How are fields used to move electricity?

RMS

- **compare sinusoidal AC voltages produced as a result of the uniform rotation of a loop in a constant magnetic field with reference to frequency, period, amplitude, peak-to-peak voltage ($V_{p\text{–}p}$) and peak-to-peak current ($I_{p\text{–}p}$)**
- **compare alternating voltage expressed as the root-mean-square (rms) to a constant DC voltage developing the same power in a resistive component**
- **convert between rms, peak and peak-to-peak values of voltage and current**

Transformers

- **analyse transformer action with reference to electromagnetic induction for an ideal transformer:** $\frac{V_p}{V_s} = \frac{N_p}{N_s} = \frac{I_s}{I_p}$

Transmission

- **analyse the supply of power by considering transmission losses across transmission lines**
- **identify the advantage of the use of AC power as a domestic power supply.**

Paper	Multiple choice	Short Answer	Idea	Marks	%	Type
2022		5a	Power supplied	1	83%	Calculation
		5b	Power loss, transmission	3	72%	Calculation
		5c	Transmission concept	3	60%	Calculation
2022 NHT	5		Application of turns ratio	1	NA	Calculation
		6a	Turns ratio	2	NA	Calculation
		6b	Application of turns ratio	2	NA	Calculation
2021	7		$\text{Power}_{in} = \text{Power}_{out}$	1	69%	Calculation
		7a	Transmission principles	2	31%	Explanation
		7b	Power = VI	2	43%	Calculation
		7c	Power loss, transmission	3	38%	Calculation
2021 NHT	6		Peak-peak voltage	1	NA	Calculation
	7		Transmission principles	1	NA	Concept
		7a	Definition of ‘ideal’	1	NA	Concept
		7b	Turns ratio	1	NA	Calculation
		7c	$P = \frac{V^2}{R}$	2	NA	Calculation
		7d	ΔV, transmission lines	3	NA	Calculation
		7e	Parallel circuit, effect of transmission lines	3	NA	Explanation

2020	7		DC input	1	16%	Concept
		7a	Peak voltage	2	80%	Calculation
		7b	Turns ratio	1	83%	Calculation
		7c	Turns ratio	2	58%	Calculation
2019	5		Concept	1	84%	Concept
	6		Current ratio	1	57%	Calculation
		6a	Power = VI	1	84%	Calculation
		6b	Power loss in cables	4	24%	Explanation
		6c	Transformer concept	2	22%	Explanation
2019 NHT	5		Turns ratio	1	NA	Calculation
	6		RMS voltage concept	1	NA	Concept
		4a	Power loss	2	NA	Calculation
		4b	RMS voltage	3	NA	Calculation
		4c	Power loss	3	NA	Calculation
2018		4a	RMS voltage, DC equivalent	2	55%	Calculation
		5a	Power	2	45%	Calculation
		5b	Voltage drop	3	47%	Calculation
		5c	Power loss	2	75%	Calculation
		5d	Power loss	3	23%	Calculation
		5e	Concept	2	70%	Explanation
2018 NHT	5		Peak voltage	1	NA	Calculation
	6		Turns ratio	1	NA	Calculation
	7		Power	1	NA	Calculation
		5a	Power loss	2	NA	Calculation
		5b	Transmission concept	4	NA	Calculation
		5c	Concept	2	NA	Explanation
2017	4		Turns ratio	1	84%	Calculation
	5		P = VI, RMS to peak	1	51%	Calculation
		6a	i^2R	2	74%	Calculation
		6b	Power loss	2	48%	Calculation

RMS questions can be grouped into the following ideas.

Concepts

Power calculations	Worked example 1
RMS to DC equivalent	
RMS to Peak	Worked example 5

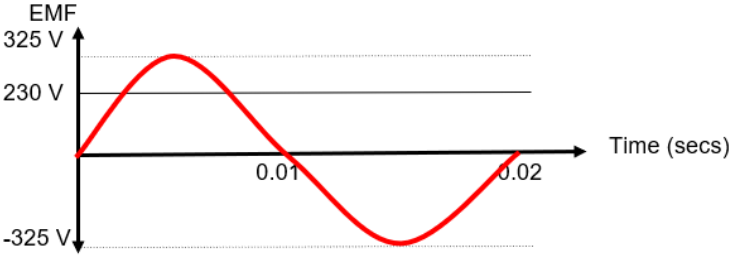
Transformer questions can be grouped into the following ideas.

