Chapter 19 – Practical Electricity

Subject content

Content
- Electric power and energy
- Dangers of electricity
- Safe use of electricity in the home

Learning outcomes
(a) describe the use of the heating effect of electricity in appliances such as electric kettles, ovens and heaters
(b) recall and apply the relationships P = VI and E = VIt to new situations or to solve related problems
(c) calculate the cost of using electrical appliances where the energy unit is the kWh
(d) compare the use of non-renewable and renewable energy sources such as fossil fuels, nuclear energy, solar energy, wind energy and hydroelectric generation to generate electricity in terms of energy conversion efficiency, cost per kWh produced and environmental impact
(e) state the hazards of using electricity in the following situations:
  (i) damaged insulation
  (ii) overheating of cables
  (iii) damp conditions
(f) explain the use of fuses and circuit breakers in electrical circuits and of fuse ratings
(g) explain the need for earthing metal cases and for double insulation
(h) state the meaning of the terms live, neutral and earth
(i) describe the wiring in a mains plug
(j) explain why switches, fuses, and circuit breakers are wired into the live conductor

Definitions

Term	Definition	Symbol	SI unit
Power	Rate of conversion of electrical energy	P	W
Electrical energy		E	J kWh

Formulae

Ohm's Law	Power		
V = IR	**P = VI**	**$P = I^2R$** (when I is constant)	**$P = V^2/R$** (when V is constant)
Electrical energy			
E = Pt	**E = (VI)t**	**$E = (I^2R)t$**	**$E = (V^2R)t$**

19.1 Uses of Electricity

Use	Energy	Description	Application
1. **Heating**	electrical → thermal	Nichrome (heating element): alloy of nickel + chromium ● high resistivity → heat up rapidly ● high mp ● X oxidise easily at high temp	● Electric kettle ● Electric iron ● Electric radiator ● Electric hotplate
2. **Lighting**	electrical → light	Tungsten (wire): thin, coiled ● high resistivity ● high mp ● filled with inert gas (X burnt)	● Filament lamp
3. **Power motors**	electrical → mechanical		● Motors

19.2 Measuring Electrical Energy

19.3 Sources of Electrical Energy

Type	Renewable			Non-renewable	
Source	**Solar power**	**Hydroelectric power**	**Wind power**	**Nuclear power**	**Fossil fuel**
Energy conversion	Light energy → electrical energy	GPE → electrical energy	KE → electrical energy	Nuclear energy → thermal energy → electrical energy	Chemical PE → thermal energy → electrical energy
Efficiency	High ● daylight + minimal cloud cover ● excess energy: stored / fed back to power grid	Highest ● water flow is concentrated + easily controlled	Varies ● depend on wind direction + speed	High ● small amt of uranium generate large qty of energy	High ● most countries: well-established tech + energy distribution systems
Cost	High ● manufacture solar panel ● cost of fuel (sunlight) is free	High ● construct dam + power plant ● maintenance (silt build up behind dam & block water flow)	Low ● tech improve ● maintainence	High ● dispose radioactive waste	Rising ● declining supply ● rising demand for energy
Envt impact	Clean energy ● large area cleared to install solar panel	Clean energy ● building dam disrupt ecosystem	Clean energy ● spinning turbines → noise pollution ● large open area	X clean energy ● waste from uranium mining contaminate ground water + surface water sources	X clean energy ● extensive mining: disrupt ecosystem ● burning: air pollution

