We have seen how Ohm’s law defines the ohm; similarly, we can use Watt’s law to define the watt. The term ‘watt’ comes from a Scottish engineer called James Watt (1736–1819) and is the unit used to measure the amount of electricity used by a device in which the potential difference is one volt and the current is one ampere.

Power is expressed in watts (W) and the definition of power is work done in a given time.

Power can be calculated from Watt’s law using this formula:

\[ P = \text{Current} \times \text{Voltage} \]

or

\[ P = \text{Watts} = \frac{\text{Amperes} \times \text{Volts}}{} \]

Example 2

In the circuit in Figure 5.22, the power produced within the circuit is 6 W and the current flowing is 0.5 A. Using Watt’s law, the voltage applied to the circuit is 12 V. Using Watt’s law, the current flow (I in amperes) in the circuit can be calculated:

\[ I = \frac{P}{V} = \frac{6 \text{ W}}{12 \text{ V}} = 0.5 \text{ A} \]

The above calculation shows:

\[ \begin{align*}
W &= I \times V \\
&= 0.5 \text{ A} \times 12 \text{ V} \\
&= 6 \text{ W}
\end{align*} \]

Calculation formula is: \( \text{Watts} = \frac{\text{Amperes} \times \text{Volts}}{} \)

Example 3

In the circuit in Figure 5.22, the power produced within the circuit is 6 W and the current flow (I in amperes) is 0.5 A. Using Watt’s law, the voltage applied in the circuit can be calculated:

\[ V = \frac{W}{I} = \frac{6 \text{ W}}{0.5 \text{ A}} = 12 \text{ V} \]

The above calculation in Figure 5.21 shows:

\[ \begin{align*}
W &= I \times V \\
&= 0.5 \text{ A} \times 12 \text{ V} \\
&= 6 \text{ W}
\end{align*} \]

Calculation formula is: \( \text{Watts} = \frac{\text{Amperes} \times \text{Volts}}{} \)

5.3.7 Open and short circuits

There are two types of common faults that can occur in a circuit:

- Open circuit
- Short circuit

Open circuit

When electrical current is unable to flow due to a break in the circuit, this is termed an ‘open circuit’. A switch is the most common component used to provide an intentionally open circuit. The ‘on and off’ flow of current within the circuit is controlled by the switch.

Another form of open circuit occurs when there has been a fault within the electrical circuit (see Figure 5.24).

Due to the break in the cable, the flow of current is prevented and the circuit cannot work. In Figure 5.24, an ammeter is used to measure the amount of current or amperes, also forming part of the circuit itself. In effect, the meter measures the flow rate and indicates the amount of current in the circuit. In the case of this circuit, the reading on the ammeter will be zero due to the break in the wire, which is causing an open circuit.

Figure 5.22 Calculation using Watt’s law

Figure 5.23 Calculation to find voltage using Watt’s law

Short circuit

A fuse is a short length of thin wire or metal that is designed to melt and break the circuit if the current exceeds the rated value marked on the fuse. Provided it is of the correct rating, a fuse reduces the risk of fire in the event of a short circuit.

Figure 5.24 A short circuit

Another form of open circuit occurs when there is a break in the circuit, usually as near as possible to the positive supply circuit. This will act to protect the wiring and other components as it will break or blow and cause an open circuit situation. As mentioned, an open circuit does not have current flow. This then protects the rest of the circuit and prevents a possible fire.

A number of fuses, or other forms of thermal circuit breaker, are fitted to protect the various circuits of a vehicle (Figures 5.26 and 5.27). Some electrical components require a comparatively large current, so in these cases a fuse having a high ‘amperage’ is specified. Fuses are generally fitted to the supply side of the circuit, usually as near as possible to the positive battery or supply terminal such as a switch or relay.

Figure 5.25 A short circuit

The unwanted outcome is that the full amperage or current flow from the battery going directly to earth will cause large heat build-up due to the circuit no longer containing any load device to absorb the power. This can result in the current flow becoming so high that the wiring could melt. In this event, some extra form of protection would be needed.

To protect the circuit, a fuse is normally fitted in the supply circuit. This will act to protect the wiring and other components as it will break or blow and cause an open circuit situation. As mentioned, an open circuit does not have current flow. This then protects the rest of the circuit and prevents a possible fire.