Basic concepts	Worked example 3
Turns ratio	Worked example 4
Power	
DC input to transformer	

Transmission questions can be grouped into the following ideas.

Power	Worked example 8
Power loss	Worked example 9
Basic concept	Worked example 10
Voltage drop	Worked example 11

RMS Voltage – Peak to Peak.



The peak to peak voltage is from +325 to – 325. The peak voltage is 325 V. The Root Mean Square (RMS) voltage is the square root of the mean of the square of the potential difference.

The DC potential difference that transfers the same energy is given by $\sqrt{\frac{V_0^2}{2}}$ where V_0 is 325 V. In Australia, the RMS is equal to 230 V. An AC current can be given an RMS equivalent value in exactly the same manner. When doing calculations involving power etc. always use the RMS values, unless otherwise stated.

It should be noted that with a sinusoidal voltage the average value will be less than the peak value, and that the peak value will be half of the peak to peak value. This is summarised as

$$V_{\text{peak to peak}} = 2\,V_{\text{peak}}, \text{ and } V_{\text{peak}} = \sqrt{2}\,V_{\text{RMS}}.$$

Household electricity supply

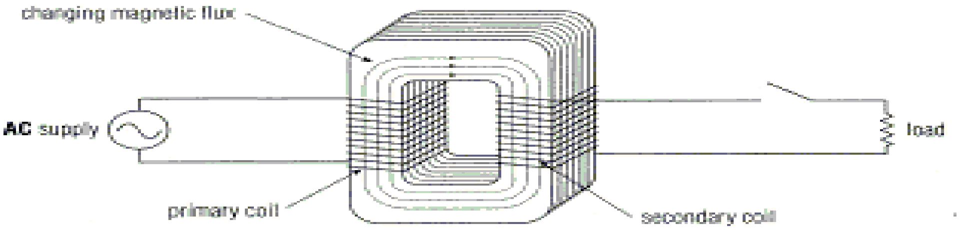
Two wires come from the power pole to the house. The ACTIVE wire is 230 V_{RMS}. The NEUTRAL wire is 0 V and is connected to the ground.

The cable from the pole goes first to a mains connection which contains a fuse in the active wire. Then it is connected to the switchboard or fuse box.

A main switch is placed in the active wire so that the power can be easily cut in case of emergency.
Several lighting and power circuits originate at the switchboard and each has a fuse or circuit breaker (again in the active wire) so that individual circuits can be isolated and cut.

Transformers

Transformers are a major component of the electrical distribution system because they enable energy losses in transmission lines to be reduced. The changing (alternating) current in the primary coil generates a changing (alternating) magnetic field in the iron core. This changing field passes through the secondary coil and induces an EMF in the secondary.



In an ideal transformer the total transfer of magnetic flux is assumed, ∴ energy (power) is conserved. Input power = Output power $P_{in} = P_{out}$

$$V_pI_p = V_sI_s$$

In the **ideal** case: $\frac{V_p}{V_s} = \frac{N_p}{N_s} = \frac{I_S}{I_P}$

I_P = current in primary coil I_S = current in secondary coil.

V_P = voltage in primary coil V_S = voltage in secondary coil.

N_P = number of turns in primary coil N_S = number of turns in secondary coil.

Step up, step down transformers

In a step-up transformer, the number of secondary turns exceeds that in the primary coil, and therefore the output voltage is greater than the input voltage. In a step up transformer the current is stepped down by the same factor by which the potential difference is stepped up.

Step up transformer $V_{OUT} > V_{IN} \Rightarrow N_{OUT} > N_{IN}$ **Step down transformer $V_{IN} > V_{OUT} \Rightarrow N_{IN} > N_{OUT}$**

DC supply voltage

In a transformer using a DC battery as a supply, it is possible to induce a current in the secondary coil in only two circumstances: if the initial current in the primary coil is zero, and then a switch is used to allow the current to flow, and induced current will flow in the secondary coil as the current (primary) is changing from zero to a constant value.

Power loss in transmission lines

Resistance of power lines is proportional to the length of the lines.