19.4 Dangers of Electricity

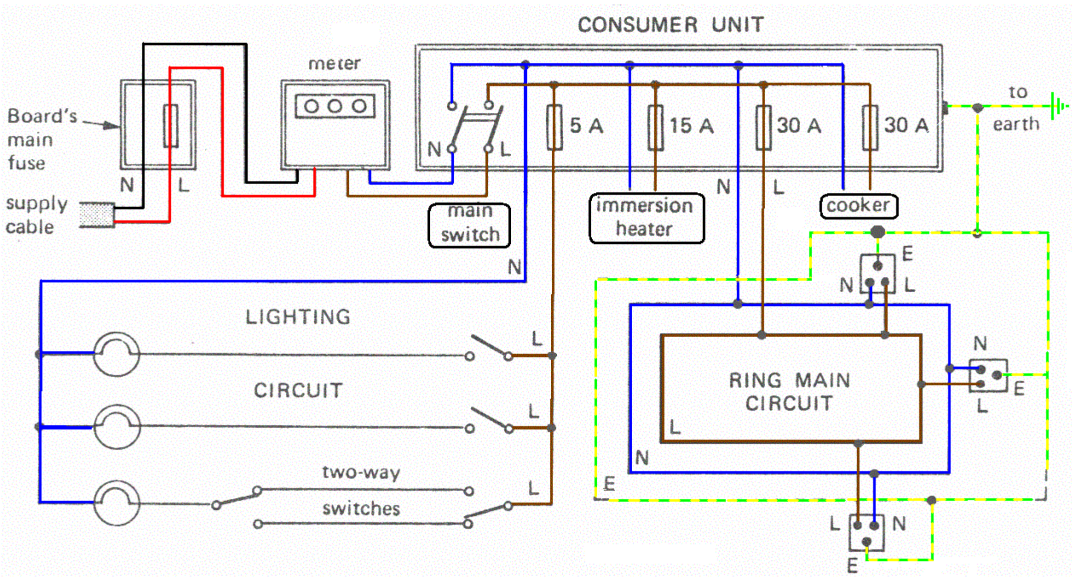
Major dangers / hazards

1. **Electrical shock**
2. **Electrical fire**

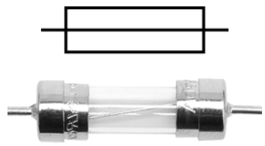
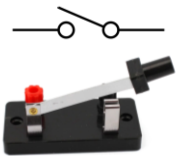
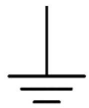
Causes	**Electrical fire**	**Electrical shock**
Damaged insulation ● replace cable	Exposed L touch N directly → short circuit ● current become very large ● enough heat to start fire	Touch exposed L ● current flow from L → body → ground
Damp environments ● X operate appliance with wet hands ● keep switches / plugs / sockets / connecting wires in dry condition		(Conducting wires exposed / damaged insulation) Wet skin → resistance fall to few hundred ohms ● water provide conducting path for current ● large current may cause death
Overloaded power socket (parallel) ● distribute connection of appliances across multiple power outlets	● Total resistance: reduced ● Total current flow through main electric cable: too large → <u>overheating</u> ● Damage wire insulation → fire	
Use of inappropriate wires ● fit wires of suitable thickness to match correct power rating of appliance	High power electrical appliances: draw large current ● large current flow + high resistance (thin wire) → <u>overheating</u> ● Damage wire insulation → fire	
Supply excessive voltage ● supply correct voltage based on power rating of appliance	● High voltage → larger current flow → <u>overheating</u> ● Damage wire insulation → fire	

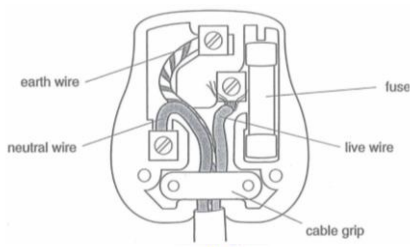
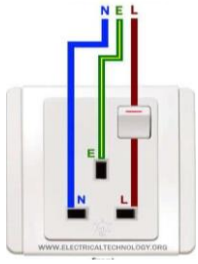
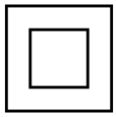
19.5 Safety Features in Home Circuits

Typical home circuitry

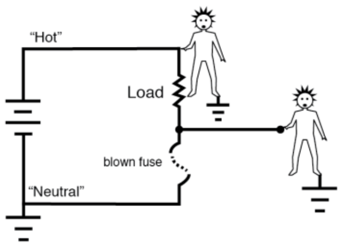
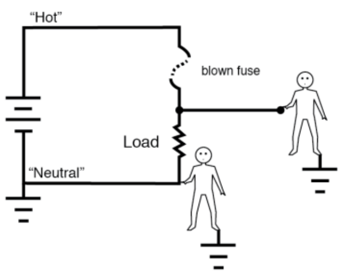


