9.Electrical equipment testing and connection

Insulation Resistance

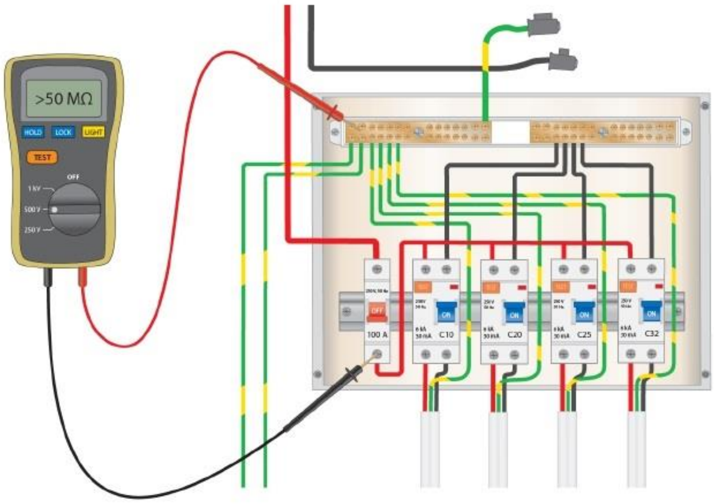
The purpose of insulation resistance testing is to verify the integrity of the insulation between conductors. This helps to ensure there won't be any short circuit hazards arising when the installation is energised. The following table describes the conditions, equipment and test results required for this test.

Insulation Resistance Testing	
Conditions:	• The supply to the installation must be isolated. • The MEN link should be disconnected. • All functional switches of circuits under test should be placed in the ON position. • Sheathed heating elements (e.g. in a water heater) should be disconnected from the circuit and tested separately. • Lamps should be removed from lamp holders prior to testing lighting circuits.
Equipment:	An insulation resistance tester set to at least twice the nominal circuit voltage, for example: • A test voltage of 500 V d.c. is suitable to test between active and earth of a single phase 230 V a.c. circuit. • A test voltage of 1,000 V d.c. is suitable* to test between each phase of a three phase 400 V a.c. submains set. *Note: the minimum test voltage required by the Wiring Rules for the purposes of verification is 500 V, however the use of the 1 kV test setting is considered 'best practice' when testing between phases as a 400 V r.m.s. circuit has a peak voltage of 565 V. Therefore the 500 V test voltage does not sufficiently stress the insulation for the service conditions.
Test Results:	• $\geq$ 1 MΩ between conductors of consumer mains and submains. • $\geq$ 1 MΩ between live and earthed parts of an installation. • $\geq$ 0.01 MΩ for sheathed heating elements.

There are several parts to this test, these are to check the insulation resistance of:

- Consumer mains and submains:
    - Between phases.
    - Between each phase and neutral.
    - Between each phase and earth.
    - Between neutral and earth.
- Final subcircuits:
    - Between each phase and earth.
    - Between neutral and earth.

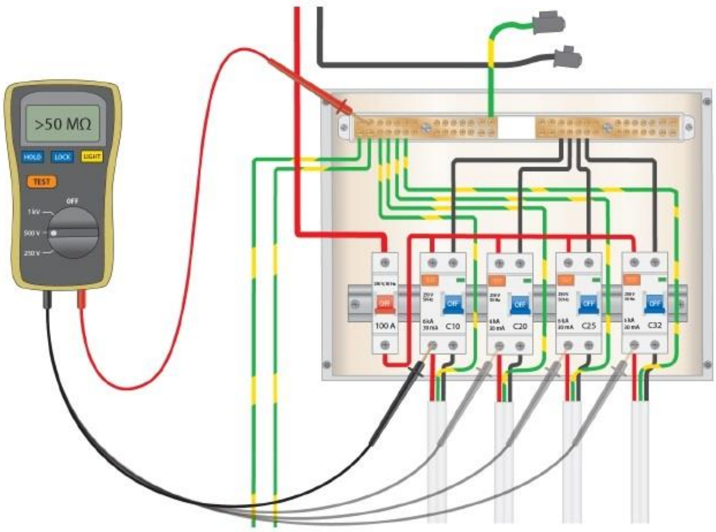
Insulation resistance testing can be carried out on individual circuits separately, or on multiple circuits simultaneously. The following diagram shows how the insulation resistance between active and earth for an entire small installation can be tested.



Points to note about this test:

- The main switch is in the OFF position, and each circuit protection device is in the ON position.
- The test voltages used for insulation resistance testing can be potentially destructive to electronic components – do not test between the active and neutral conductors of circuits that have electronic components connected (e.g. light dimmers).

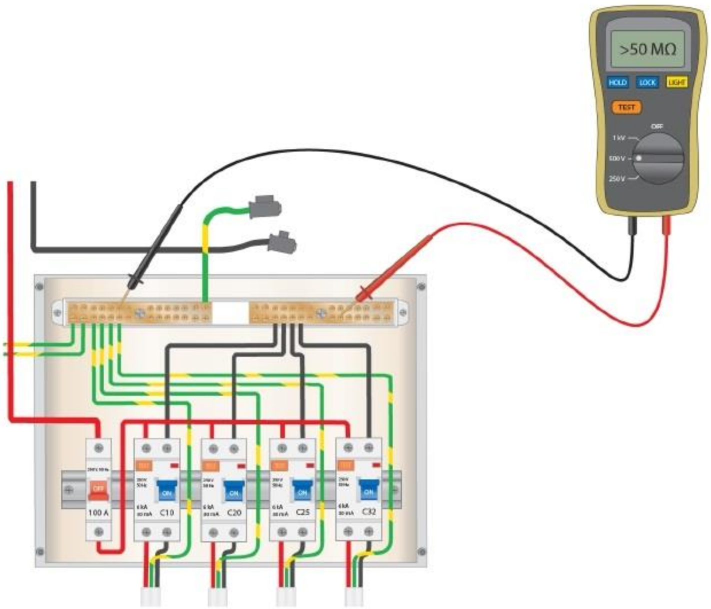
If a low insulation resistance is measured using this technique, then each circuit would need to be tested individually to narrow down the location of the defect. The following diagram shows how this could be performed.



