

Theme 6: Electricity



Prior Knowledge

It is recommended that you revise the following topics before you start working on these questions.

- Conductors and Insulators
- Static Electricity
- Electric Current, Voltage and Resistance; Ohm's Law
- Series and Parallel Circuits



The Kite Experiment

American scientist, Benjamin Franklin, is famous for flying his kite in a lightning storm. This is quite dangerous because as little as 150 mA of current across the body is enough to kill a human. He is reported to have felt only a mild shock when he touched the metal key hung on the kite string. In Benjamin's mind, this was enough to demonstrate that lightning was indeed an electrical phenomenon. Based on the available literature, Benjamin seems to have set up the experiment such that a part of the kite string was made of hemp and some part of silk. By staying indoors, the silk part was kept dry and the assumption was that the dry silk would offer enough resistance for electricity and hence prevent the lightning shock from travelling to Benjamin.

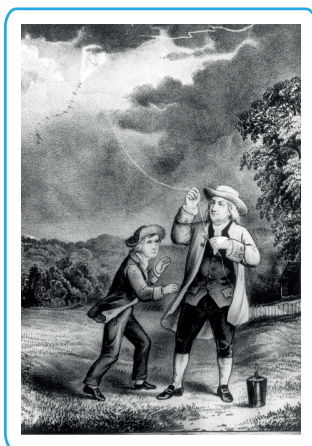


Fig.6.1, Franklin's Kite Experiment; Image by ENERGY.GOV - HD.11.029 via Wikimedia Commons

Case Study A - Kite Experiment Electrical Parameters

Valuable learnings and applications have resulted from Benjamin's experiment but many people wonder how practical was the experiment and in fact, some people even doubt if it was actually conducted or was just a thought experiment. Let us imagine and put some numbers for different parameters in his experiment. Table 6.1 provides some numbers assumed based on the known range for each of these parameters:

Potential difference between the thunder cloud and ground	300 million volts
Resistance offered by air column between Benjamin and thunder cloud (value simplified to make approximate calculations)	1000 M Ω
Resistance offered by Benjamin's body ** negligible compared to the resistance of the air column	Negligible **
Value of current which can be fatal for Benjamin	150 mA

Table 6.1, Values of electric parameters in Benjamin's experiment

Question 1

Would a voltage level of the thunder mentioned in Table 6.1 have proved fatal for Benjamin? Justify your answer.

Answer

Question 2

The electrical conductivity of air depends on the level of humidity. Which of the following changes to the resistance of the air column between Benjamin and thunder cloud would change the answer to Question 1?

a. 1.5 times increase

b. 2.5 times increase

c. 1.5 times decrease

d. 2.5 times decrease

Answer

Question 3

A group of students who were fascinated by Benjamin's experiment as well as courage, wanted to understand the impact of resistance on the current flow without putting their lives in danger like Benjamin. They conducted a simpler and controlled experiment using a 3 V battery, a bulb and a couple of resistors. The circuit diagrams (Fig. 6.2 - 6.5) represent the four different set-ups of the experiment. The luminescence of the light emitted by the bulb was measured in each case. Predict and arrange the four set-ups in the decreasing order of luminescence. Note that the bulb would be brighter with a higher current when compared to lower current passing through it.

