Last Week

Current and Charge

$$I = \frac{Q}{t} \qquad \text{therefore:} \qquad Q = It \qquad t = \frac{Q}{I}$$

- Problems:
  - if a current of 40 mA exists for 0.8 min, how many coulombs of charge have passed through the wire?
  - will a fuse rated at 1 A blow if 86 C pass through it in 1.2 min?

Last Week

SI Prefixes

- The SI convention defines multiplying **prefixes** to indicate multiple or fractional values of units:

name	symbol	factor
kilo	k	
mega	M	
giga	G	
tera	T	
peta	P	

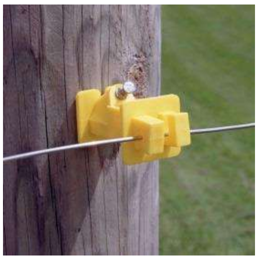
name	symbol	factor
milli	m	
micro	μ	
nano	n	
pico	p	
femto	f	

Conductors and Insulators, Resistors, Capacitors and Inductors

Conductors and Insulators

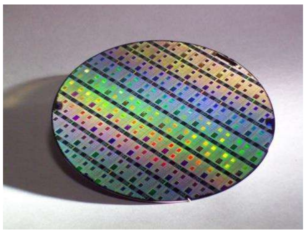
- **Conductors** are materials that allow **a large number of free electrons** to flow with very little voltage applied
  - for example: metals (cu, Al)

- **Insulators** are materials that have very few free or no electrons and therefore does not allow current flow.
  - for example: plastics



Semiconductors

- **Semiconductors** are a specific group of elements that exhibit characteristics between those of insulators and those of conductors
  - for example: silicon (Si)
- Semiconductors are the key for the entire electronics industry



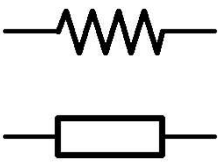
a silicon wafer

integrated circuits

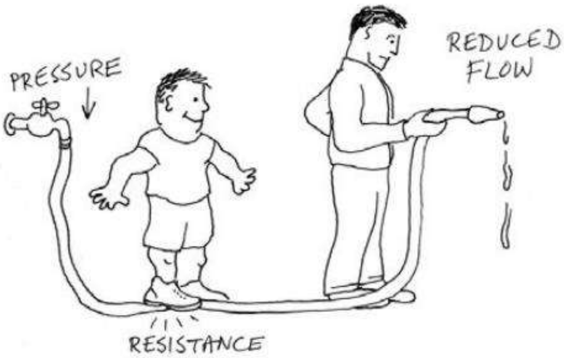
computer motherboard

Resistance

- The opposition to the flow of charge through an electrical circuit is called **resistance**, R, and is measured in ohms, Ω
- Conductors have low resistance while insulators have high resistance.



circuit symbols for a resistor



Resistance

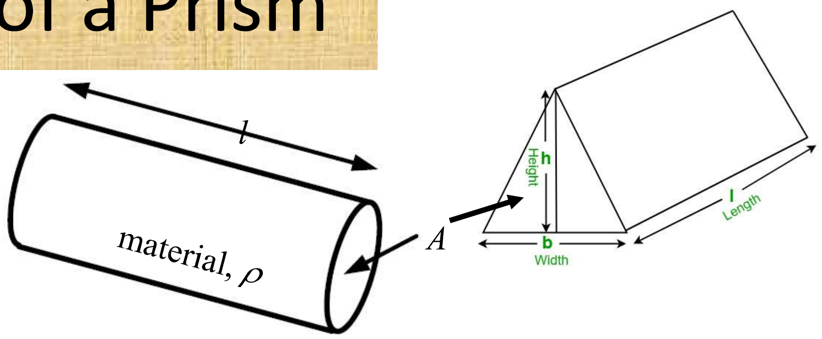
- The resistance is a material property and its dimensions:
  - **length**, l

    a longer wire has a higher resistance
  - **cross-sectional area**, A

    a thicker wire has a lower resistance
  - **resistivity**, ρ

    a value that quantifies how strong a material opposes the flow of electrons; the higher the resistivity, the higher the resistance. This is a material property.

