AS Level Physics

Chapter 7 – Electricity

7.4.2 Power

Worked Examples

Power

Exam Style Question 1

A gardener installs a solar powered fountain in a sunny part of his garden. He has the following data about the solar panel from the manufacturer.

Under best conditions:

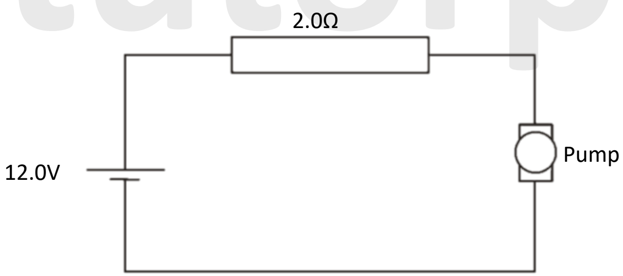
- Voltage across terminals $12.0\ V$
- Power available $5.9\ W$

The solar panel provides power to a water pump.

(a) (i) Calculate the maximum current in the pump. Assume that the resistance of the connecting cable is negligible.

(ii) Show that the electrical resistance of the pump is about $24\ \Omega$.

(b) He decides to install another identical fountain in a shady area of the garden. He has to place the solar panel some distance away from the pump so that it is in the sunlight. He then uses a much longer connecting cable. The connecting cable to this pump has a total resistance of $2.0\ \Omega$. The circuit is equivalent to that shown below.



Calculate

(i) the current in this circuit,

(ii) The power available to the pump.

(c) State one way in which the power available to the pump in the shady area could be improved. The positions of solar panel and fountain cannot be changed.

Power

Exam Style Question 1

(a)(i) Calculate the maximum current in the pump. Assume that the resistance of the connecting cable is negligible.

Use $P = IV$ and rearrange for I:

$$I = \frac{P}{V} = \frac{5.9\ W}{12.0\ V} = 0.491666\ldots A$$
$$I = 0.49\ A$$

(ii) Show that the electrical resistance of the pump is about $24\ \Omega$.

Use $V = IR$ and rearrange it for R:

$$R = \frac{V}{I} = \frac{12\ V}{0.49\ A} = 24.4897\ldots \Omega$$
$$R = 24.5\ \Omega$$

(b) (i) Calculate the current in this circuit,

Use $V = IR$ and rearrange for I but use the correct resistance.

Because we are calculating the current for this circuit we need the total resistance which includes the resistor plus the pump.

$$I = \frac{V}{R} = \frac{12\ V}{(24.5\ \Omega + 2.0\Omega)} = 0.452830\ldots A$$
$$I = 0.45\ A$$

(b) (ii) The power available to the pump.

Use $P = I^2R$

$$P = (0.45\ A)^2(24.5\ \Omega) = 4.96125\ W$$
$$P = 5.0\ W$$

(c) State one way in which the power available to the pump in the shady area could be improved. The positions of solar panel and fountain cannot be changed.

Lower the resistance in the wire by using a thicker wire or use more solar panels.

Power

Exam Style Question 2

The maximum power input to a domestic fan heater is $2.6\ kW$ when connected to the $230\ V$ mains supply. The electric circuit of the fan heater consists of two heating elements (resistors) rated at $1.5\ kW$ and $1.0\ kW$, a motor rated at $100\ W$ and three switches.

ai) Show that the resistance of the $1.5\ kW$ heating element is about $35\ \Omega$.

aii) The $1.5\ kW$ heating element is made from a wire of cross-sectional area $7.8\ \times\ 10^{-8}\ m^2$ and resistivity $1.1\ \times\ 10^{-6}\ \Omega\ m$. Calculate the length of the wire.

b) With only the first switch closed, the fan rotates; closing the second switch gives the heater an output of $1.5\ kW$ and closing the third switch increases the output to $2.5\ kW$. The elements will not heat up unless the fan is switched on. The heater cannot give an output of $1.0\ kW$.

Complete the circuit diagram of Fig. 1.1 to show the fan, the heating elements and the switches connected so that the heater will work as described. Label the switches and the elements.