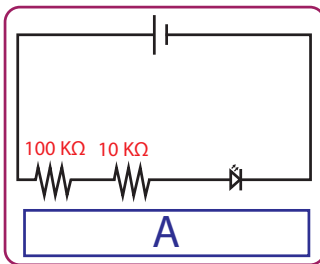


Fig. 6.2

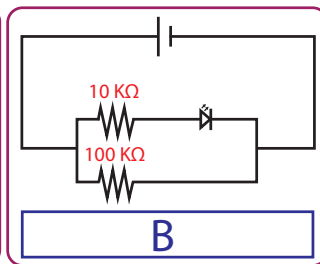


Fig. 6.3

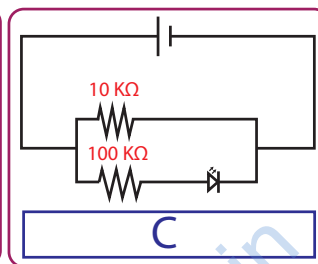


Fig. 6.4

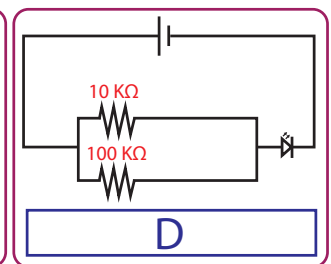



Fig. 6.5

In the circuit diagrams (Fig. 6.2 to 6.5),  represents the bulb.

a. D, A, C, B

b. B, C, A, D

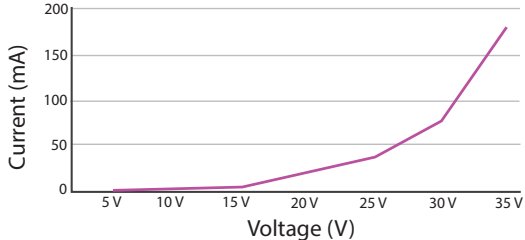
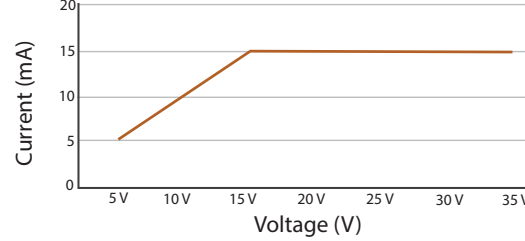
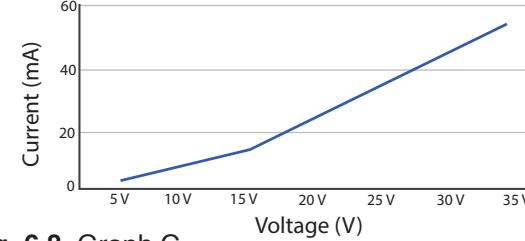
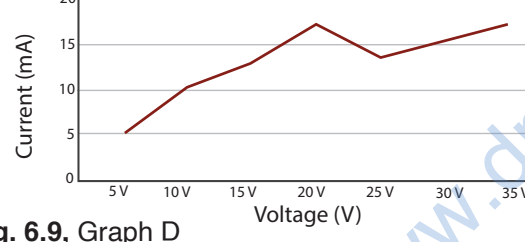
c. B, D, C, A

d. D, B, C, A

Answer

Question 4

One of the students observed during the experiment described above that the luminescence of the bulb did not remain constant in some cases and hence, decided to observe the value of current passing through a circuit as the voltage was varied. As part of the study, the students also connected variable resistors to various circuits to see the impact on current as the resistance was varied. The values of current and voltage were plotted for four set-ups. The graphs are given in Fig. 6.6 to Fig. 6.9. Connect the graphs to the inferences. The y-axis shows current and x-axis represents voltage.

Graphs	Inferences
 <p>Fig. 6.6, Graph A</p>	<p>Inference A Resistance remains constant initially and starts increasing beyond a certain value of voltage. Increase in resistance is proportional to voltage.</p>
 <p>Fig. 6.7, Graph B</p>	<p>Inference B Resistance remains constant initially and starts decreasing beyond a certain value of voltage.</p>
 <p>Fig. 6.8, Graph C</p>	<p>Inference C Resistance remains constant initially and starts increasing beyond a certain value of voltage. Increase in resistance is random.</p>
 <p>Fig. 6.9, Graph D</p>	<p>Inference D High resistance initially and reduces drastically beyond a certain voltage.</p>

Match the graph to the appropriate inference and write the name of the inference in the blank spaces given.