Resistance of a Prism



- Resistance of a prism:

$$R = \frac{\rho l}{A}$$

- Re-arranging the equation for resistivity:

$$\rho = \frac{RA}{l}$$

- Unit of resistivity is Ωm

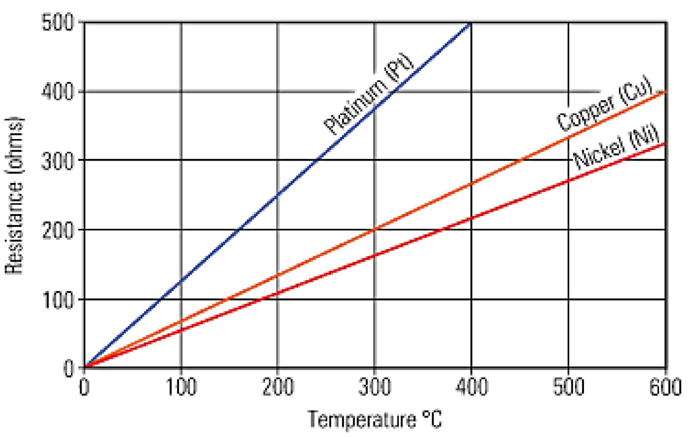
Resistivity of some materials

Material	Resistivity ρ (ohm m)	
Silver	1.59	$\times10^{-8}$
Copper	1.68	$\times10^{-8}$
Copper, annealed	1.72	$\times10^{-8}$
Aluminum	2.65	$\times10^{-8}$
Tungsten	5.6	$\times10^{-8}$
Iron	9.71	$\times10^{-8}$
Platinum	10.6	$\times10^{-8}$
Manganin	48.2	$\times10^{-8}$
Lead	22	$\times10^{-8}$
Mercury	98	$\times10^{-8}$
Nichrome (Ni,Fe,Cr alloy)	100	$\times10^{-8}$
Constantan	49	$\times10^{-8}$
Carbon* (graphite)	3-60	$\times10^{-5}$
Germanium*	1-500	$\times10^{-3}$
Silicon*	0.1-60	...
Glass	1-10000	$\times10^{9}$
Quartz (fused)	7.5	$\times10^{17}$
Hard rubber	1-100	$\times10^{13}$

Source : http://hyperphysics.phy-astr.gsu.edu/hbase/Tables/rstiv.html

Temperature and Resistance

- Temperature also has an effect on resistance:
  - a higher temperature causes the ions in the metal to vibrate more making it harder for electrons to move through the metal



Example

- Calculate the resistance of a 6 mm diameter and 3 m long copper cylindrical wire. The resistivity of the copper is 1.68×10^{-8} Ω.m.

Solution:

$R = \rho L / A$

Area (A) $= \pi r^2 = \pi(3 \times 10^{-3})^2$

$R = 1.68 \times 10^{-8} \times 3 / (\pi \times (3 \times 10^{-3})^2$

$= 1.78 \times 10^{-3}\ \Omega$

Radius (r) = 6/2 mm

$= 3 \times 10^{-3}$ m

Change into SI units

Example Problem

Determine the increase in resistance of a copper conductor if the cross-sectional area is reduced by a factor of 6 and the length is doubled. The original resistance of the conductor was 0.2 Ω. Assume the temperature remains fixed.

Solution:

$R = \rho L / A$

R(original) $= \rho L / A$

R(new) $= \rho L \times 2 / (A/6)$

$= 12 \rho L / A$

so the increase in resistance is 12 times

Note:

$$\frac{a/b}{c/d} = \frac{a}{b} \div \frac{c}{d} == \frac{a}{b} \times \frac{d}{c} = \frac{ad}{bc}$$

Example:

$$\frac{2/3}{4/5} = \frac{2 \times 5}{3 \times 4} = \frac{5}{6}$$

Example Problem 3

Imagine a conductor in a cylindrical shape. Calculate the relative increase or decrease in resistance if the cross-sectional area is reduced by 30% and the length is increased by 40%. The resistivity is fixed. Ignore the influence of temperature variation on the resistance.

Solution:

$R = \rho L / A$

$R(\text{original}) = \rho L / A$

$R(\text{new}) = \rho \times 1.4L / (0.7A)$

$= 2\rho L / A$

so the resistance will be increased by a factor of 2.