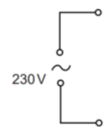


Fig. 1.1

c) Both heating elements are made of wire of the same resistivity and length.

i) Explain, without calculation, why the diameter d of the $1.0\ kW$ heater wire must be less than the diameter D of the $1.5\ kW$ heater wire, designed for use with a $230\ V$ supply.

ii) Show that d is approximately equal to $0.8\ D$.

d) Circle the correct fuse for the plug of this appliance from the values below.

3A 5A 13A

Justify your choice.

ei) Define the kilowatt-hour

eii) Calculate, to the nearest penny, the cost of using the heater for $4.0\ hours$ with only one of the heating elements switched on. The cost of $1\ kWh$ is $18\ p$.

Power

Exam Style Question 2

ai) Show that the resistance of the $1.5\ kW$ heating element is about $35\ \Omega$.

Use $P = \frac{V^2}{R}$ and rearrange for resistance

$$R = \frac{V^2}{P} = \frac{(230\ V)^2}{1.5\ kW} = \frac{(230\ V)^2}{1500\ W}$$

$$R = 35.26666667\ \Omega$$

Therefore the resistance of the $1.5\ kW$ heating element is about $35\ \Omega$.

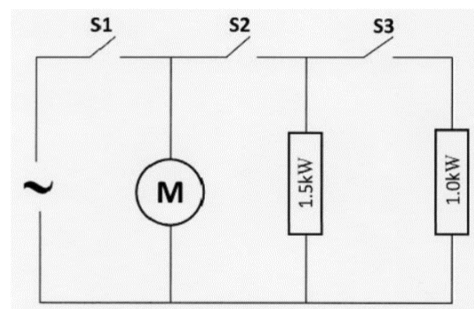
aii) Calculate the length of the wire.

Use $R = \frac{\rho L}{A}$ and rearrange it for L

$$L = \frac{RA}{\rho} = \frac{(35\ \Omega)(7.8 \times 10^{-8}\ m^2)}{(1.1\ \times\ 10^{-6}\ \Omega\ m)} = 2.481818\ldots m$$

$$\therefore L = 2.5\ m$$

b) Complete the circuit diagram of Fig. 1.1 to show the fan, the heating elements and the switches connected so that the heater will work as described. Label the switches and the elements.



Power

Exam Style Question 2

The maximum power input to a domestic fan heater is $2.6\ kW$ when connected to the $230\ V$ mains supply. The electric circuit of the fan heater consists of two heating elements (resistors) rated at $1.5\ kW$ and $1.0\ kW$, a motor rated at $100\ W$ and three switches.

ai) Show that the resistance of the $1.5\ kW$ heating element is about $35\ \Omega$.

aii) The $1.5\ kW$ heating element is made from a wire of cross-sectional area $7.8 \times 10^{-8}\ m^2$ and resistivity $1.1 \times 10^{-6}\ \Omega\ m$. Calculate the length of the wire.

b) With only the first switch closed, the fan rotates; closing the second switch gives the heater an output of $1.5\ kW$ and closing the third switch increases the output to $2.5\ kW$. The elements will not heat up unless the fan is switched on. The heater cannot give an output of $1.0\ kW$.

Complete the circuit diagram of Fig. 1.1 to show the fan, the heating elements and the switches connected so that the heater will work as described. Label the switches and the elements.

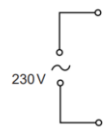


Fig. 1.1

c) Both heating elements are made of wire of the same resistivity and length.

i) Explain, without calculation, why the diameter d of the $1.0\ kW$ heater wire must be less than the diameter D of the $1.5\ kW$ heater wire, designed for use with a $230\ V$ supply.

ii) Show that d is approximately equal to $0.8\ D$.

d) Circle the correct fuse for the plug of this appliance from the values below.

3A 5A 13A

Justify your choice.

ei) Define the kilowatt-hour

eii) Calculate, to the nearest penny, the cost of using the heater for $4.0\ hours$ with only one of the heating elements switched on. The cost of $1\ kWh$ is $18\ p$.