Safety features

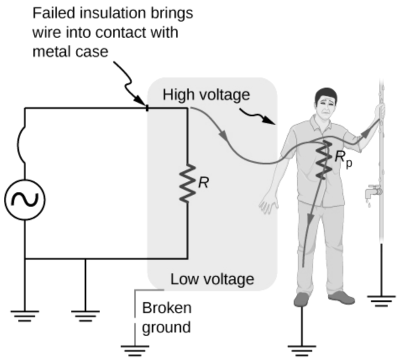
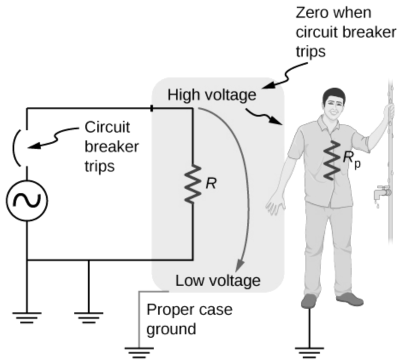
Feature	Explanation	Figure
1. **Circuit breaker**	• Trip when excessive current flow through → break circuit → isolate appliance from high voltage mains supply • Connected to **L wire** • Can be reset easily	
2. **Fuse**	• Thin wire with low mp • Excessive current (current flow exceed rating): melt → break circuit → isolate appliance from high voltage mains power supply → X overheating → protect circuit • Connected to **L wire** • Fuse rating: slightly higher than current drawn by appliance	
3. **Switch**	• Turn on/off electrical appliance • Open → disconnect appliance from high voltage mains power supply • Connected to **L wire**	
4. **Earth wire**	• Connects **metal casing** to ground • L wire touch metal casing → large current flow to Earth → blow fuse • Metal case X 'live' → X electric shock	

5. **Three-pin plug**	1) Fuse 2) Longer earth plug ● <u>make contact</u> with earth point in power socket before L and N when inserting plug → ensure personal safety before L and N connected ● <u>break contact</u> with earth point in power socket after L and N when removing plug → ensure personal safety until L and N disconnected ● Larger: provide <u>less resistance</u> to current flow → more fault current passed to ground during fault	 
6. **Double insulation**	<u>Plastic</u> layer 1) electric cable ⇔ internal component 2) internal component ⇔ external casing	

Fuse

Usage		Explanation	Figure
✗	placed in N wire	● Fuse blown / switch open: circuit open → no current flow ● L wire still at <u>high potential</u> (240 V) ● Touch exposed L wire: p.d. → <u>current flow</u> through body to earth → electric shock	 *voltage present between either side of load and ground!*
✓	placed in L wire	● Fuse blown / switch open: circuit open → no current flow ● L wire + appliance disconnected from high potential → <u>zero potential</u> (0 V) ● Touch exposed L wire: no p.d. → <u>X current flow</u> through body to earth → X electric shock	 *no voltage between either side of load and ground*

Earth wire

Usage		Explanation	Figure
✗	Not connected to metal casing	• Electrical fault: L wire exposed + touch metal casing → short circuit • Casing becomes live (240 V) • Touch metal casing: p.d. → current flow through body to earth → electric shock	
✓	Connected to metal casing	• Electrical fault: L wire exposed + touch metal casing → short circuit • Earth wire divert excessive current into earth • Large amt of current flow to earth → fuse melt → circuit open • Touch metal casing: X p.d. → X current flow through body to earth → X electric shock	

Typical questions

Multiple choice questions

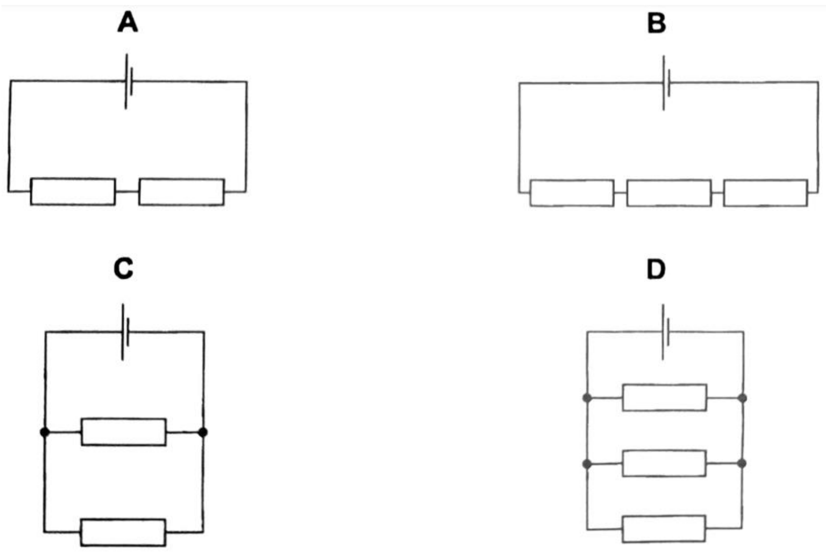
1 An electrical cable contains three wires: live, neutral and earth. The cable is correctly wired to a plug which contains a 3 A fuse. The insulation becomes damaged and bare metal wires show. Five possible events can occur.