Note:
Increase by x% means multiply the original value by (1+x/100)
Decrease by x% means multiply the original value by (1-x/100)

Example:
Increase 60 by 25% → 60 x (1+ 25/100) = 60 x 1.25 = 75
Decrease 80 by 15% → 80 x (1-15/100) = 80 x 0.85 = 68

Conductance

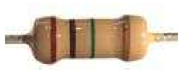
- The reciprocal of resistance, G, is the **conductance** of a material and is measured in siemens, (S)
  - a measure of how well a material conducts electricity

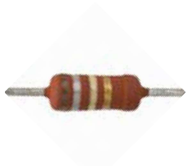
$$G = \frac{1}{R}$$

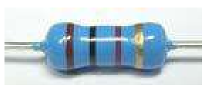
- **Conductivity**, σ, is a value that quantifies how good a material is at allowing electrons to flow
  - the higher the conductivity, the lower the resistance
  - conductivity has units of Sm^{-1}

Fixed Resistors

fixed resistor type	appearance	characteristic
carbon film	beige body	inexpensive, 5-20% tolerance
metal film	stronger colour (such as brick red or dark green)	precise ±1% tolerance high power rating
metal-oxide film	softer pastel colour (such as blue)	
thin/thick film	surface mount	small size
wire wound	(see images below)	tolerate very high temperature, but not good for high frequency


carbon film


metal film


metal-oxide film

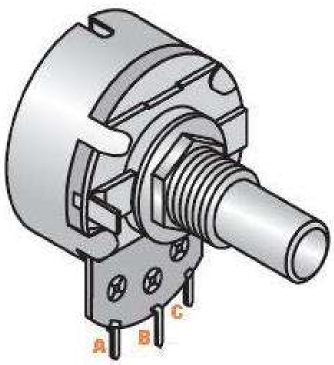
thin/thick film


wire wound

Variable Resistors

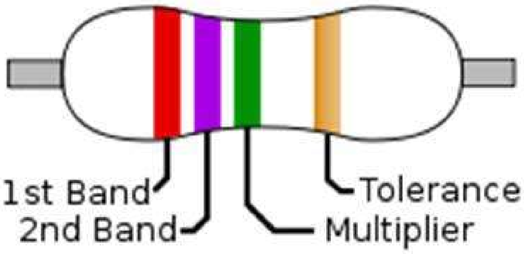
- Also called **potentiometers**:
  - the resistance between the wiper arm and either outside terminal can be varied from 0 Ω up to the full rated resistance value of the potentiometer
  - the sum of the two resistances between the wiper arm and each outside terminal is equal to the full rated resistance of the potentiometer:

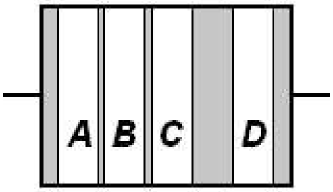
$$R_{AC} = R_{AB} + R_{BC}$$



Resistor Colour Code

- The resistor colour code is used indicate the value of a resistor:





the big gap between the C and D bands appears on the right

Band A is the first significant figure

Band B is the second significant figure

Band C is the decimal multiplier

Band D indicates tolerance of the value

FIRST DIGIT First Colour Band		SECOND DIGIT Second Colour Band		MULTIPLIER Third Colour Band	
BLACK	0		0		x 1
BROWN	1		1		x 10
RED	2		2		x 100
ORANGE	3		3		x 1,000
YELLOW	4		4		x 10,000
GREEN	5		5		x 100,000
BLUE	6		6		x 1,000,000
VIOLET	7		7		x 10,000,000
GREY	8		8		x 100,000,000
WHITE	9		9		x 1,000,000,000

Tolerance
Fourth Colour Band:

BROWN 1%	RED 2%	GOLD 5%	SILVER 10%	SALMON 20%

Resistor Colour Code (4 band)

FIRST DIGIT First Colour Band		SECOND DIGIT Second Colour Band		MULTIPLIER Third Colour Band	
BLACK	0		0		x 1
BROWN	1		1		x 10
RED	2		2		x 100
ORANGE	3		3		x 1,000
YELLOW	4		4		x 10,000
GREEN	5		5		x 100,000
BLUE	6		6		x 1,000,000
VIOLET	7		7		x 10,000,000
GREY	8		8		x 100,000,000
WHITE	9		9		x 1,000,000,000

Tolerance
Fourth Colour Band:

BROWN	RED	GOLD	SILVER	SALMON
1%	2%	5%	10%	20%

the resistance is: 1 5 × 100 = 1500 = 1.5 kΩ
the tolerance is: 5%

FIRST DIGIT First Colour Band		SECOND DIGIT Second Colour Band		THIRD DIGIT Third Colour band		MULTIPLIER Fourth Colour Band	
BLACK	0		0		0		x 1
BROWN	1		1		1		x 10
RED	2		2		2		x 100
ORANGE	3		3		3		x 1,000
YELLOW	4		4		4		x 10,000
GREEN	5		5		5		x 100,000
BLUE	6		6		6		x 1,000,000
VIOLET	7		7		7		
GREY	8		8		8	GOLD	x 0.1
WHITE	9		9		9	SILVER	x 0.01
Tolerance Fifth Colour Band:							
BROWN 1%							