Power

Exam Style Question 2

ci) Explain, without calculation, why the diameter d of the $1.0\ kW$ heater wire must be less than the diameter D of the $1.5\ kW$ heater wire, designed for use with a $230\ V$ supply.

$P = \frac{V^2}{R}$ and $R = \frac{\rho L}{A}$

So we know power is inversely proportional to the resistance for the same voltage.

But the resistance of the wire is inversely proportional to the cross-sectional area. And the cross sectional of the wire is a circle which is $A_{circle} = \pi r^2$.

So because the $1.5\ kW$ heater wire provides more power, the $1.5\ kW$ heater wire needs to have a larger diameter, to increase the cross-sectional area, which decreases the resistance which in turn increases the power.

$$\uparrow diameter = \uparrow A = \downarrow R = \uparrow P$$

Power

Exam Style Question 2

The maximum power input to a domestic fan heater is $2.6\ kW$ when connected to the $230\ V$ mains supply. The electric circuit of the fan heater consists of two heating elements (resistors) rated at $1.5\ kW$ and $1.0\ kW$, a motor rated at $100\ W$ and three switches.

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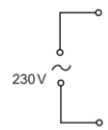

Fig. 1.1

c) Both heating elements are made of wire of the same resistivity and length.

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eii) Calculate, to the nearest penny, the cost of using the heater for $4.0\ hours$ with only one of the heating elements switched on. The cost of $1\ kWh$ is $18\ p$.

Power

Exam Style Question 2

cii) Show that d is approximately equal to $0.8\ D$.

$P = \frac{V^2}{R}$ and $R = \frac{\rho L}{A}$

$$\therefore P = \frac{V^2}{\left(\frac{\rho L}{A}\right)} = \frac{V^2 A}{\rho L}$$

So: $P \propto A$

And we know $A = \pi r^2$ and $radius\ (r) = \frac{diameter\ (d)}{2}$

$$A = \pi\left(\frac{d}{2}\right)^2 = \frac{\pi d^2}{4}$$

So $P \propto d^2$

Now take ratios for power and diameter which is:

$$\frac{1.0\ kW}{1.5\ kW} = \left(\frac{d}{D}\right)^2$$

$$\frac{2}{3} = \left(\frac{d}{D}\right)^2$$

$$\frac{d}{D} = 0.82$$

$$d = 0.82\ D$$

You get this formula because:
$P \propto d^2$
$P_{1.0kW} = kd^2$ (power for 1.0kW heater)
$P_{1.5kW} = kD^2$ (power for 1.5 kW heater)

As the voltage is the same (because the heaters are in parallel) and they have the same length and material the two formulas are related by their constant (k):

$$k = \frac{P_{1.0kW}}{d^2} = \frac{P_{1.5kW}}{D^2}$$

$$\frac{P_{1.0kW}}{P_{1.5kW}} = \frac{d^2}{D^2}$$

$$\frac{P_{1.0kW}}{P_{1.5kW}} = \left(\frac{d}{D}\right)^2$$

Power

Exam Style Question 2

The maximum power input to a domestic fan heater is $2.6\ kW$ when connected to the $230\ V$ mains supply. The electric circuit of the fan heater consists of two heating elements (resistors) rated at $1.5\ kW$ and $1.0\ kW$, a motor rated at $100\ W$ and three switches.

ai) Show that the resistance of the $1.5\ kW$ heating element is about $35\ \Omega$.

aii) The $1.5\ kW$ heating element is made from a wire of cross-sectional area $7.8 \times 10^{-8}\ m^2$ and resistivity $1.1 \times 10^{-6}\ \Omega\ m$. Calculate the length of the wire.

b) With only the first switch closed, the fan rotates; closing the second switch gives the heater an output of $1.5\ kW$ and closing the third switch increases the output to $2.5\ kW$. The elements will not heat up unless the fan is switched on. The heater cannot give an output of $1.0\ kW$.

Complete the circuit diagram of Fig. 1.1 to show the fan, the heating elements and the switches connected so that the heater will work as described. Label the switches and the elements.