- A person touches the earth wire.
- A person touches the neutral wire.
- A person touches the live wire.
- The live wire touches the neutral wire.
- The live wire touches the earth wire.

How many of these five events cause the fuse in the plug to blow? (2011 P1 Q33)

A 1
B 2
C 3
D 4

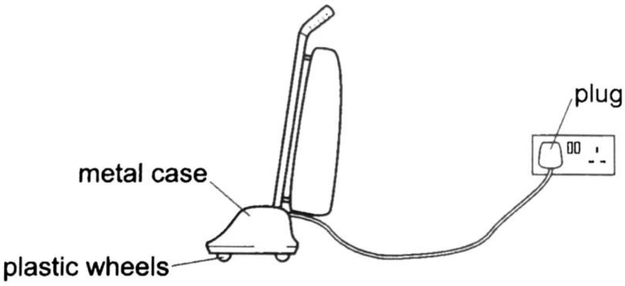
2 The circuits show a cell joined to different combinations of identical resistors.
In which circuit is electrical energy transformed at the greatest rate? (2012 P1 Q36)



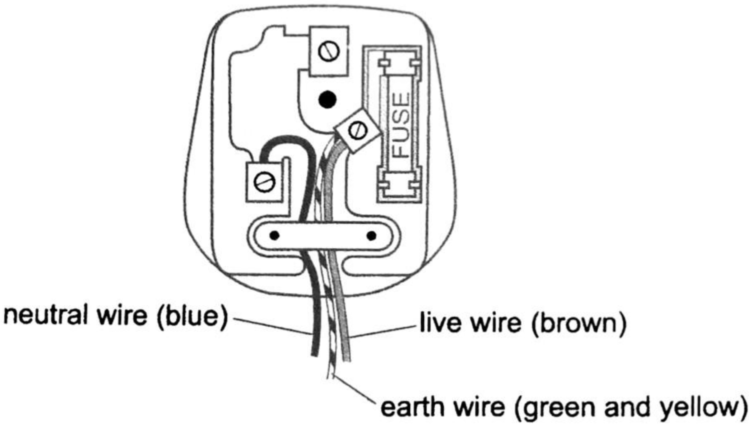
3 In a mains circuit, the switch of an electric heater is always wired into the live conductor.
This is because, if the switch is wired into the neutral conductor, (2013 P1 Q35)

the circuit in the heater remains live when the switch is open.
the fuse blows if the current is less than the fuse rating.
the heater continues to operate when the switch is open.
the heater does not operate when the switch is closed.

4 The diagram shows an old vacuum cleaner with a metal case and plastic wheels.



The plug of the vacuum cleaner is incorrectly wired, as shown.



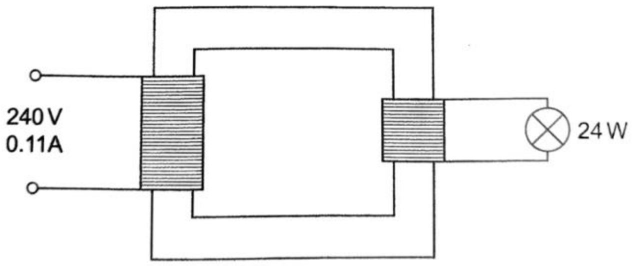
What is the effect of using the plug wired this way? (2014 P1 Q32 / 2019 P1 Q34)

The fuse in the plug blows.
The metal case becomes live.
The vacuum cleaner catches fire.
The vacuum cleaner does not work.

5 An old spotlight is found and a new filament lamp with a power rating 500 W is inserted.
When the spotlight is plugged into the mains and switched on, it does not light up.
What is a possible cause of this? (2016 P1 Q34)

The earth wire in the plug is disconnected.
The fuse in the circuit has too high a rating.
The neutral wire in the plug is disconnected.
The spotlight is doubly insulated.

6 A transformer connected to a 240 V mains supply is used to light a 24 W lamp.



The input current to the transformer is 0.11 A and the input voltage is 240 V. The useful output power of the transformer is 24 W.
What is the efficiency of the transformer? (2017 P1 Q13)

0.10
0.91
1.1
2.6

7 Which statement explains why a bird can stand on an overhead high-voltage transmission line without suffering any harm? (2018 P1 Q33)

Both feet are at the same voltage.
Its body has a very high resistance.
Its feet are very good insulators.
The spaces between its feathers act as insulators.