In the case of this circuit, the reading on the ammeter will be zero due to the break in the wire, which is causing an open circuit.

Figure 5.26 Early types of fuses – glass tube and ceramic
If a fuse blows, it must be replaced with the same size and type and the cause of the blow should be investigated. If the fuse blows immediately when the new fuse is placed in the fuse box, a short circuit situation should be followed up. This process involves isolating each of the components on the circuit until the fuse no longer blows.

Many fuses fitted today are of the blade type because they are slim and compact. These come in three different sizes and are colour coded with the ampere capacity written on the fuse body. The fusible rating ranges from 5A up to a maximum protection of 60A.

**J Case fuses**

The J Case fuse is a common type of fuse used in today’s vehicle electrical systems. They are used in electrical circuits that have a need for protection, rating from 30A up to a maximum of 60A.

**Bolt-down fuses (fusible links)**

Within the automotive electrical system some components will demand or generate high levels of power. In these instances, fuses need to be able to protect these circuits. These fuses are high amperage and often called ‘fusible links’. They are normally available in 40–500A. The fusible link has thicker wire acting as the fuse to allow for the higher amperage running through the circuit. Fusible links will react in the same way as normal fuses when subjected to a dead short or higher amperage current by melting the wire to create an open circuit and provide protection. Sometimes they are known as mega fuses because of their protection rating (Figure 5.29). If at any time a fusible link blows, it should be replaced and the circuit should be assessed for any faults, such as short circuits, prior to the vehicle running on the road.

**Circuit breakers**

Some circuits with a heavy draw on current, such as sunroofs or electric windows, are protected by circuit breakers. Once a certain level of current is reached, the circuit breaker will stop the current from flowing (this is called ‘tripping’) and the circuit will no longer work. These are similar in operation to the circuit breakers found in household electric systems. Circuit breakers can either reset themselves automatically once the current has returned to a safe level, or they can be reset manually.

**5.3.9 Switches**

In most conventional circuits the flow of electricity is controlled via a switch. The internal structure of the switch comprises a set of contacts; these can be either open or closed. An open contact breaks the circuit so current is unable to flow. When the switch is turned on, the contacts close, allowing the electrical current to flow through the circuit. Vehicles have many types of switches fitted that control different circuits. These include push-on/off switches, lever-operated switches, rotary switches and temperature/pressure switches.

**Push-on/off switches**

Push-on/off switches are simple in design and are frequently used to control many electrical circuits in a motor vehicle. Figure 5.30 shows a selection of different options but all are of the push-on/off type.

**Lever-operated switches**

These types of switches are conventionally used to operate items such as the indicators and wipers. This type of multi-contact switch controls a number of functions needed by the driver, depending on driver demands and external conditions. For convenience and accessibility, they are normally fitted to the top of the steering column. The switch is fitted at the bottom of the lever and by pushing the end of the lever up or down different circuits will function (Figure 5.31). Lever-operated switches often also house a multi-function unit that handles a large number of components and data across the auxiliary and lighting circuits.

**Rotary switches**

This type of switch is operated by turning the knob, which in turn moves a set of contacts at the bottom of the shaft. A good example of a rotary switch is a headlight dial (Figure 5.32). Also in Figure 5.32 you can see a different version of a rotary switch designed for adjusting the brightness of the instrumentation lighting. Rotary switches can also be used for adjusting heater fan speeds, or even as an ignition switch on the steering column.

**Temperature/pressure switches**

In modern vehicles many components are operated automatically through the use of temperature and pressure switches. These switches perform their operation without the need of input from the driver because the contacts are activated by temperature or pressure.

**Pressure-operated switches**

This type of switch would normally be located within a circuit that needs to monitor the pressure of its operating fluid. The switch contacts will be closed when the pressure of the fluid is at its lowest, but when the pressure increases to its predetermined level, the contacts will open. A pressure switch can be used to detect low refrigerant pressure in an air-conditioning system. This would then prevent the compressor being run, which would cause a great deal of damage. Many pressure-operated switches also provide a warning light, situated in the instrument cluster to warn the driver of any failure, such as low oil pressure (Figure 5.34).
5.3.10 Relays

Incorporated within most electrical circuits you will find a relay as part of the system’s control functionality. Relays come in a number of different sizes and a wide variety of current ratings and types, depending upon the circuit application (Figure 5.35a). All relays function as an electrically operated remote switch, where they use a relatively low current flow to control the operation of a circuit that has a much higher demand on current flow.