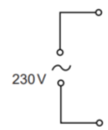

Fig. 1.1

c) Both heating elements are made of wire of the same resistivity and length.

i) Explain, without calculation, why the diameter d of the $1.0\ kW$ heater wire must be less than the diameter D of the $1.5\ kW$ heater wire, designed for use with a $230\ V$ supply.

ii) Show that d is approximately equal to $0.8\ D$.

d) Circle the correct fuse for the plug of this appliance from the values below.

3A 5A 13A

Justify your choice.

ei) Define the kilowatt-hour

eii) Calculate, to the nearest penny, the cost of using the heater for $4.0\ hours$ with only one of the heating elements switched on. The cost of $1\ kWh$ is $18\ p$.

Power

Exam Style Question 2

d) Circle the correct fuse for the plug of this appliance from the values below. Justify your choice.

Calculate the total current in the circuit using $P = IV$ and rearrange for I:

$$I = \frac{P}{V} = \frac{2.6\ kW}{230\ V} = \frac{2600\ W}{230\ V} = 11.30434783\ A$$

Therefore you need to round up to $12\ A$ and as we don't have a $12A$ fuse we need to use the $13\ A$ fuse.

Therefore a $13\ A$ fuse is required.

ei) Define the kilowatt-hour.

One kilowatt hour is the energy transfer when 1kW of power is supplied for exactly 1 hour.

$$1kWh = 1000W \times 3600s = 3.6 \times 10^6 J$$

eii) Calculate, to the nearest penny, the cost of using the heater for $\mathbf{4.0}$ *hours* with only one of the heating elements switched on.

In other words how much would it cost us to have the $1.5\ kW$ heating element on for $4\ hours$.

Remember the $1.5\ kW$ heating element can only be on if the fan is on and the fan is rated at $100\ W$. Therefore the power used for using the heater with only one element is:

$$Total\ power = power\ for\ heating\ element + power\ for\ fan$$

$$Total\ power = 1500\ W + 100\ W = 1600\ W = 1.6\ kW$$

$$Cost\ (in\ pennies) = power\ rating\ (kW) \times time\ used\ (hours) \times cost\ per\ kWh\ (in\ pennies)$$

$$Cost = 1.6kW \times 4\ h \times 18\ p$$

$$\mathbf{Cost = 115.2\ pence}$$

And to the nearest penny it is $115\ p$.

Power

Exam Style Question 3

A filament lamp is described as being $230\ V$, $25\ W$.

Describe what is meant by '$230\ V, 25\ W$' for a lamp.

The power of a $230\ V$ mains filament lamp is $40\ W$.

a) Define power.

b) The lamp is connected to the $230\ V$ supply. Calculate:

i) The current I in the filament

ii) The resistance R of the filament.

c) The cross-sectional area of the wire of the filament is $3.0 \times 10^{-8}\ m^2$. The resistivity of the filament when the lamp is lit is $7.0 \times 10^{-5}\ \Omega\ m$. Use your answer to (b)(ii) to calculate the length L of the filament wire.

d) Explain whether the filament of a $60\ W, 230\ V$ lamp is thicker or thinner than that of the $40\ W, 230\ V$ lamp. The length and material of the filament are the same in both lamps.

e) The $40\ W$ filament lamp is left on for $8\ hours$.

i) Calculate the charge Q passing through the lamp in this time.

ii) 1) Define the kilowatt-hour

2) Calculate the cost of leaving the lamp switched on. The cost of $1\ kWh$ is $22\ p$.