- a. Graph A → Inference _____
- b. Graph B → Inference _____
- c. Graph C → Inference _____
- d. Graph D → Inference _____

Case Study B - Fuse

To understand the change in resistance, the students dug deeper and collected the following information:

Electric resistance	Changes as the temperature of the material changes.
Heating effect of current	As current flows through a material, it gets heated and the amount of heat is directly proportional to the resistance and the square of the current.
Effect on electric appliances	During electric hazards like short circuits, there is a significant increase in the amount of current which can damage the circuit and may also cause fire.
Protection against the heating effect	We make use of the same heating property to protect against its side effects. A fuse is a protective device which is part of the circuit and it melts when the amount of current increases beyond a point.

Table 6.2, Information on heating effects of electric current

Question 5

Using the information in Table 6.2, the students decided to design a fuse for a house. All the wiring in this house was done using copper wires since copper is less oxidative than other metals and it has less resistivity. What kind of wire would you recommend to the students for making the fuse? While choosing the option from below, compare the electrical resistance and melting point of the metal/alloy with copper, since house wiring is done using copper.

- a. Lower resistance, higher melting point
- b. Higher resistance, higher melting point
- c. Higher resistance, lower melting point
- d. Lower resistance, lower melting point
- e. Copper wire itself

Answer

Question 6

Since this was a custom made fuse, the students did not find a predefined location for fixing the fuse. The wiring of the house was done by 4 different electricians. Some electricians were not comfortable with representing circuits as diagrams. Each of them gave a different circuit diagram to the students.

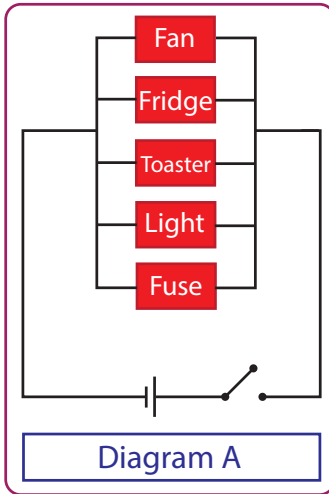


Fig. 6.10

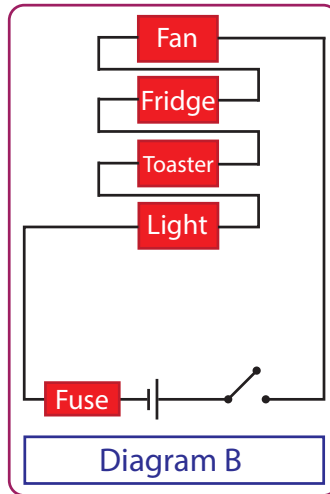


Fig. 6.11

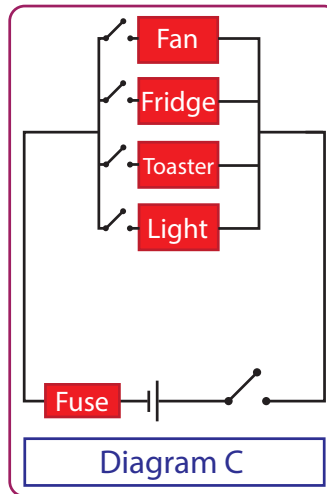


Fig. 6.12

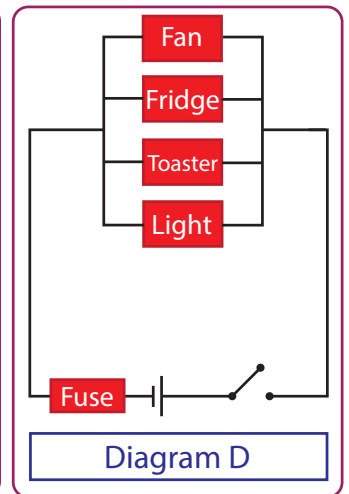


Fig. 6.13

The toaster is malfunctioning and draws current significantly higher than the safety limits. If the house wiring is implemented as per the circuit diagram, in which case will the fuse not play its intended role? Wherever we have switches in the circuit, assume that all are in the ON position.

a. A and B	b. A, B and D	Answer
c. A only	d. C and D	

Case Study C - Properties of Heating Element

To diagnose the problem with the toaster, the students disassembled it. They noticed that the toaster had a coil inside. After some discussion, they concluded that it was the heating element of the toaster which was malfunctioning. The students observed that the heating element also looked like a metal wire and they assumed it to be a good conductor of electricity for current to pass through.