Structured questions

1 Fig. 1.1 below shows two bulbs are connected in parallel with a 250 V power supply. The rated power is indicated beside each bulb.

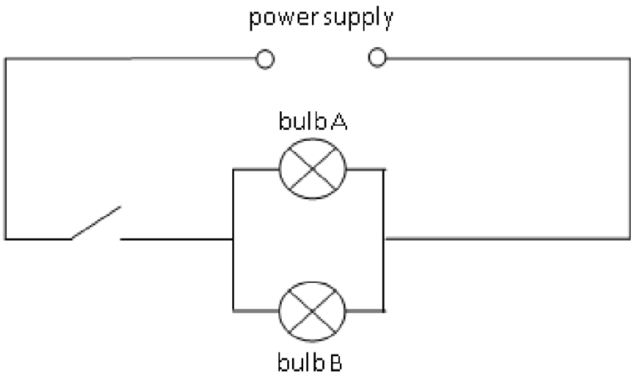


Fig. 1.1

Bulb A is rated 250 V, 150 W. Bulb B is rated 250 V, 90 W.

(a) Will the brightness of the bulbs change when an additional bulb is added in parallel to the existing bulbs?

No. Voltage across the bulbs A and B will still be the same. With the same resistance for each bulb, using $P = V^2/R$, the working power will remain the same.

Fig. 1.2 shows the same bulbs connected in series with a 250 V power supply.

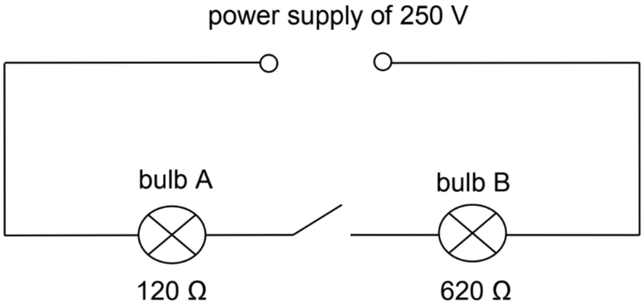


Fig. 1.2

When connected in this circuit, the resistance of A is 120 Ω and the resistance of B is 620 Ω.

(b) Which of these two bulbs will be brighter when the switch is closed?

Bulb B.

The same current flows through A and B. Using $P = I^2R$, bulb B with a higher resistance will have a larger power.

(c) Explain why the resistance of A and B are lower when connected in this circuit (compared to Fig. 1.1).

The total resistance of circuit in Fig. 1.2 is higher.

The current flowing through each bulb is lower.

Both bulbs will be at lower temperature, hence resistance of each bulb is lower.

(d) Will the brightness of the bulbs change when an additional bulb is added in series to the existing bulbs?

Yes.

Current flowing in existing bulbs decreases as the total resistance in the circuit is increased. Resistance of each bulb would be lower due to it being at a lower temperature. Using $P = I^2R$, working power will be reduced for each of the bulbs when an additional bulb is added in series.

2 The cost of a unit (kWh) of electricity is 22 cents. The table below shows the daily usage of various home appliances.

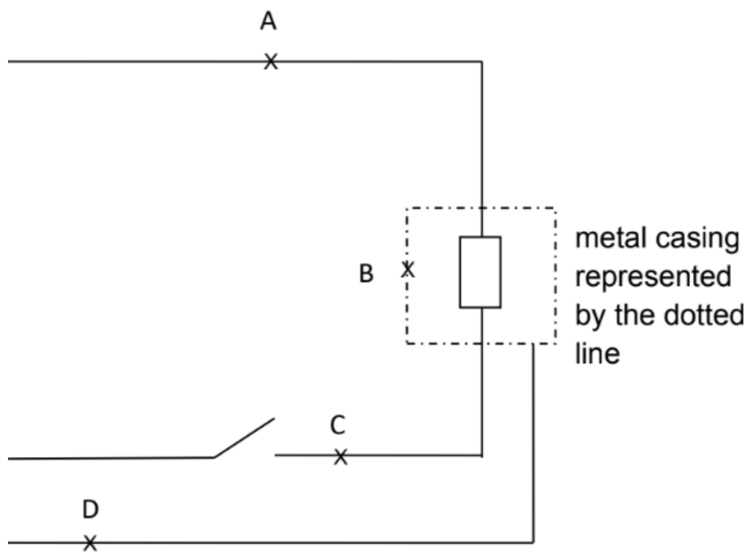
Appliance	**Power rating**	**Time used per day**

Water heater	3 kW	45 mins
Rice cooker	800 W	2 hours
Electric kettle	1.5 kW	30 mins
Television	200 W	4 hours

Calculate the cost of electricity usage at the end of the 30-day month.