Power

Exam Style Question 3

Describe what is meant by '$230\ V, 25\ W$' for a lamp.
When connected to the $230\ V$ supply, the power (or energy per second) from the supply is $25\ W$.
In other words when the lamp is connected to the $230\ V$ supply the rate at which the lamp transfers electrical energy into other energy forms is $25\ W$.

a)Define power.
Work done or energy transferred per unit time.

$$P = \frac{W}{t}$$

bi) Calculate the current I in the filament.
Use: $P = IV$ and rearrange for I.

$$I = \frac{P}{V} = \frac{40\ W}{230\ V} = 0.17391 \ldots\ A$$
$$I = 0.17\ A$$

bii) Calculate the resistance R of the filament.
Use $V = IR$ and rearrange for R:

$$R = \frac{V}{I} = \frac{230\ V}{0.17\ A} = 1352.941176\ \Omega$$
$$R = 1353\ \Omega$$

c) Use your answer to (b)(ii) to calculate the length L of the filament wire.
Use $R = \frac{\rho L}{A}$ and rearrange it for L

$$L = \frac{RA}{\rho} = \frac{(1353\ \Omega)(3.0 \times 10^{-8}\ m^2)}{(7.0 \times 10^{-5}\ \Omega\ m)} = 0.579857 \ldots m$$
$$\therefore L = 0.58\ m$$

Power

Exam Style Question 3

A filament lamp is described as being $230\ V$, $25\ W$.

Describe what is meant by '$230\ V, 25\ W$' for a lamp.

The power of a $230\ V$ mains filament lamp is $40\ W$.

a) Define power.

b) The lamp is connected to the $230\ V$ supply. Calculate:

i) The current I in the filament

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c) The cross-sectional area of the wire of the filament is $3.0 \times 10^{-8}\ m^2$. The resistivity of the filament when the lamp is lit is $7.0 \times 10^{-5}\ \Omega\ m$. Use your answer to (b)(ii) to calculate the length L of the filament wire.

d) Explain whether the filament of a $60\ W, 230\ V$ lamp is thicker or thinner than that of the $40\ W, 230\ V$ lamp. The length and material of the filament are the same in both lamps.

e) The $40\ W$ filament lamp is left on for $8\ hours$.

i) Calculate the charge Q passing through the lamp in this time.

ii) Calculate the cost of leaving the lamp switched on. The cost of $1\ kWh$ is $22\ p$.

Power

Exam Style Question 3

d) Explain whether the filament of a $60\ W, 230\ V$ lamp is thicker or thinner than that of the $40\ W, 230\ V$ lamp. The length and material of the filament are the same in both lamps.

$P = \frac{V^2}{R}$ and $R = \frac{\rho L}{A}$

$$\therefore P = \frac{V^2}{\left(\frac{\rho L}{A}\right)} = \frac{V^2 A}{\rho L}$$

So: $P \propto A$

And we know $A = \pi r^2$ and $radius\ (r) = \frac{diameter\ (d)}{2}$

$$A = \pi\left(\frac{d}{2}\right)^2 = \frac{\pi d^2}{4}$$

Therefore the filament of a $60\ W$ lamp is thicker than the $40\ W$ as the $60\ W$ lamp can provide more power.

$$\uparrow diameter = \uparrow A = \downarrow R = \uparrow P$$

ei) Calculate the charge Q passing through the lamp in this time.

Use $Q = It$

But convert t from hours into seconds:

$$t = 8\ hours \times 60\ mins \times 60\ sec = 28800\ seconds$$

$$Q = (0.17\ A)(28800\ seconds)$$

$$Q = 4896\ C$$

eii) Calculate the cost of leaving the lamp switched on. The cost of $1\ kWh$ is $22\ p$.

$Cost\ (in\ pennies)$

$= power\ rating\ (kW) \times time\ used\ (hours) \times cost\ per\ kWh\ (in\ pennies)$

Convert $40\ W$ into kW giving us $0.040\ kW$

$$Cost = 0.040\ kW \times 8\ h \times 22\ p$$

$$\boldsymbol{Cost = 7.04\ pence}$$

Exam Style Question 4

An electric heater has a constant resistance of $42.5\ \Omega$. It is connected to the $230\ V$ mains supply by wires of total resistance $2.50\ \Omega$. See Fig. 2.1.