Question 7

They wondered why the heating element wire heated up when current passed through it, though the connecting wire, which connected the toaster to the main power supply, did not. Can you give them the best possible explanation from the options below?

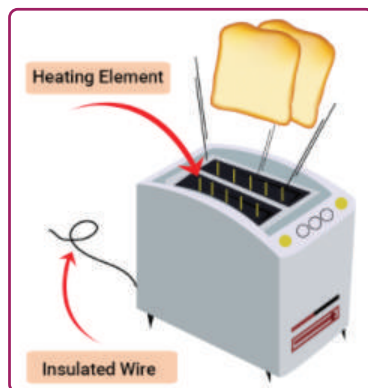


Fig. 6.14, Pop up toaster

- The connecting wire as well as the heating element have low electrical resistivity
- The connecting wire has low electrical resistivity while the heating element has high electrical resistivity
- Both have high electrical resistivity
- The connecting wire has high electrical resistivity while the heating element has low electrical resistivity

Answer

Question 8

As the students dived deep into the design of the heating element of electric appliances like toasters, they learnt that in appliances like geysers, the heating element has three layers. The innermost layer gets heated as high current passes through it. This heat is transferred to the outermost layer through another layer of a material in between. The outermost layer passes the heat to water. While heat should get transferred from the innermost layer to water, electric current should not.

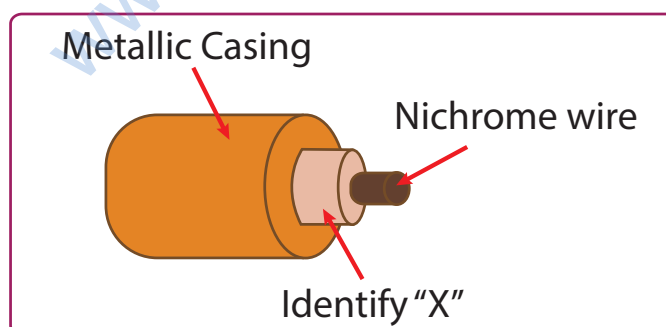


Fig. 6.15, A cross section of a 3-layered heating element

Fig. 6.15 shows the cross-sectional view of the 3-layered heating element immersed in water in appliances like geysers. Based on the properties of the materials given in Table 6.3, select suitable material for making the middle layer of the heating element.

a. Nichrome	b. Copper	Answer
c. PVC	d. Magnesium oxide	

Material	Electrical Resistivity	Thermal conductivity*	Melting Point (°C)
Nichrome	High	Low	1,400
Copper	Very low	Very high	1,085
PVC	Very high	Very low	100 - 260
Magnesium oxide	Very high	Very high	2,852

*The thermal conductivity of a material is a measure of its ability to conduct heat.

Table 6.3, Material properties of some substances

Case Study D - Power Consumption by Home Appliances

Akash's home provides an uninterrupted power supply through a UPS and 2 batteries. The capacity of the batteries can provide a power backup up to 3000 W for 1 hour. This implies that if the power usage is reduced to 1500 W per hour then it can last for 2 hours. There was a power cut for 8 hours on one of the nights and Akash had the following constraints:

- i. He had to use his desktop computer for 2 hours before sleeping
- ii. The heat of May did not allow Akash to sleep without a fan
- iii. His eye doctor had prescribed him to not work on a computer in the dark
- iv. The refrigerator cannot be switched off for more than 2 hours to prevent food from getting spoilt.