Total energy used per day = 3(0.75) + 0.8(2) + 1.5(0.5) + 0.2(4) = 5.4 kWh
Total energy for a month = 30 x 5.4 = 162 kWh
Cost of electricity for a month = 162 x 0.22 = **$ 35.64**

3 At which position (A, B, C or D) should the fuse be placed in the circuit below? Explain your answer.



Neither. It should be placed before the switch.
When there is excessive current and the fuse blows, the appliance and the switch will be disconnected from the high voltage mains supply and will be at 0 V.

4 Explain how in an appliance,
(a) a fuse prevents damage or injury to users when a fault occurs in the appliance.

Fault	When the current flowing into the appliance exceeds the fuse rating,

Function + injury	the fuse will melt and the circuit will be opened. This disconnects the appliance from the high voltage mains supply. This prevents the appliance from damage due to heating up when excessive current flows through.

(b) an earth wire prevents damage or injury to users when a fault occurs in the appliance.

Fault	When the live wire touches the metal casing, the metal casing will be ‘live’ (at high voltage).
Function + injury	The earth wire helps to conduct current to the ground instead of through the user’s body, thus preventing electrocution.
Fuse blow	The current is excessive (as it is a short circuit). This makes the fuse blow and disconnects the appliance from the high voltage mains supply so that the appliance is at 0 V.

5 The figure below shows the electrical wiring in a table lamp.

(2012 P2B Q11 EITHER)

(a) Explain why wire A rather than wire B is connected to the live terminal in the plug. [2]

The switch is connected to wire A. Thus, if wire A is connected to the live terminal, it ensures that the table lamp is isolated from the live wire when the switch is off.

If wire B is connected to the live terminal, the table lamp will still be charged to ‘live’ even when the switch is off.

(b) The cable is connected to a plug which contains a fuse. Explain the purpose and the action of the fuse. [3]

The fuse prevents the excessive flow of current in the table lamp.

When the current in the circuit exceeds the fuse rating, the fuse (which is made of a thin wire), melts and breaks the circuit, thus preventing the appliance from overheating.

(c) Wire A becomes loose and touches the metal case. Explain why a person who later touches the case feels no shock and is not harmed. [1]

Wire C, the earth wire, is connected to the metal case. Thus when wire A touches the metal casing, the current flows through wire C, which has a lower resistance, rather than through the person who touches the metal casing.

As the earth wire has a lower resistance, a large current flows through, which melts the fuse and breaks the circuit.

(d) The lamp is marked “230 V, 100 W”.

(i) Calculate the resistance of the lamp when it is working normally. [2]

$P = V^2/R$
$R = V^2/P = 230^2/100 =$ **<u>529 Ω</u>**

(ii) A second lamp is marked “230 V, 60 W”.
Calculate the ratio of the resistance of the first lamp to the resistance of the second lamp when they are working normally. [1]

METHOD 1:
For the second lamp,
R = V2/P = 2302/60 = 882 Ω
Ratio of resistance = 529 : 882 = **<u>3 : 5</u>**

METHOD 2:
From P = V2/R, P is inversely proportional to resistance.

$$\frac{P_1}{P_2} = \frac{R_2}{R_1}$$

$$\frac{R_1}{R_2} = \frac{P_2}{P_1} = 60 / 100 = 3 / 5$$

Ratio of resistance = **<u>3 : 5</u>**

(e) The second lamp is doubly insulated and there is no wire connected to the case.
Explain why this lamp is safe to use. [1]

The casing of the second lamp is made of an insulator.

Thus, even if the live wire breaks and touches the casing, no current will be able to flow in the casing.

Hence even if a person touches it, he will not get an electric shock.