Points to note about this test:

- In this case, each circuit protection device needs to be in the OFF position to isolate the final subcircuit active conductor under test from the rest of the installation active conductors.
- The test results will indicate which circuit contains damaged insulation.

The following diagram shows how the insulation resistance can be tested between neutral and earth for an entire small installation.



Watch the following short video to further develop your understanding of how to test for insulation resistance.

01:42

For further details of testing techniques, refer to AS/NZS 3017:2022 Figures 4.5 to 4.6 inclusive.

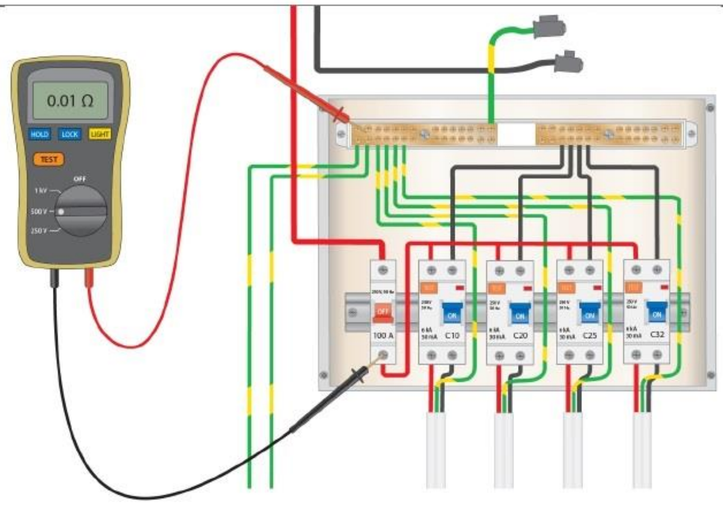
Insulation Resistance Faults

When conducting an insulation resistance test, a reading of below 1 MΩ (or below 0.01 MΩ for sheathed elements) indicates that there is a problem with the insulation. Examples of readings that would indicate a fault are:

- 0.01 Ω between the active and earthing conductors of a lighting circuit.
- 109 kΩ between two phase conductors of a three phase motor circuit.

The following table explains some of the typical problems that can result in these readings, as well as the underlying causes and solutions.

Insulation Resistance Faults

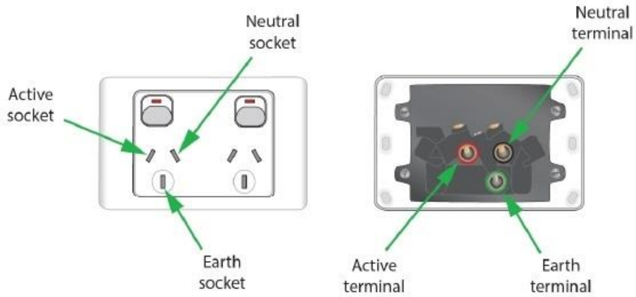


Typical Problem	Possible Causes	Solution
Damaged insulation.	There are a number of different factors that can cause damage to insulation, including: • Rodents. • Insufficient bushing at penetrations. • A cable being drawn in over a sharp edge, e.g. at the corner of a cable tray. • Thermal stress.	Replace the length of cable that has damaged insulation.

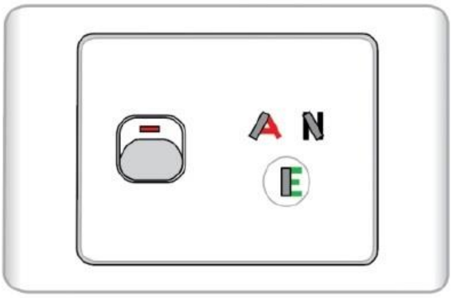
Single Phase Socket Outlets

AS/NZS 3000:2018 Clause 4.4.5 requires that when a three-pin/flat-pin socket outlet is viewed from the front, the order of the connections starting from the vertical earth pin slot shall be earth, active, neutral in a clockwise direction.

Single phase socket outlets have a basic A, N, E terminal arrangement, as shown in the following diagram.

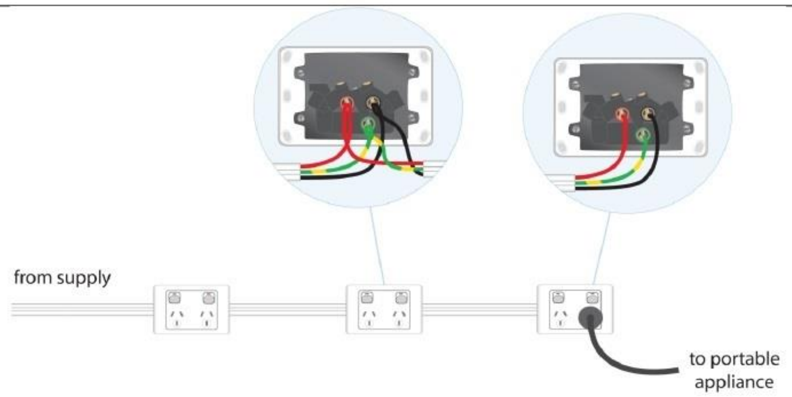


The following diagram shows a simple memory aid that can help for identifying the sockets on an outlet when viewed from the front:



The following diagram shows the connections for single phase socket-outlets.