Resistor Colour Code (5 band)

FIRST DIGIT First Colour Band		SECOND DIGIT Second Colour Band		THIRD DIGIT Third Colour band		MULTIPLIER Fourth Colour Band	
BLACK	0		0		0		x 1
BROWN	1		1		1		x 10
RED	2		2		2		x 100
ORANGE	3		3		3		x 1,000
YELLOW	4		4		4		x 10,000
GREEN	5		5		5		x 100,000
BLUE	6		6		6		x 1,000,000
VIOLET	7		7		7		
GREY	8		8		8	GOLD	x 0.1
WHITE	9		9		9	SILVER	x 0.01
Tolerance Fifth Colour Band:							
BROWN 1%							

the resistance is: 4 7 5 × 100 = 47500 = 47.5 kΩ

the tolerance is: 1%

Capacitors

- Capacitor stores energy in the form of electrostatic charge.
- A capacitor is a two-terminal electrical component.
- Capacitance, C, tells you how good a capacitor is at storing charge, Q, which is dependent on the voltage, V:

$$C = \frac{Q}{V}$$

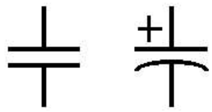
- The unit of capacitance is the farad, F
  - few capacitors store 1 C when charged up to 1 V, so most capacitors have values of picofarads, pF (10^{-12} F) or microfarads, μF (10^{-6} F)

Capacitors

- When a dc voltage is applied to a capacitor, it **charges** up:
  - electrons are pushed onto one plate and repelled from the other
  - when fully charged, the capacitor stores charge Q

- If the voltage is removed, the charge flows back around the circuit
  - the capacitor **discharges**

circuit symbols for a capacitor

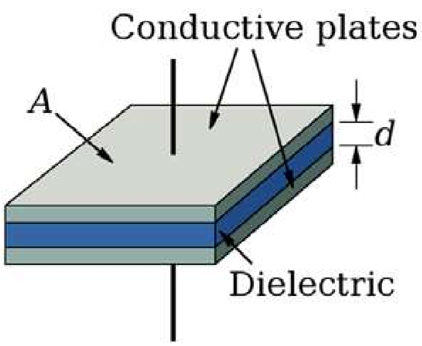


normal polarised

Capacitance of a parallel plates

A common capacitor consists of two conductive plates separated by a dielectric (insulator)

$$C = \varepsilon \frac{A}{d}$$



ε – epsilon (Greek alphabet)

symbol	meaning	Unit
C	capacitance	F
$\varepsilon = \varepsilon_o \varepsilon_r$	permittivity of the dielectric	Fm^{-1}
ε_o	permittivity of free space(vacuum) = 8.85 x 10^{-12}	Fm^{-1}
ε_r	relative permittivity of dielectric	No unit
A	area of the plate	m^2
d	distance between the plates	m

Example

Question 1: A parallel plate capacitor consists of two metal plates, each of area A = 150 cm^2, separated by a air gap, d =0.60 cm thick. What is the capacitance of this device?

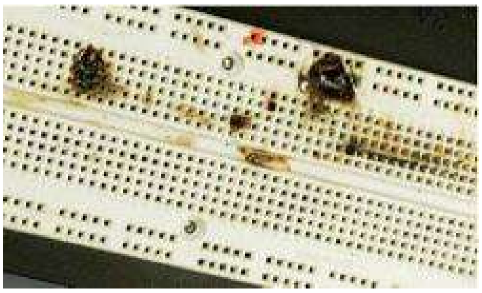
$$C = \varepsilon \frac{A}{d}$$

Solution: $$C = 8.85 \times 10^{-12} \frac{150\times10^{-4}}{0.6\times10^{-2}}$$
$$= 2.21 \times 10^{-11} = 0.221 \text{ pF}$$

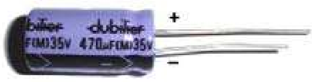
Capacitor values are usually pico-Farads (pF), nano-Farads (nF) or micro-Farads (μF)

Check Polarity!