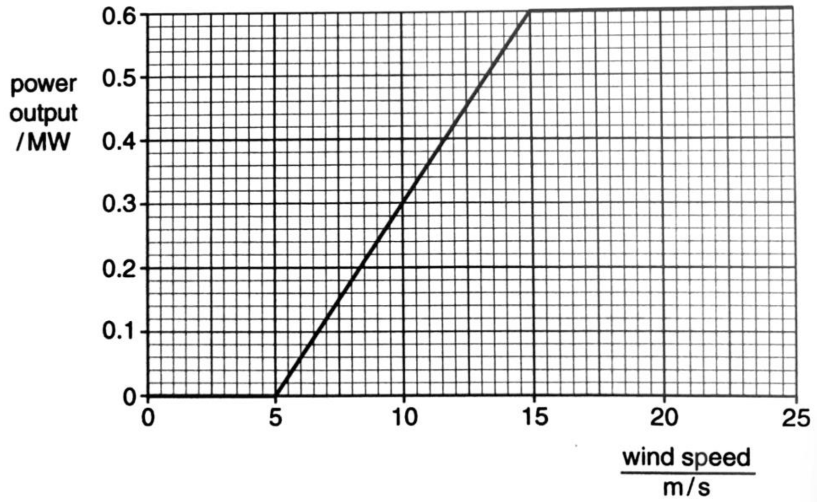
6 A wind turbine uses a renewable energy source to generate electricity. (2014 P2B Q9)

(a) State one disadvantage of using wind turbines to produce a high proportion of the electricity in Singapore. [1]

- Singapore has many high-rise buildings which impede the free-flow of air/wind to the turbines.
- In addition, to generate a high proportion of electricity, a large land area is needed to house the wind turbines, which is not possible in land scarce Singapore.

- Lastly, as the strength of the wind is not constant and cannot be easily stored, the power grid would still need to supplement the electricity supply with electricity from other sources (e.g. coal power stations).

(b) The figure below shows how the power output of a wind turbine varies with wind speed.



(i) Using the figure above, describe how the power output varies with the wind speed. [3]

- When the wind speed is from 0 to 5 m/s, there is no power output from the wind turbine.
- When the wind speed is from 5 to 15 m/s, the power output increases constantly from 0 to 0.6 MW.
- When the wind speed is greater than 15 m/s, the power output remains constant at 0.6 MW.

(ii) The wind speed is recorded at one-minute intervals, as shown in the table below. Use the data in the figure and table above to estimate the total energy produced in the ten-minute interval. Give your answer in joules. [3]

time / min	wind speed / m/s	power output / MW	energy generated in 1 minute / J
0	2	**0**	**0**
1	3	**0**	**0**
2	16	**0.6**	**3.6×10^7**
3	16	**0.6**	**3.6×10^7**
4	0	**0**	**0**
5	0	**0**	**0**

6	20	**0.6**	**3.6×10^7**
7	22	**0.6**	**3.6×10^7**
8	10	**0.3**	**1.8×10^7**
9	10	**0.3**	**1.8×10^7**
Total energy generated			**1.8×10^8**

(iii) Explain why your answer to **(ii)** is only an estimate. [1]

As the wind speed is not constant in the minute following the measurement, the power output would not be constant, affecting the amount of energy generated.

(c) A wind turbine produces an alternating current of 600 V. Electric cables connect the wind turbine to houses some distance away.
Energy is wasted within the cables.
State and explain one method to reduce the amount of energy that is wasted. [2]

METHOD 1:

Use transformers to step up the voltage (to a few tens of thousands of volts) in the transmission cables, and then step down the voltage for consumption in the houses. By stepping up the voltage in the transmission cables, the current is reduced, thus reducing the amount of energy wasted in the transmission cables, bearing in mind that $P_{loss} = I^2R$.

METHOD 2:

Use thicker wires for transmission, as thicker wires have a lower resistance. By having a lower resistance, less energy is lost as heat in the wires.

7 A restaurant uses electrical appliances connected to mains sockets in the kitchen and lamps connected to a lightning circuit. (2016 P2B Q11 EITHER)

(a) Describe **two** potential hazards of using electricity from a mains socket. [2]

1) Overheating due to overloading of sockets, possibly resulting in a fire.
2) Electrical shock due to touching mains supply with wet hands.

(b) There are 35 lamps at various places in the restaurant. The table below shows details of the lamps used in the restaurant.

Position of lamps	Number of lamps	Power of each lamps / W
dining area	26	12

kitchen	5	40
entrance	4	18

In the lightning circuit, all the lamps are connected in parallel to each other and to the mains supply. The voltage of the mains supply is 230 V.