Single Phase Socket Outlet Connections

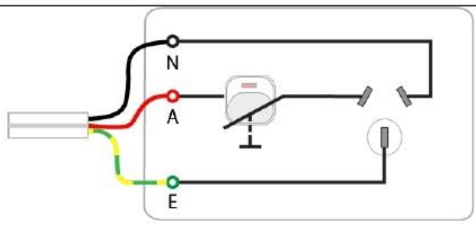
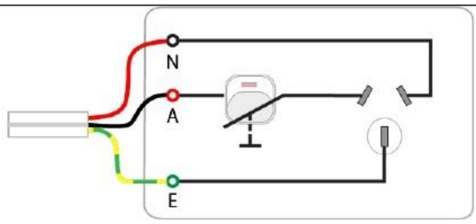
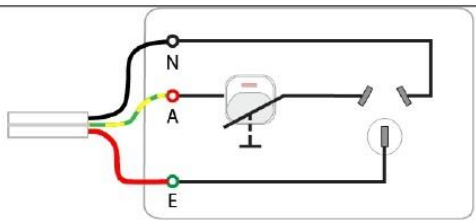


Dangers of Incorrect Polarity

In a socket outlet with **reversed polarity**, i.e. active and neutral wires have been swapped, the switch will operate in the neutral conductor only and the neutral socket terminal will be live at all times, regardless of the switch position.

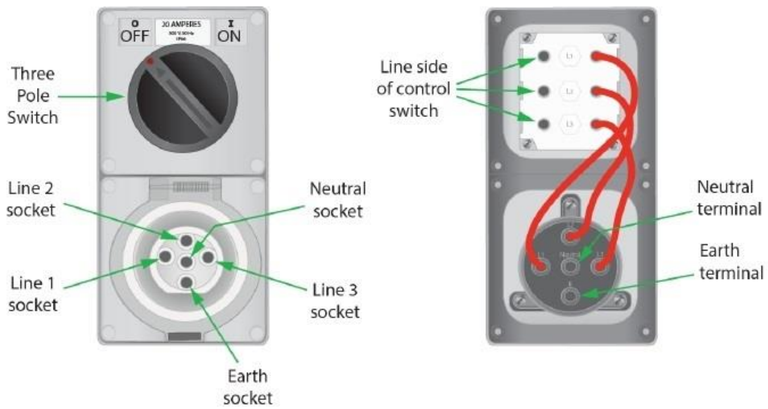
In a socket outlet where the **active and earth wires have been swapped**, the earth socket will be live at all times. This means that when equipment is plugged in, a potentially fatal touch voltage will appear between the earthed parts of the equipment (e.g. exposed conductive parts) and earth (i.e. the ground).

An incorrectly wired socket outlet represents an *extremely dangerous situation* which could result in a severe electric shock or death from electrocution.

Dangers of Incorrect Polarity	
Correctly wired socket outlet	
Incorrectly wired – active and neutral swapped (neutral terminal is always live!)	
Incorrectly wired – active and earth wires swapped (earth terminal is always live!)	

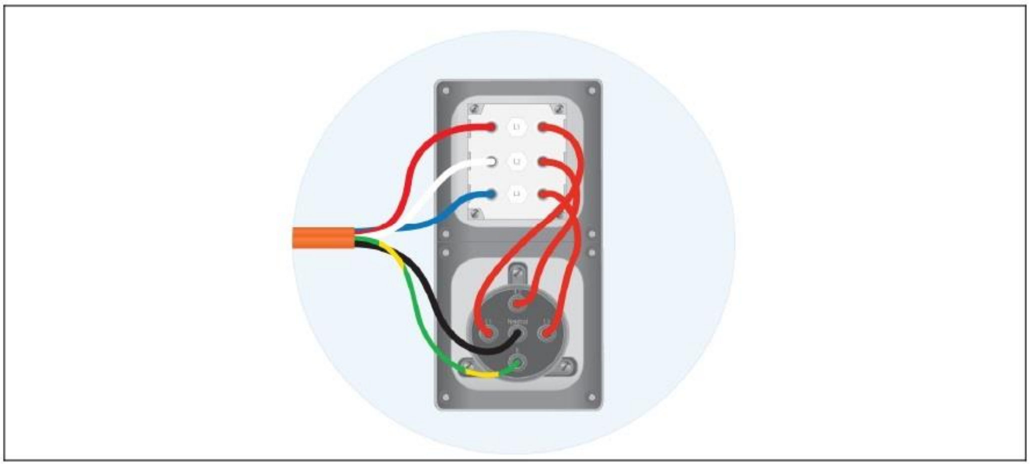
Three Phase Socket Outlets

As discussed on the previous page, three phase socket outlets are available in four and five pin models. The diagram below shows the socket configuration of a five pin outlet. A four pin outlet is essentially the same, except that there is no neutral terminal.

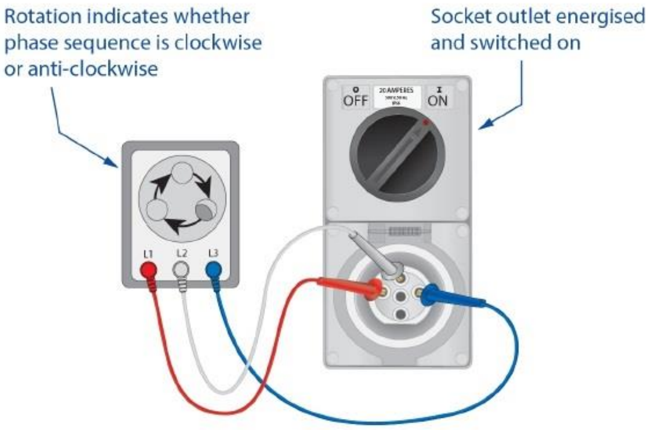


The following diagram shows the connections for a five pin three phase socket-outlet. Again, the four pin outlet is the same but without the neutral connection.