$P_{loss} = V_{loss} \times I_{transmission}$ but, $V_{loss} = I_{transmission} \times R$ $\Rightarrow P_{loss} = I^{2}_{transmission} \times R$

Transmitting at high voltages and relatively low current reduces power losses. This requires stepping up the voltage at the power station and stepping it down for industrial and domestic use. Typically, the power is sent from the generating station at voltages as high as 500 kV. As it arrives at a terminal station it is stepped down to 66 kV and then down to 11 kV at a substation. Pole transformers further step it down to 415 and 230 volts for domestic use. Power losses in transmission lines need to be considered in some questions. The power is not actually lost, it is degraded into heat, which becomes unusable. The power supplied to the consumer is equal to the power supplied at the start minus the power lost in transmission.

The power is transmitted in AC because it is able to be transformed either up or down. In contrast DC current is unable to be transformed necessitating transmission of large amounts of power, which would increase the energy loss resulting from large voltage drops.

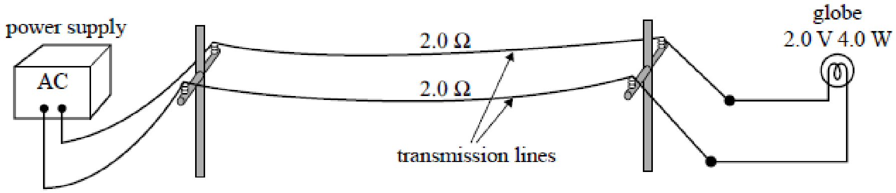
Power loss problem solving strategy

The power loss in the cables is given by $P = i^2R$. As the resistance of the cables is fixed, the way to reduce power loss is to minimise the current, i.

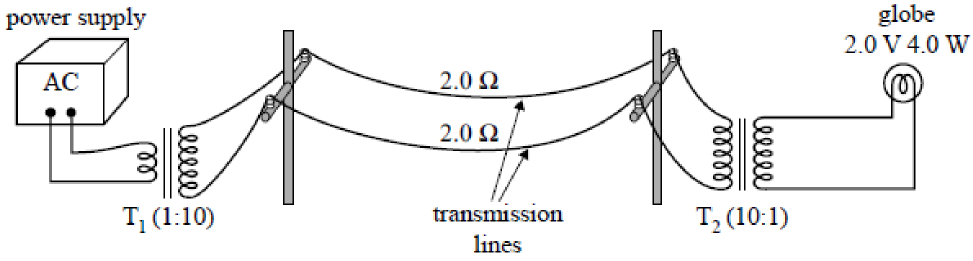
This is done by increasing the voltage V, because if the power being supplied remains constant then from the equation P = VI, as V increases, I must decrease. This only occurs if the power supplied remains constant.

Just saying an increase in V results in a decrease in I, **is not correct**, unless you specifically state that the power being delivered is the same.

Typical problems look like:



You are either provided with the supply voltage and asked to find the output voltage or in this case you are supplied with the output voltage and expected to work back to find the supply voltage. Typically you find the current in the wires, and to use this to determine the voltage drop across the transmission lines and the power loss in the lines.
Then the circuit has transformers included.



The step up transformer is always at the supply end. Stepping up the voltage, reduces the current in the transmission lines for the same power being supplied. The decrease in current leads to less power loss in the transmission lines, which leads to more power at the output. The step down transformer at the output, brings the voltage down to manageable levels.

Worked example 1: RMS Concept: Power calculations.

A 24 watt globe draws 4.0 A_{RMS} from an alternating current supply.

1985 Question 50, 1 mark (modified)

What is the peak value of the supply voltage?

Solution

The power is given by P = VI
$\therefore P = V_{RMS} \times I_{RMS}$
$\therefore 24 = V_{RMS} \times 4.0$
$\therefore V_{RMS} = 6.0$

Use $V_{PEAK} = V_{RMS} \times \sqrt{2}$
$= 6.0 \times \sqrt{2}$
∴ 8.5 V (ANS), (80%)

Current study design:

2018 NHT Question 7

Worked example 2: RMS Concept: RMS to DC equivalence.

2012 Question 3, 2 marks

Ferdi is deciding on an electricity supply for his caravan.

One option is an AC generator that provides a peak voltage of 150 V. With the AC supply, the total resistance of the appliances in the caravan is 6.0 Ω.

Another option is a DC supply of 120 V. With the DC supply, the total resistance of the appliances in the caravan is 7.0 Ω.

Use calculations to determine which of these options will provide the most power to the caravan.