Using long wire to carry a high current can result in an unacceptable voltage drop and a subsequent reduction in current flow. This would affect the operation of the light bulbs or other electrical items. In addition, there are safety concerns when high currents pass through long pieces of wire. The current flow can generate heat in the wire and switch contacts, which could cause them to fail and even result in fire. To avoid each of these scenarios, the costs associated with using a relay have to be low to be attractive to the manufacturer and beneficial in the production of the vehicle itself. The added benefit of a less heavy wiring harness makes the use of relays cost effective.

Relay construction and operation

To understand the principle function of a relay, we need to establish how they are constructed and how the relay functions when energised. As mentioned previously, a relay is a type of switch with a very important purpose. It switches high current circuits on and off that would quickly damage a normal switch. A relay is a type of switch that carries a higher current. The use of thinner wire to act as the switch circuit and thicker wire to carry the higher current to the headlights keeps the amount of wire to a minimum, which lowers the weight of cable required for a given circuit.

When the driver switches on the headlights a low current is passed through the relay. This low current closes the relay switch allowing the main supply current to flow via the fusible link to the headlight circuit and on to the headlamp units. Using a relay enables the manufacturer to use less high-amperage cable to power the circuits, as the relays can be mounted close to the headlamp units. This reduces the chance of resistance build-up and also provides lighter wiring harnesses.

Wiring harness: the cabling routed throughout the vehicle to provide electrical power to each component. It is designed to be as light and strong as possible to ensure that no faults associated with open, short or high-resistance circuits occur.

In Figure 5.35b the relay is used to switch on the headlight circuit. The headlights have a relatively high current requirement operating at around 15–20 A. Most relays are located within a junction box for containment to reduce the amount of wiring but, if needed, the relay could be located nearer to the headlights. Reduced length of wiring required.

The relay itself can be activated by a very low current; this means that only a very thin wire is needed between the headlight switch and the relay, which in turn allows the switch to be designed for low current values. However, a thicker wire would be needed from the relay to the headlights because it’s carrying a higher current. The use of thinner wire to act as the switch circuit and thicker wire to carry the higher current to the headlights keeps the amount of wire to a minimum, which lowers the weight of cable required for a given circuit.

When the driver switches on the headlights a low current is passed through the relay. This low current closes the relay switch allowing the main supply current to flow via the fusible link to the headlight circuit and on to the headlamp units. Using a relay enables the manufacturer to use less high-amperage cable to power the circuits, as the relays can be mounted close to the headlamp units. This reduces the chance of resistance build-up and also provides lighter wiring harnesses.

When the driver switches on the headlights a low current is passed through the relay. This low current closes the relay switch allowing the main supply current to flow via the fusible link to the headlight circuit and on to the headlamp units. Using a relay enables the manufacturer to use less high-amperage cable to power the circuits, as the relays can be mounted close to the headlamp units. This reduces the chance of resistance build-up and also provides lighter wiring harnesses.

To identify the difference between the two relay standards, both manufacturers use different terminal numbering. This is normally visible on the base or outer housing of the relay.

Table 5.4 Relay standards and terminal numbering

<table>
<thead>
<tr>
<th>ISO DIN Designation</th>
<th>ISO DIN Designation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 86 Switched feed</td>
<td>1 86 Switched feed</td>
</tr>
<tr>
<td>2 85 Ground</td>
<td>2 85 Ground</td>
</tr>
<tr>
<td>3 30 Ignition or constant feed</td>
<td>3 30 Ignition or constant feed</td>
</tr>
<tr>
<td>4 87a Switched feed change over</td>
<td>4 87 Switched feed change over</td>
</tr>
<tr>
<td>5 87 Switched feed from relay to consumer</td>
<td>5 87 Switched feed from relay to consumer</td>
</tr>
</tbody>
</table>

Although we have identified two manufacturing versions, you will find that there are a number of functional versions available depending on the system that the relay is operating within. These types are known as:

- 4-pin normally open
- 4-pin normally closed
- 5-pin change over