Three Phase Socket Outlet Connections



In addition to the correct polarity, it's important for three phase socket outlets to be connected with the correct *phase sequence*, i.e. the order in which the phase conductors are connected. Reversed phase sequence could cause a connected appliance to malfunction and could potentially cause damage. The following diagram shows a three phase five pin socket outlet undergoing a phase rotation test:



Introduction

Most forms of electric heating is achieved by passing current through a resistive element. The temperature can be controlled by adjusting the amount of current flowing through the element.

In this topic you will investigate the various methods of heating control, including the use of thermostats, simmerstats and electronic controls.

Methods of Control

Electrical heating controls can be divided into either manual or automatic types:

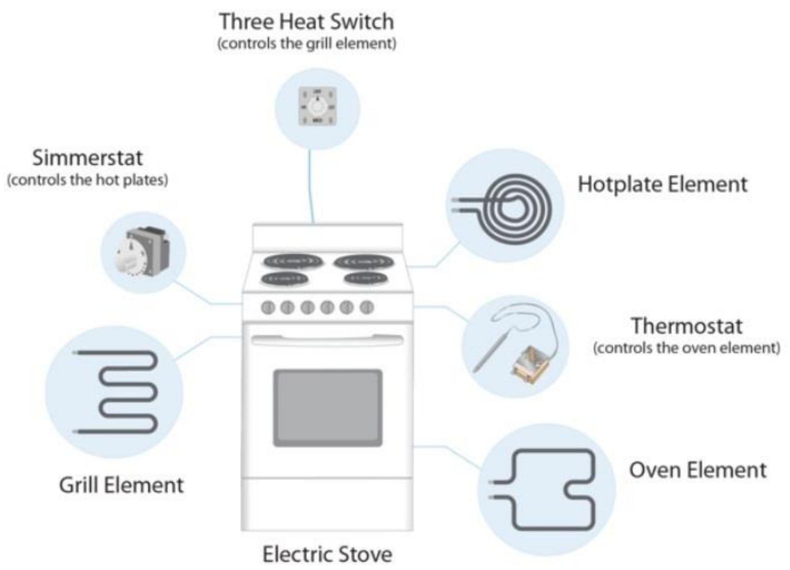
Manual control:

- ON/OFF switches
- Three heat switches

Automatic control:

- Thermostats
- Simmerstats
- Electronic/programmable types

The following diagram shows a typical example of a domestic stove that incorporates manual and automatic heating controls:

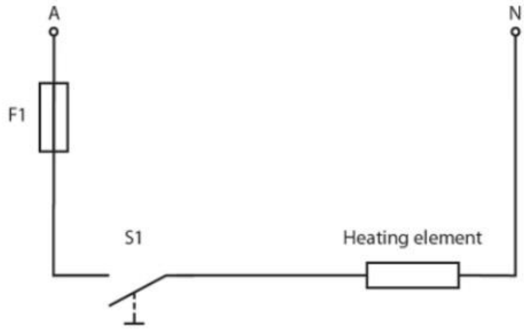


Manual Control

Manual control relies on the manual operation of a switch to control current through the heating element, and does not provide any means for monitoring its temperature.

ON/OFF Control

Manual ON/OFF control is a simple form of heat control where the heating element is controlled by a single pole single throw (SPST) switch which opens or closes the circuit to the heating element. This diagram shows a single ON/OFF switch controlling a heating element.

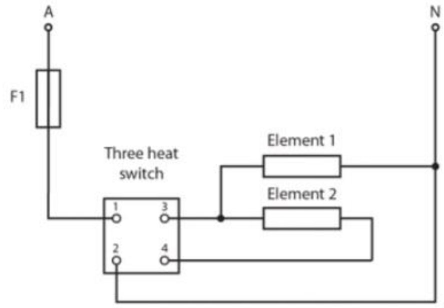
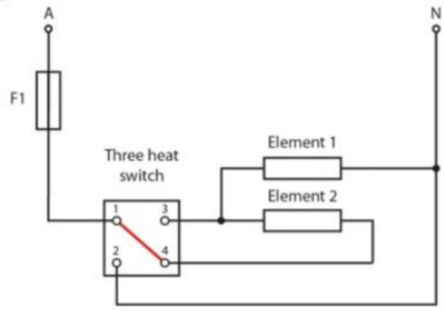
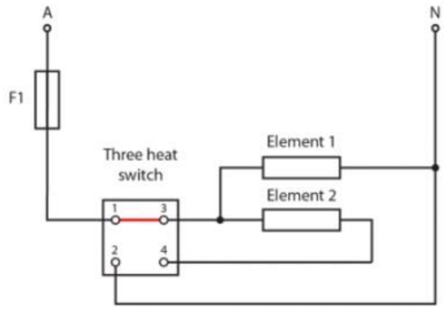


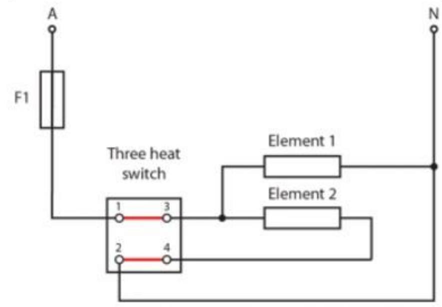
Typical applications for manual ON/OFF control includes:

- Heated towel racks.
- One-bar radiators.
- Auto rear-window demisters.