(i) Calculate the total current in the lightning circuit when all the lamps are switched on. [3]

Total current
= (26 × 12/230) + (5 × 40/230) + (4 × 18/230)
= **2.54 A**

(ii) Suggest a suitable rating for the fuse in the lighting circuit. [1]

Suitable fuse = **3 A**

(c) The maximum current in the mains cable to the restaurant.

(i) The power loss in one section of the cable must be less than 5.0 W.
Calculate the maximum resistance of this section of the mains cable. [2]

$P = I^2R$
$R = P/I^2 = 5.0/65^2 =$ **0.00118 Ω**

(ii) Different sections of the mains cable have different lengths and different cross-sectional areas. The current is the same in all the sections.

1. Same sections have equal cross-sectional areas but different lengths.
State the relationship between the power P lost in each of these sections and the length ***l*** of the section. [1]

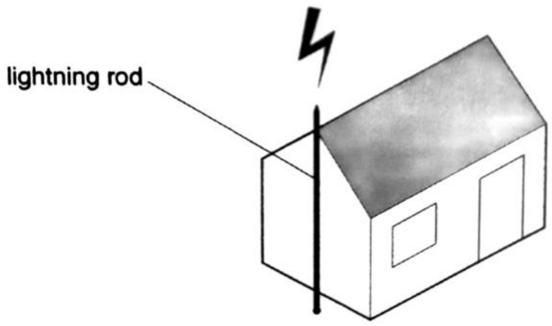
Resistance is proportional to length, and power loss is proportional to resistance, so power loss is proportional to length.

2. Other sections have equal lengths but different cross-sectional areas.
State the relationship between the power P lost in each of these sections and the cross-sectional area A of the section. [1]

Resistance is inversely proportional to cross-sectional area, and power loss is proportional to resistance,

so power loss is inversely proportional to cross-sectional area.

8 During a thunderstorm, lightning strikes at the lightning rod at the side of the house shown in the figure below.



The lightning rod is made of metal, with one end buried in the ground. Charge from lightning strikes passes into the ground and the lightning rod heats up. (2019 P2B Q9b,c)

(a) During the major part of a lightning strike, there is a current in the lightning rod of 30000 A for a time of 12 ms.

(i) Show that the thermal energy E produced in the lightning rod during this time is given by the equation

$E = 11 \times 10^6 \times R$

where R is the resistance of the lightning rod in Ω and the value of E is in J. [2]

$E = Pt$ and $P = I^2R$

$E = (I^2R)(t) = 30000^2 \times (12 \times 10^{-3}) \times R$

$= 11 \times 10^6 \times R$

(ii) The thermal energy produced in the lightning rod causes a rise in temperature of the rod. The lightning rod has length 10 m, cross-sectional area 2.5 x 10–5 m2 and is made of copper.

Using the equation in (a)(i) and data from the Table, calculate the rise in temperature of the rod during the 12 ms.

density of copper = 9000 kg/m^3

specific heat capacity of copper = 390 J/(kg °C)

From Table, resistance $R = 6.8 \times 10^{-3}$ Ω

$E = 11 \times 10^6 \times (6.8 \times 10^{-3}) = 74800$ J

$Q = mc\,\triangle\theta$

$$\triangle\theta = \frac{Q}{mc} = \frac{74800}{[(2.5 \times 10^{-5})(10)(9000)](390)} = \underline{\mathbf{85.24°C}}$$

(iii) A manufacturer considers using iron instead of copper for the lightning rod.

The Table shows data for identical lightning rods, made from either copper or iron.

Table

	resistance of rod / Ω	melting point / °C
copper rod	0.017	1100
iron rod	0.096	1500

The specific heat capacity of the iron and copper rods are similar.
The manufacturer considers a lightning strike in each rod that lasts for the same time and has the same high value of current.
Based on the manufacturer's consideration, explain why the iron rod is more likely to melt during the lightning strike. [2]

The resistance of iron is more than 5 times the resistance of copper.

Based on the equation from (b)(i), the amount of thermal energy would be more than 5 times as much, which would lead to more than a 5 times increase in temperature of the iron. However, the melting point of iron is only slightly higher than copper, hence it is more likely the iron would melt.

(b) Describe the difference between the action of a fuse and the action of a copper lightning rod. [1]

A fuse prevents excessive current, as it melts when there is too much current;

a copper lightning rod directs excess electrical charges safely to the ground.