Solution

The power is given by $P = \frac{V^2}{R}$

Need to use RMS, not peak, $\frac{150}{\sqrt{2}}$

AC $P = \frac{150^2}{(\sqrt{2})^2 \times 6} = 1875$ W

DC $P = \frac{120^2}{7} = 2057$ W
DC will provide more power (ANS), (68%)

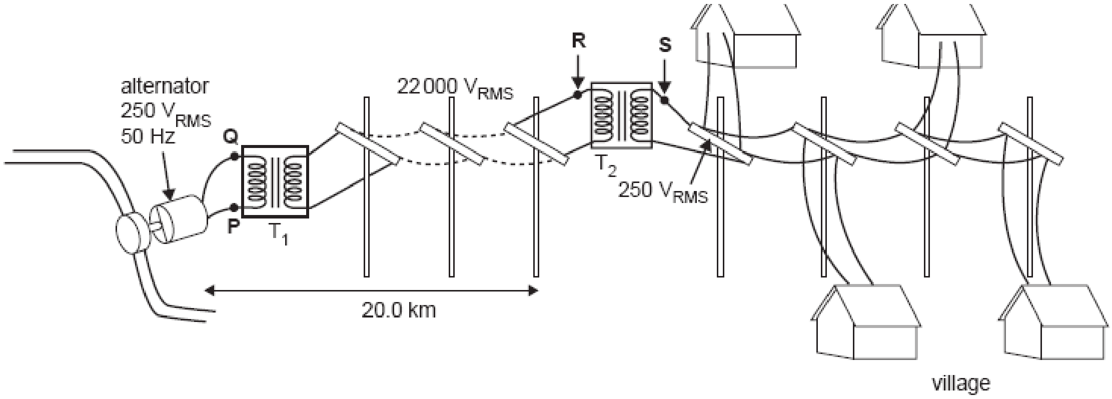
Current study design:

2016 NHT Question 6

2018 Question 4a (55%)

Worked example 3: Transformers: Basic concepts.

A village has a maximum electrical power requirement of 100 kW. The power is supplied by an alternator, approximately 20.0 km from the village, which generates electricity at 250 V_{RMS} at a frequency of 50 Hz. This is converted by a step-up transformer (T_1) to 22 000 V_{RMS}, transmitted to the edge of the village by power lines with a total resistance of 2.0 Ω, and converted back to 250 V_{RMS} by a step-down transformer (T_2) near the village. A diagram of the system is below.

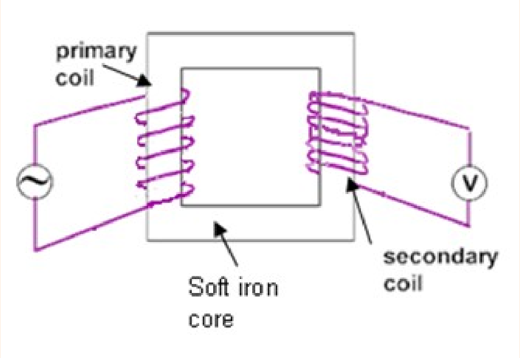


2006 Question 14, 3 marks

Explain the operation of a transformer in terms of electromagnetic induction.

Solution

A changing current at the primary coil produces an alternating *B* inside the soft iron core. The secondary coil is linked to the primary through the soft iron core. The changing *B* in the soft iron core results in a changing flux in the secondary coil. This changing flux induces an EMF in the secondary coil.



According to Faraday's Law: $EMF_{AVE} = -n \frac{\Delta \phi}{\Delta t}$

(50%)

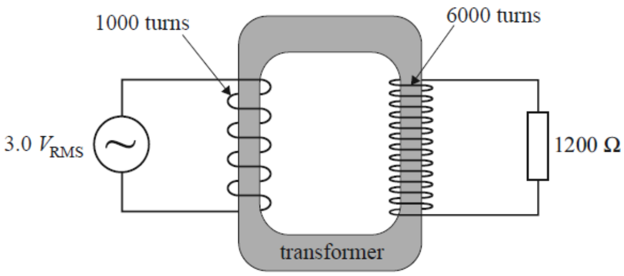
Current study design:

2021 NHT Question 7a

2019 Question 5 (84%)

Worked example 4: Transformers: Turns ratio.

Students are experimenting with an ideal transformer. The circuit is shown below.



The primary coil has 1000 turns; the secondary coil has 6000 turns. There is a 1200 Ω resistor in the secondary circuit. A 3.0 V_{RMS} AC power supply is connected across the primary coil.