Three Heat Control

A three heat switch has four positions: *off*, *low*, *medium* and *high* which controls two heating elements. The following table shows the switch positions for a three heat switch controlling two heating elements.

Three Heat Control		
Position	**Description**	**Circuit Diagram**
OFF	In the off position, the circuit is open so neither element is connected across the supply.	
Low	In the *low* position, the two heating elements are connected in *series* across the supply. Connecting the resistive elements in series gives the highest possible resistance, the lowest current and lowest heat output.	
Medium	In the *medium* position, only one element (Element 1) is connected across the supply, reducing the resistance of the circuit, causing an increase in current and increasing the heat output.	

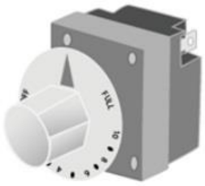
High	In the *high* position, both elements are connected in *parallel* across the supply, further reducing the resistance, increasing the current and providing the highest heat output.	

Typical applications for three heat control includes:

- Hot water urns.
- Twin element stoves.
- Twin element ovens.
- Two-bar radiant heaters.

Automatic Heating Control

Automatic controls operate by switching the element current on or off, in response to the temperature of the element. The following table lists three types of automatic heating control devices.

Automatic Heating Control		
Type	**Illustration**	**Description**
Thermostat		Basic operating principle: • An increase in temperature causes the contacts to open which disconnects the element from the supply. • A decrease in temperature causes the contracts to close which connects the element to the supply. • Typical applications: • Hot water heaters. • Electric irons. • Electric ovens. • Air-conditioning heating controls.
Simmerstat		Basic operating principle: • Consists of a cam adjustable bi-metal strip and a set of snap action contacts. • Operates on an OFF/ON cycle. • Usually has settings from 0 to 10. • The higher the setting the longer the ON time. • The lower the setting the shorter the ON time. Typical applications: • Electric hotplates (stove). • Electric fry pans.

Electronic Controls	 	Basic operating principle: • Provides very accurate heating control. • Monitors the temperature via a temperature sensor such as a thermistor, thermocouple, RTD or solid state device. • A microprocessor controls the current through the element through: o Phase control. o Zero voltage switching. Typical applications: • Industrial heating systems that require precise heating control. • Domestic/commercial air-conditioning heating control.

Check your understanding of the content by clicking the link below then undertaking the activity.

Load the Activity

Thermostats

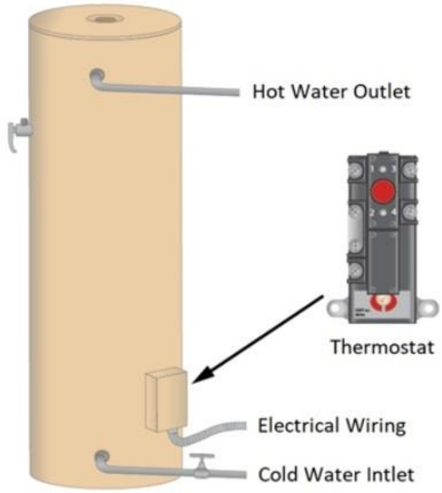
Thermostats operate by sensing the temperature of the heated material with which they are in contact (e.g. air, a liquid or a metallic surface):

When the temperature drops below the 'lower temperature limit', the thermostat switches the heating element ON.

When the temperature rises above the 'upper temperature limit', the thermostat switches the heating element OFF.

For example, in an electric water heater the thermostat is in direct contact with the hot water. As the water temperature increases above the specified maximum limit, the thermostat operates to disconnect the heating element. With the element switched off, the water temperature starts to cool down. When the water temperature drops below the specified minimum limit, the thermostat operates to reconnect the element and start the heating process again.

This process continues, maintaining the water temperature between the upper and lower temperature limits.



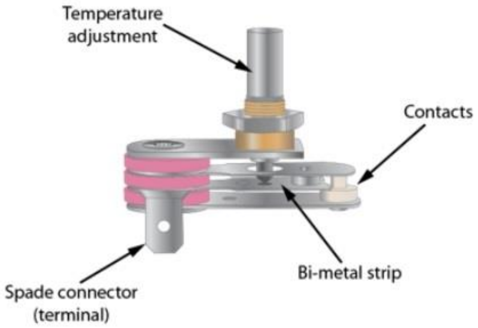
Thermostat Types

There are three basic types of thermostats:

- Bi-metal thermostats.
- Capillary type thermostats.
- Expanding tube type thermostats.

Bi-metal Thermostat

A bi-metal thermostat operates through the action of a bi-metal strip, which consists of two dissimilar metals bonded together and fixed at one end. The two dissimilar metals have different temperature coefficients and therefore expand at different rates. As each metal strip is heated, the different expansion rates cause the bi-metal strip to bend in one direction. This deformation can be utilized in a circuit to open and close contacts.
This diagram shows an example of a bi-metal type thermostat.



Applications for bi-metal strip thermostat control include:

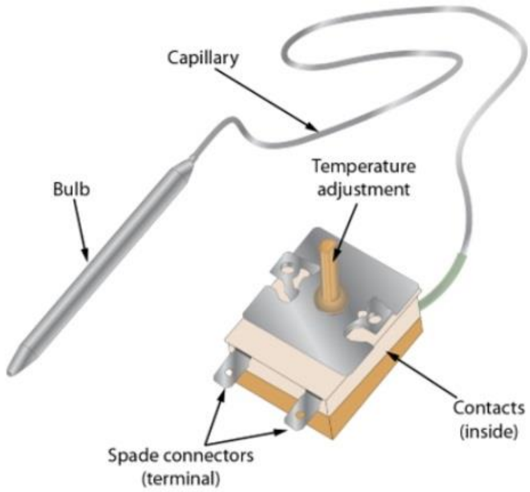
- Electric kettles.
- Electric irons.