- Usually, polarity is very clearly indicated on the case of polarised capacitors:



the result of a capacitor being connected the wrong way around

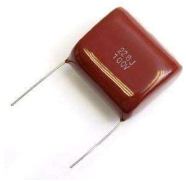


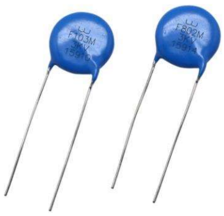
for **aluminium electrolytic** capacitors, a bar across the side of the capacitor is usually used to indicate the negative terminal and the positive terminal lead is longer than the negative lead

for **tantalum** capacitors, the positive terminal is indicated by a thick bar

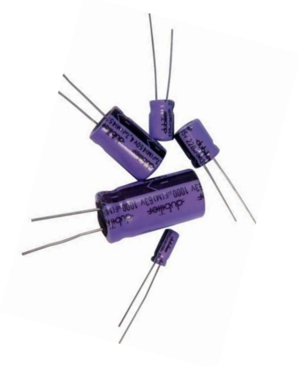
IF UNCERTAIN, STUDY THE DATA SHEET OR ASK!

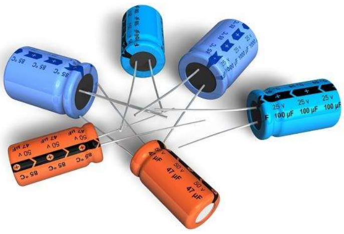
Capacitor Types





characteristic	ceramic	electrolytic
capacitance	small	very large
shape	disc	miniature tin
colour	often yellow	any
polarised	no	yes
example value	100 pF	1000 μF

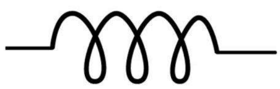




Inductor

- An **inductor** is a passive electrical component that stores energy in the form of a magnetic field. In its simplest form, an **inductor** consists of a wire loop or coil.
- In a inductor voltage is proportional to rate of current but opposes the change in current.

symbol L – Inductance



Symbol of an inductor

Units of inductance is henry and symbol is H.

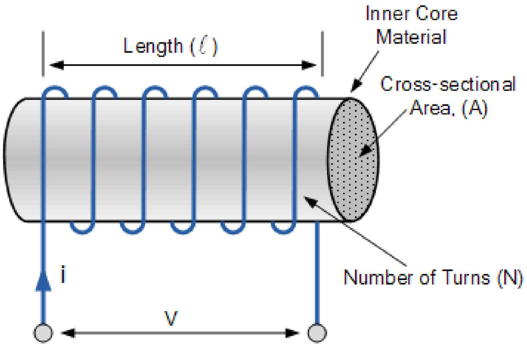
Types of Inductors

Solenoid

- Coil
- Ferromagnetic core (e.g. steel and iron) to improve the magnetic field strength
- Act like a permanent bar magnet with north and south poles
- An example of an electro-magnet

Solenoid acts as an electromagnet when applied with a DC current	This is the basis for relay and valve
Solenoid acts as an inductor when applied with an AC current	This is the basis for storing magnetic energy
Solenoid Induces an e.m.f. when it experiencing changing magnetic flux	This is the basis for transformer

Inductance of a solenoid



$$\text{Inductance (L)} = \frac{\mu N^2 A}{l}$$

where, L is in Henries

$\mu = \mu_o \mu_r$ - permeability of the medium
μ_o - permeability of free space ($4.\pi.10^{-7}$ H/m)
μ_r - relative permeability of the medium of the core
N - number of turns
A - inner core Area ($\pi.r^2$) in m^2
l - length of the coil in metres

Relative permeability of common materials

Material	Relative permeability	Permeability (H/m)
water	0.999	1.25×10^{-6}
Vacuum / Air	1	1.26×10^{-6}
Steel	100	1.26×10^{-4}
Ferrite	640	1.26×10^{-4}
nickel–iron soft ferromagnetic alloy	20000	2.52×10^{-2}

Solenoid and Inductor - example

1) Find the inductance of a solenoid if the number of loops is 500, cross sectional area is 1 cm^2 and the Length of the coil is 20 cm. The core is air.

$$L_S = \frac{\mu N^2 A}{l_c} = \frac{4\,\pi \times 10^{-7} \times 500^2 \times 1 \times 10^{-4}}{0.2} = 0.157\ \text{mH}$$

2) What will be the inductance if the length is doubled and core has changed with a material with relative permeability of 200?