2013 Question 15a, 1 mark

Calculate the RMS voltage across the resistor.

Solution

The ratio of the number of turns is 1:6

∴ the ratio of the voltages will be the same

∴ 3.0 : 18.0

∴ 18.0 V (ANS), (77%)

Current study design:

2022 NHT Question 5

2022 NHT Question 6a

2021 NHT Question 7b

2020 Question 7b (83%)

2019 NHT Question 5

2018 NHT Question 6

2017 Question 4 (84%)

Worked example 5: RMS Concept: RMS to peak.

2013 Question 15b, 1 mark

Calculate the peak voltage across the resistor.

Solution

Peak voltage = 18.0 × $\sqrt{2}$

∴ 25.5 V (ANS), (76%)

Current study design:

2021 NHT Question 6

2020 Question 7a (80%)

2018 NHT Question 5

Worked example 6: Transformers: Power calculations.

2013 Question 15c, 2 marks

Calculate the power dissipated in the resistor.

Solution

Power is always calculated using RMS values.

$$\therefore P = \frac{V^2}{R}$$

$$\therefore P = \frac{18^2}{1200}$$

∴ P = 0.27 W (ANS), (66%)

Current study design:

2022 Question 5a (83%)

2022 NHT Question 6b

2021 Question 7, (51%)

2021 NHT Question 7c

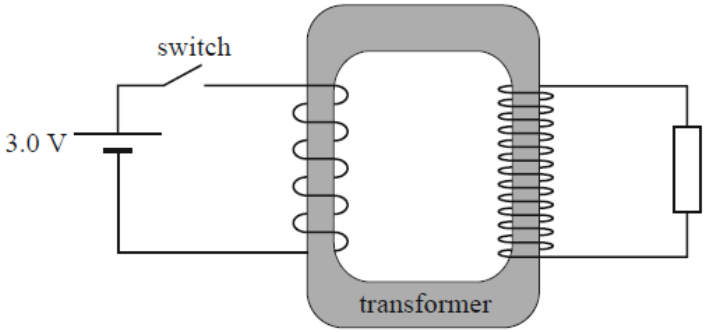
2020 Question 7c (51%)

2019 Question 6 (57%)

2017 Question 5 (51%)

Worked example 7: Transformers: DC input.

The students now modify the circuit, and connect a 3.0 V DC battery and a switch in the primary circuit, as shown below.



2013 Question 15d, 3 marks

The students have been asked to observe the current in the resistor as the switch is closed. Before the switch is closed, there is no current in the resistor. This does not surprise them. When the switch is closed, there is a very short pulse of current in the resistor. When the switch remains closed, there is no current in the resistor.

Explain why there is a short pulse of current as the switch is closed and why there is no current in the resistor as the switch remains closed. No numbers are required in your answer, but you should refer to the relevant law of physics.

Solution

As the switch closes, the current changes from 0 to a maximum value.
This change in current creates a changing flux in the iron core of the transformer. This change in flux induces and EMF across the secondary coil. As the circuit is complete this will lead to a brief current through the resistor. This is an application of Faraday's law.
Once the switch is closed, there won't be any change in the current, therefore no change in the flux, therefore no induced current. (36%)

Current study design:

2020 Question 7 (16%)

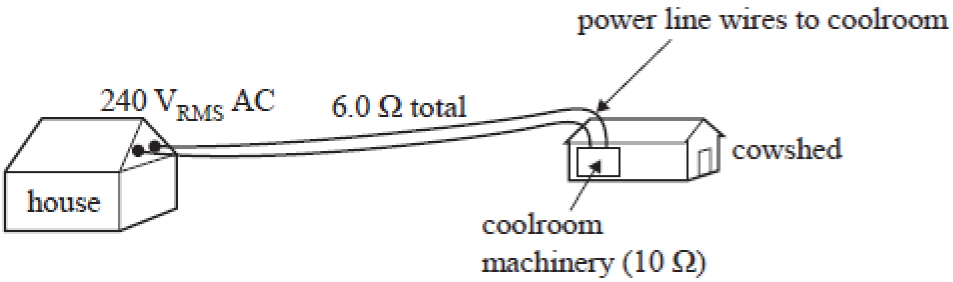
Worked example 8: Transmission: Power.

A farmer wishes to run a power line from his house to a cowshed to operate a large coolroom.

The voltage available at the house is 240 V_{RMS} AC.