Capillary Type Thermostat

Capillary type thermostats, also called vapour pressure type, consist of a bulb and a capillary. The bulb may contain a liquid such as mercury, which expands and contracts with changes in temperature. This expansion and contraction causes variations in pressure in the capillary which is used to make and break electrical contacts.

In situations where food is being prepared or processed, mercury can not be used as it is *poisonous*. Instead the bulb is filled with a vaporising liquid such as Ethyl Chloride, Ethyl Alcohol or Toluene which also expands and contracts with changes in temperature.

This diagram shows an example of a capillary/vapour pressure type thermostat.



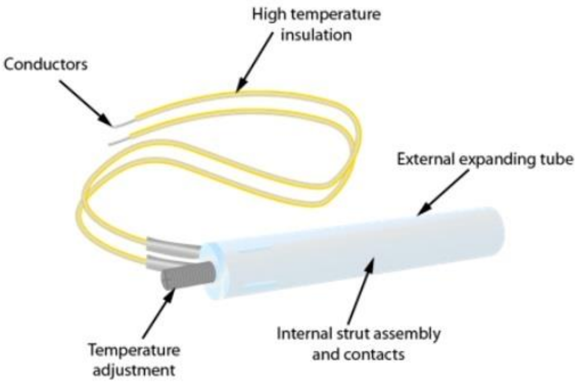
Applications for capillary type thermostat control include:

- Electric ovens.
- Storage water heaters.
- Washing machines.
- Dish washers.
- Deep fryers.
- Reptile enclosures.

Expanding Tube Type Thermostat

Expanding tube thermostats operate by having a metal outer shell with a high temperature coefficient and an inner metal strut with a low temperature coefficient. As the temperature increases, the outer shell expands at a greater rate than the inner strut assembly. A pair of electrical contacts is mounted on the inner strut assembly. The expansion and contraction makes and breaks the electrical contacts which switch the heating element off and on. An adjustable sleeve can alter the point at which contact is made to provide a means of temperature adjustment.

This diagram shows an example of an expanding tube type thermostat.



Applications for expanding tube type thermostat control include:

- Hydraulic laminating presses.
- Label adhesive applications.
- Paint drying equipment.
- Hot stamp printers.
- Vending machines.

Thermostat Sensitivity

Thermostat sensitivity is the ability of the thermostat to detect temperature change, i.e. the number of degrees required to operate the thermostat.

Thermostat Differential

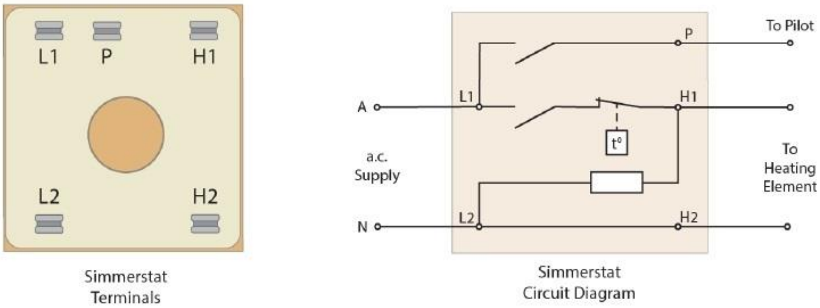
Thermostat differential is the temperature range between which the thermostat *cuts in* and *cuts out* the supply. Too small a differential can result in excessive switching causing wasted energy, but too large a differential can result in inconsistent temperatures.

Simmerstats

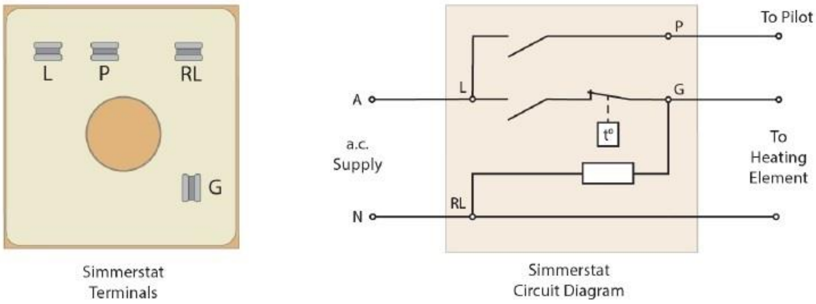
A simmerstat, also called an 'energy regulator' or 'infinite switch', operates on a fixed cycle of OFF and ON times. By varying the ratio between OFF and ON times within the cycle, the amount of energy delivered to the heating element is controlled.

Simmerstat Operation

The following diagram shows the terminal arrangement and internal wiring of a simmerstat.