Question 9

Akash decides to keep the fridge and fan off while he is working for the first two hours and then sleep for 5 hours with lights off (fan & fridge are ON). Which of the 4 plots from Fig. 6.16 to Fig. 6.19 gives the best representation of the power consumption during the 8 hours? Note that he switches off all appliances after waking up. Consider the data in Table 6.4 on power consumption while answering the question.

Power consumed by the appliances			
Filament Bulb	Ceiling Fan	Fridge	Desktop Computer
100 W	75 W	400 W	200 W

Table 6.4, Power consumption data for various appliances

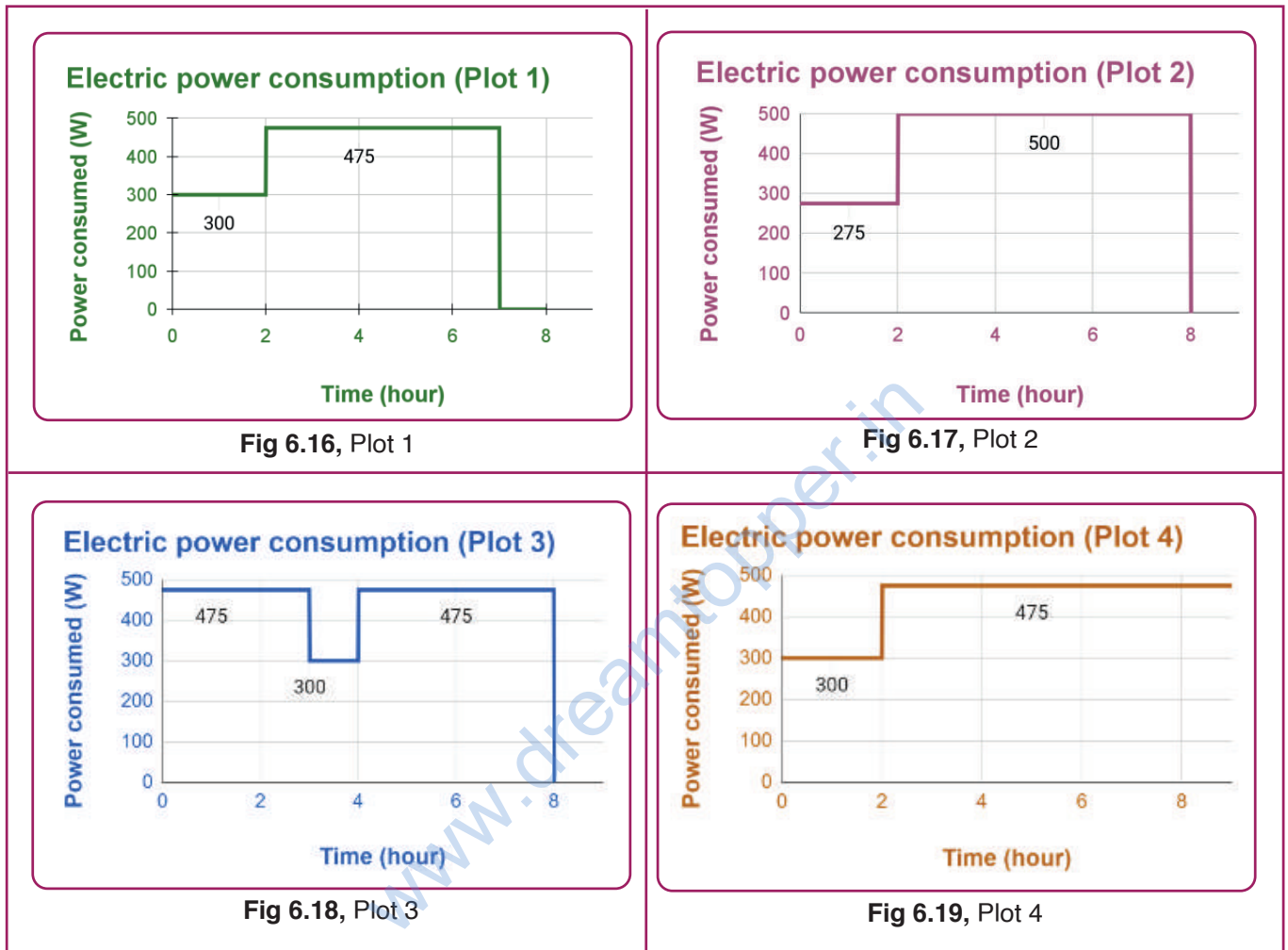


Fig 6.16, Plot 1

Fig 6.17, Plot 2

Fig 6.18, Plot 3

Fig 6.19, Plot 4

a. Plot 1

b. Plot 2

c. Plot 3

d. Plot 4

Answer

Question 10

Akash decides to reduce the power consumed by his filament bulb. He has a couple of resistors lying at home. Which of the following options will work for him and why?

- a. Decrease the resistance of the circuit by adding a resistor parallel to the bulb. This will reduce the power dissipated by the bulb.
- b. Resistance of the bulb has to be decreased, not the circuit. So, no option other than replacing the bulb.
- c. Increase the resistance by adding a resistor in series with the bulb. This will reduce the current drawn by the bulb.
- d. Increase the resistance by adding a resistor in series with the bulb. This will increase the current drawn by the bulb.

Answer

Question 11

To confirm his hypothesis, Akash purchases two more filament bulbs. One with a power of 40 W and the other with 60 W and connects them in series and observes the brightness of the two bulbs. He then connects them in parallel and observes the brightness. Which bulb will be brighter?

- a. Series - 60 W; Parallel - 60 W
- b. Series - 40 W; Parallel - 60 W
- c. Series - 40 W; Parallel - 40 W
- d. Series - same; Parallel - 60 W
- e. Series - depends on which bulb is connected first from the positive terminal of the power source; Parallel - 60 W