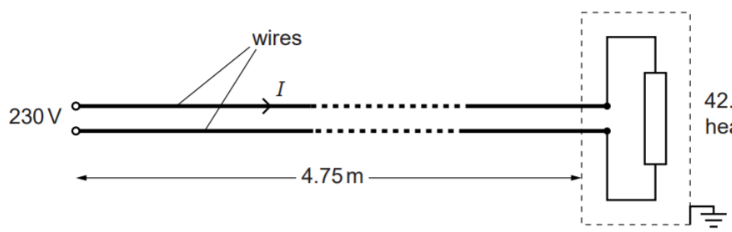

Fig. 2.1

(a) (i) Show that the current I in the wires is about $5\ A$.

(ii) Calculate the total power P dissipated in the heater and wires. Give your answer to three significant figures.

(iii) Suggest a suitable value for the fuse in the plug connecting the cable to the mains supply.

(b) Calculate the cost, to the nearest penny, of using this heater for $4.0\ hours$, when $1\ kWh$ costs $21p$.

(c) The wires used to connect the heater to the supply have a total length of $9.50\ m$. The wires are made of copper. The resistivity of copper is $1.70\ x\ 10^{-8}\ \Omega\, m$. Calculate the cross-sectional area A of the wire.

(d) Suggest and explain one disadvantage of connecting the heater to the mains supply using thinner copper wires.

Power

Exam Style Question 4

(a) (i) Show that the current I in the wires is about $5\ A$.

Use $V = IR$ and rearrange for I

$$R = \mathrm{R}_{\text{electric heater}} + \mathrm{R}_{\text{wires}}$$
$$R = 42.5\ \Omega + 2.5\Omega$$
$$R = 45\ \Omega$$
$$I = \frac{V}{R} = \frac{230\ V}{45\ \Omega} = 5.11\ A$$

(ii) Calculate the total power P dissipated in the heater and wires. Give your answer to three significant figures.

Use $P = I^2R$

$$P = (5.11)^2(45\ \Omega)$$
$$P = 1175\ W$$

(iii) Suggest a suitable value for the fuse in the plug connecting the cable to the mains supply.

The current in the wires is $5.11\ A$ so we need an $6\ A$ fuse.

(b) Calculate the cost, to the nearest penny, of using this heater for $4.0\ hours$, when $1\ kWh$ costs $21p$.

$$Cost\ (in\ pennies) = power\ rating\ (kW) \times time\ used\ (hours) \times cost\ per\ kWh\ (in\ pennies)$$

$$Cost = \left(\frac{1175\ W}{1000}\right)(4\ h)(21\ p)$$

$Cost = 98.7 = 99\ p$ to the nearest penny.

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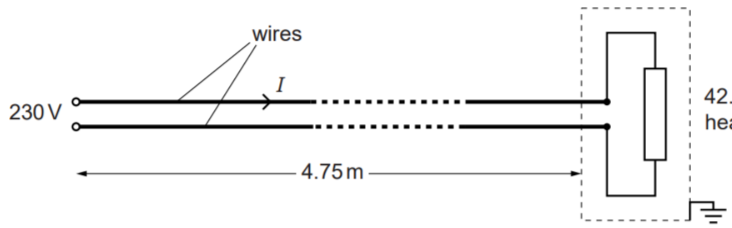
Power

Exam Style Question 4

An electric heater has a constant resistance of $42.5\ \Omega$. It is connected to the $230\ V$ mains supply by wires of total resistance $2.50\ \Omega$. See Fig. 2.1.



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(d) Suggest and explain one disadvantage of connecting the heater to the mains supply using thinner copper wires.

Power

Exam Style Question 4

(c) Calculate the cross-sectional area A of the wire.

Use $R = \frac{\rho L}{A}$ and rearrange for A

$$A = \frac{\rho L}{R} = \frac{(1.70 \times 10^{-8}\ \Omega\ m)(9.50\ m)}{(2.50\ \Omega)}$$

$$A = 6.46 \times 10^{-8}\ m^2$$

(d) Suggest and explain one disadvantage of connecting the heater to the mains supply using thinner copper wires.

Thinner wires increase the resistance of the wire and so there is a smaller current in the heater and the power dissipation in the heater is less.

Please see '7.4.1 Power notes' pack for revision notes.

For more revision notes, tutorials and worked examples please visit www.tutorpacks.co.uk.