There are variations to the terminals found on simmerstats. An alternate terminal arrangement that may be commonly encountered is pictured below:



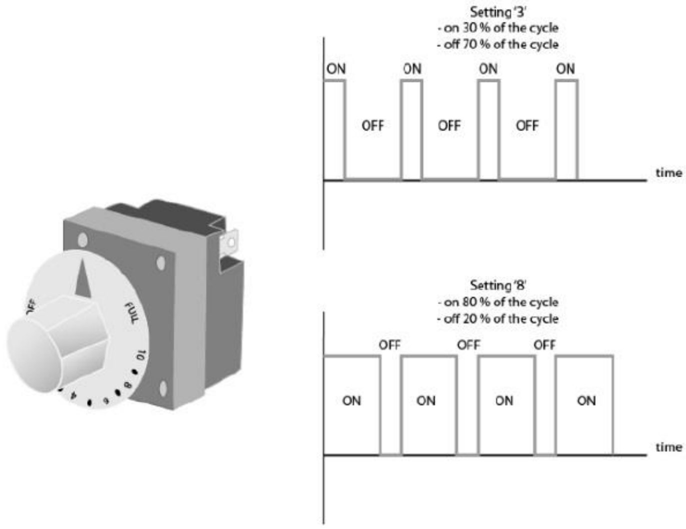
The simmerstat operates as follows:

- The two contacts of the switch mechanism close when the cam is turned to the ON position, energising the heating element, the pilot light and the small heating resistor in the simmerstat.
- The internal heating resistor warms the bimetallic contact causing it to 'snap' open, de-energising both itself and the heating element.
- The bimetallic contact cools down, closes again and the cycle begins again.
- Changing the setting alters the ratio of ON to OFF time by adjusting the pressure placed on the bimetallic contact.

Simmerstats usually have settings from 0 to 10. The higher the setting the higher the proportion of the cycle is on. For example, on the 3 setting, current might flow through the heating element for 30% of the time cycle, and is disconnected for 70% of the time cycle, whereas on the 8 setting, the element may be on for 80% of the time cycle, and off for 20%.

The longer the on time compared to the off time, the more energy is delivered to the heating element, and therefore the higher its operating temperature will be.

This diagram shows a typical simmerstat, and the ON/OFF timing diagrams for settings 3 and 8.



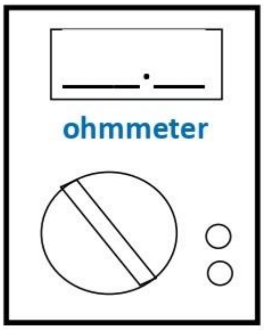
Simmerstats are not suitable for climate control, because they are unable to control a heating load to produce a desired temperature output.

Applications for simmerstat controls include:

- Electric stove hotplate.
- Electric frypan/Wok.

ELECTRICAL TRADES COLLEGE
RTO:45347

: Mandatory testing of electrical equipment



Two of the mandatory tests are to be carried out on the heating element above prior to installation. Using the meters shown, answer the following questions for each test:

Continuity test (Ohmmeter):

a. **Draw the meter connections for this test on the diagram above.**

b. The reading on this meter should be approximately? ____________ Ohms

Show your calculations here ...

Insulation resistance test (Insulation resistance tester):

c. **Draw the meter connections for this test on the diagram above.**

d. The reading on this meter should be at least? _____________

Introduction

Almost every electrical installation includes one or more lighting circuits. There are many different types of lighting arrangements and layouts, intended for a wide variety of purposes. In this topic, you will learn about general purpose lighting circuits, basic switching and control, common wiring arrangements, and associated installation requirements.

Lighting Circuits Wiring Methods

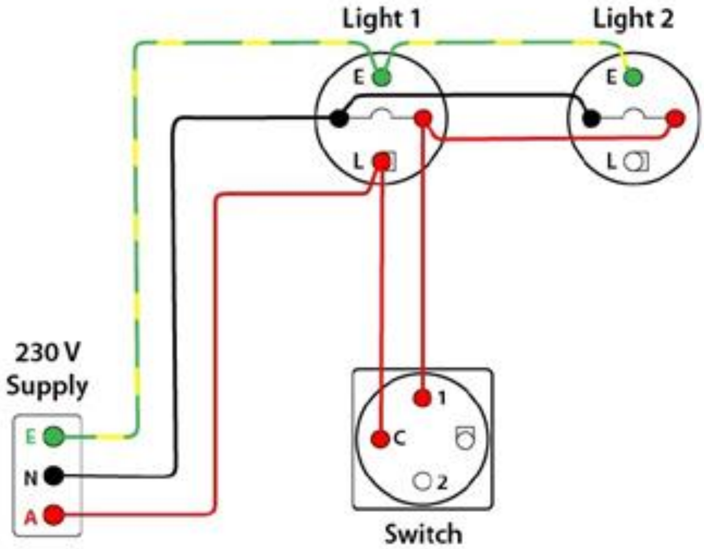
There are two common methods for wiring general purpose lighting circuits, these are:

- The 'loop at the light' method.
- The 'loop at the switch' method.

The method chosen generally depends on whether the circuit wiring is run in the roof space or the subfloor structure.

Loop at the Light

The following diagram shows the loop at the light arrangement for a single switch controlling two lighting points:



Things to note about the loop at the light arrangement are:

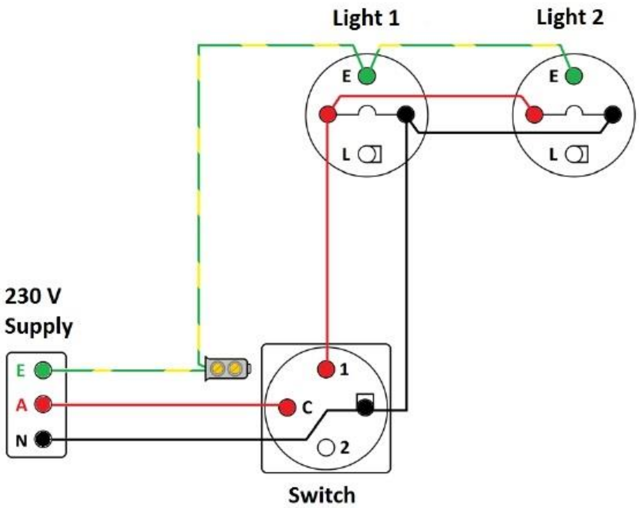
- The *un-switched active, neutral* and *earth* wires run from the switchboard to the first light fitting (i.e. Light 1).
- The *un-switched active* loops down to the switch common (C) terminal.
- A *switched active* conductor is brought back up from switch terminal 1 to the active terminal at the light fitting (Light 1).
- Light 2 is connected in parallel with Light 1.

