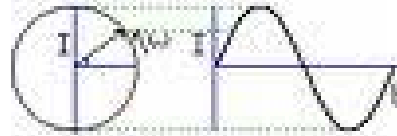
FIGURE 7-15. Phase Relationship of Voltage and Current in a Capacitive Circuit.

current lags p.d by  $90^\circ$  in an inductor in an LR circuit

This is due to the Reactive nature of capacitors in RC circuits and inductors in LR circuits.



These curves can be drawn by phasor diagrams:



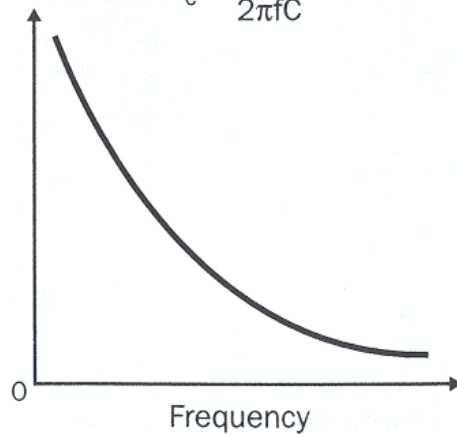
## KEY POINTS

The reactance of a capacitor is frequency dependant and given by:

$$X_c = \frac{1}{\omega C}$$

where  $X_c$  is the reactance of the capacitor ( $\Omega$ ),  $C$  is the capacitance (F) and  $\omega$  is the angular frequency of the supply voltage ( $s^{-1}$ ).

$$\text{Reactance } X_c = \frac{1}{2\pi f C}$$



The reactance of an inductor is also frequency dependant and given by:

$$X_L = \omega L$$

where  $X_L$  is the reactance of the inductor ( $\Omega$ ),  $L$  is the inductance (H) and  $\omega$  is the angular frequency of the supply voltage ( $s^{-1}$ ).

The angular frequency and the frequency are related by the equation:  $\omega = 2\pi f$

## KEY POINTS

In an LCR circuit, the overall effect on the current is determined by the impedance (a combination of the resistance and the reactance).

The resistance, capacitor reactance and inductor reactance can be used to calculate the impedance of an LCR circuit,  $Z$ . This is summarised by the equation:

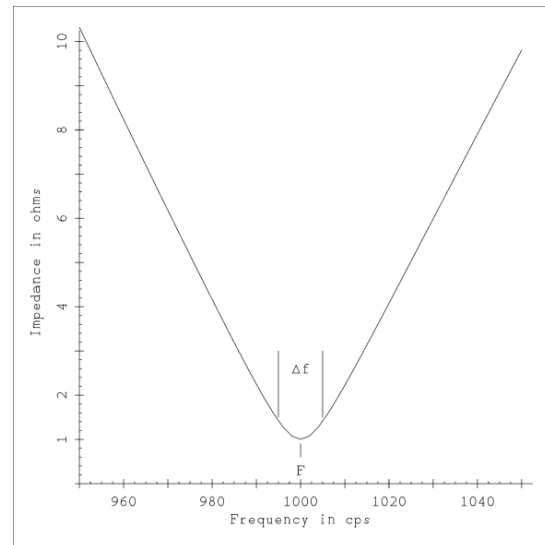
$$V = IZ$$

The alternating current in an RCL series circuit will be at a maximum when  $V_L = V_C$ . This occurs when  $X_L$  and  $X_C$  are equal (since they are opposite) and occurs at a unique frequency for each RCL circuit.

This frequency is known as the resonant frequency and can be calculated by the equation:

$$f_0 = \frac{1}{2\pi\sqrt{LC}}$$

When a circuit is supplied with a frequency that matches its resonant frequency, the circuit has minimum impedance since  $X_L$  and  $X_C$  cancel.



The maximum current flows and  $I = V/R$ . A very common use of this circuit is in tuning circuits such as radios, televisions and cell phones.