The power line wires have a total resistance of 6.0 Ω.

The coolroom machinery has a constant resistance of 10 Ω and is designed to operate on 240 V_{RMS} AC. The installation is shown below.



2017 NHT Question 15a, 2 marks

Calculate the power of the coolroom machinery when it is operating correctly as designed.

Solution

Use P = $\frac{V^2}{R}$

∴ P = $\frac{240^2}{10}$

∴ P = 5760 W (ANS)

Current study design:

2021 Question 7b (43%)

2019 Question 6a (84%)

2018 Question 5a (45%)

Worked example 9: Transmission: Power loss.

2017 NHT Question 15b, 4 marks

Calculate the power used by the coolroom machinery in the arrangement shown above.

Show your working.

Solution

Use V = iR to find the transmission current.

∴ 240 = i × 16

∴ i = 15 A

Then use P = i^2R to find power used by the coolroom.

∴ P = 15^2 × 10

∴ P = 2.25 × 10^3 W (ANS)

Current study design:

2021 Question 7a (31%)

2021 NHT Question 7

2021 NHT Question 7d

2019 Question 6c (22%)

2018 Question 5e (70%)

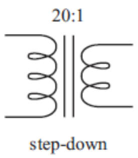
2018 NHT Question 5c

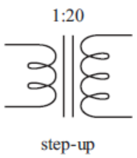
Worked example 10: Transmission: Concept.

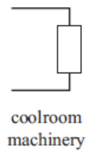
2017 NHT Question 15c, 3 marks

The farmer says the coolroom machinery is not operating correctly. An electrician says this is due to loss of voltage in the power line wires and the transmission voltage needs to be higher. The electrician has two transformers available: a step-down of 20:1 and a step-up of 1:20.

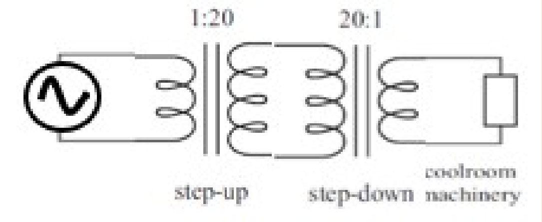
In the space provided below, sketch how these transformers should be installed in the system to improve the operation of the coolroom machinery in the cowshed. Use the symbols below in your diagram.







Solution



The voltage is stepped up before transmission in order to decrease the transmission current for the same power delivery. The reduced transmission current loses less power in the transmission wires. When the voltage is stepped down at the 'consumer' end, there is more power available as lees has ben lost in transmission.

Current study design:

2022 Question 5b (72%)

2022 Question 5c (60%)

2021 Question 7c (38%)

2021 NHT Question 7e

2019 Question 6b, (24%)

2019 NHT Question 4a

2019 NHT Question 4c

2018 Question 5c (75%)

2018 Question 5d (23%)

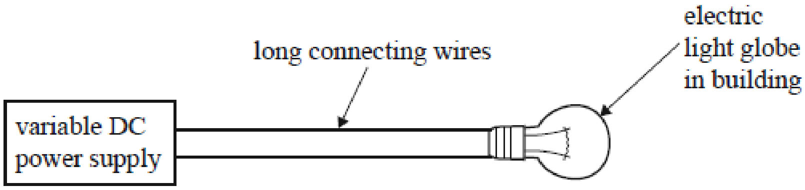
2018 NHT Question 5a

2017 Question 6a (74%)

2017 Question 6b (48%)

Worked example 11: Transmission: Voltage drop.

Jemima is planning to operate an electric light globe in a building some distance from her house. To do this, she connects two long wires from a variable voltage DC power supply in the house to an electric light globe in the building.



The wires have a total resistance of 5.0 Ω. The DC power supply produces a constant output voltage of 13 V. The light globe in the building is designed to operate at 6.0 V. Assume that its resistance is a constant 1.5 Ω.

When Jemima switches on the circuit, she measures the voltage at the light globe to be only 3.0 V.

2014 Question 15a, 1 mark

Calculate the voltage loss in the long connecting wires.

Solution	**Current study design:**
The power supply is at 13 V, and 3 V is across the light globe. **$\therefore \Delta V = 13 - 3$** **$\therefore \Delta V = 10$ V (ANS), (80%)**	**2019 NHT Question 4b** **2018 Question 5b (47%)** **2018 NHT Question 5b**