This method of wiring is typically used when the 'feed' for the lighting circuit (i.e. the unswitched active, neutral and earth) is run from the switchboard up into the roof space.

Loop at the Switch

In some cases, it may be more convenient to run the lighting circuit feed from the switchboard down into the subfloor structure. If this is the case, it makes more sense to use the loop at the switch method of wiring.

The following diagram shows the loop at the switch arrangement for the same two lighting points, controlled by a single switch:



Things to note about the loop at the switch arrangement are::

- The *un-switched active*, *neutral* and *earth* wires are run from the switchboard to the switch.
- The *un-switched active* is connected to the switch common (C) terminal.
- The *neutral* is connected to the switch loop (L) terminal.
- The *earth* is connected at the switch, via a *double screw* connector.
- The *switched active*, *neutral* and *earth* wires are run up to the active, neutral and earth terminals of the first light fitting (i.e. Light 1).
- Light 2 is connected in parallel with Light 1.

Switching Configurations

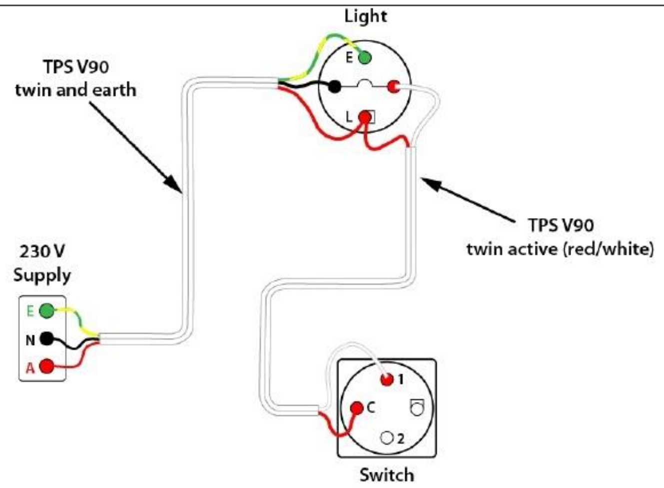
Lighting points may need to be controlled from one, two, three, or even more switches. For example, a light fitting installed over a staircase may need to be controlled from one switch at the top of the stairs and one switch at the bottom.

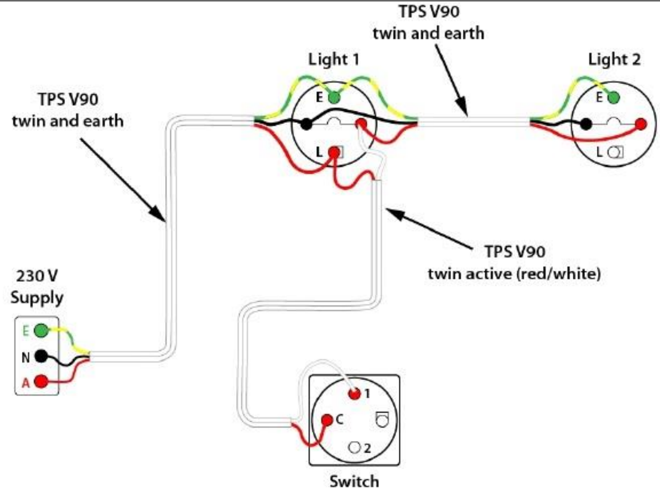
For lighting circuits, the following switching configurations can be used:

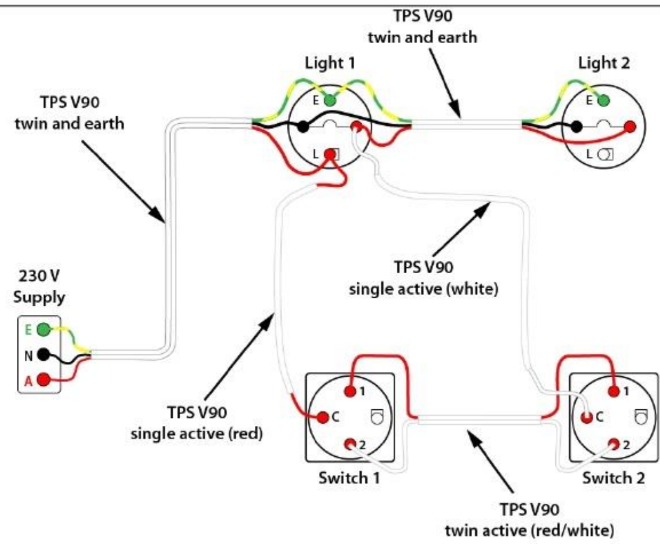
- One-way switching – controlled by a single switch.
- Two-way switching – controlled by two switches.
- Two-way intermediate switching – controlled by three or more switches.

In order to understand these switching configurations, you must first review the operation of a basic single pole double throw (SPDT) light switch – shown below:

<table>
<tr><td>One-way switching

(single light)</td><td>
</td></tr>
<tr><td>One-way switching

(two lights)</td><td>
</td></tr>
<tr><td>Two-way switching

(two lights)</td><td>
</td></tr>
</table>

Two-way Intermediate switching (two lights)