Length doubled → the above valued will be halved
Relative permeability increased by 200→ inductor value will be multiplied by 200
So new L = 0.157 x 200 / 2 = 15.7 mH

3) If the inductance is to be increased by a factor of three based on Q1 above by changing the radius of the core, what would be the radius of new core ?

A is proportional to inductance; hence r^2 is proportional to L.
Increase of L requires r^2 to be increased by factor or 3 and hence r must be increased by factor of square root of 3.

Solenoid and Inductor - example - continue

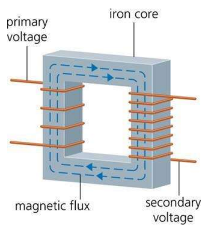
2) What will be the inductance if the length is doubled and core has changed with a material with relative permeability of 200?

Length doubled → the above valued will be halved
Relative permeability increased by 200X → inductor value will be multiplied by 200
So new L = 0.157 x 200 / 2 = 157 mH

3) If the inductance is to be increased by a factor of three based on Q1 above by changing the radius of the core, what would be the radius of new core ?

A is proportional to inductance; hence r^2 is proportional to L.
Increase of L by a factor of 3, requires r^2 to be increased by factor of 3 and hence r must be increased by factor of square root of 3.

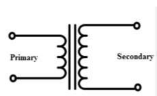
Transformers



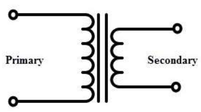
- Used to change the voltage to a higher or lower without changing the power
- Step-up transformers: to increase the voltage
  - From power stations to grid (few hundred to few thousands)
- Step-down transformer: to decreased the voltage
  - » From grid to residential area – (few thousands to 240V, may be in few steps)
  - » Mobile phone chargers – 240V to 12 V.

» Transformers have two coils wound around a ferromagnetic core

» Only works with AC voltage
  - AC voltage (current) is converted into magnetic flux in primary coil
  - Magnetic flux is converted into current again in secondary coil



Step-up transformer



Step-down transformer

Transformer Equations

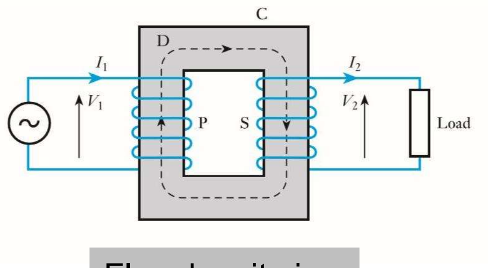
Input power (primary side) = output power (secondary side)

$$V_1 I_1 = V_2 I_2$$

$$\frac{emf\ in\ primary\ coil}{emf\ induced\ in\ secondary\ coil} = \frac{N_1 \times emf\ per\ turn}{N_2 \times emf\ per\ turn} = \frac{N_1}{N_2}$$

$$\frac{V_1}{V_2} = \frac{N_1}{N_2}$$

$$\frac{V_1}{V_2} = \frac{I_2}{I_1} = \frac{N_1}{N_2}$$



Flux density is same everywhere in the core

Losses in transformers

- Hysteresis loss in transformer – magnetization and demagnetization of core (usually iron) will not be perfect. This is known as Hysteresis and some portion electrical energy will be consumed.
- Eddy current loss in transformer - due to Stray fluxes link with the mechanical structure and winding conductors, an e.m.f will be induced which is not useful and hence considered as loss.
- Ohmic loss - lost as I^2R loss and dissipated as heat in the primary and secondary windings, because these windings have some internal resistance in them.

Transformer example

Example: A 250 kVA, 11 000 V/400V, 50Hz single-phase transformer has 80 turns on the secondary. Calculate: (a) the approximate values of the primary and secondary currents; (b) the approximate number of primary turns;

<u>Answer:</u>

apparent power at primary coil = 250 kVA

Primary voltage = 11 000 V and secondary voltage = 400V

(a) Primary current →

$250 \times 1000 = 11\,000 \times I_1$

$I_1 = 22.7A$

(b) Secondary current →

$\frac{V_1}{V_2} = \frac{I_2}{I_1} \Rightarrow \frac{11\,000}{400} = \frac{I_2}{22.7} \Rightarrow I_2 = 624\text{ A}$

(c) Number of primary turns (N1) →

$\frac{V_1}{V_2} = \frac{N_1}{N_2} \Rightarrow \frac{11\,000}{400} = \frac{N_1}{80} \Rightarrow N_1 = 2200$