Answer

Question 12

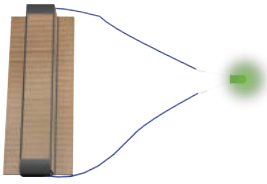
What would be the length of the tungsten filament of a 100 W filament bulb? Use the following data for the calculations.

Thickness of the filament	30 μm
Resistivity of tungsten (at around 3000 $^{\circ}\text{C}$)	$6.2 \times 10^{-7} \Omega\text{m}$
Voltage supply	230 V AC

- | | |
|--------------------|---------------------|
| a. Less than 10 cm | b. 50 to 100 cm |
| c. 2 to 4 m | d. Greater than 4 m |

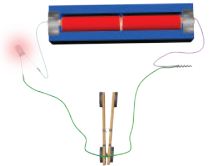
Answer

Exploration Pathway



Circuit Resistance

The electrical resistance of an object is a measure of its opposition to the flow of electric current. In this TACTivity, we understand the use of resistors in simple electric circuits and show how they behave in series and parallel. We will be using industrial resistors and understand the way they are colour coded.



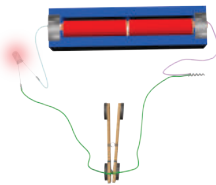
Circuit -
Series and Parallel

Components in an electric circuit can either be connected in "series" or in "parallel". But what is this Series and Parallel? How are they different? How do different components behave when connected in series or parallel? In this TACTivity, we make a simple circuit using cells, LED and a switch. We then explore making and observing parallel and series circuits by connecting the components in different ways.



Electric Heater Model

Electrical power is one of the most popular methods for heating water, rooms and cooking. High resistance conductors end up being the best materials to use for a heating element. In this TACTivity, we use steel wool to make our own mini electrical heater!



DIY Switch

A switch is a mechanism that removes, restores or diverts the conducting path in a circuit when it is operated. In this TACTivity, using ice cream sticks, magnets and some electrical tape and wire, we are going to make a simple tap switch to make or break small DC circuits.