Experiment 3:
The Electrical Properties of 3-Way Bulbs

Purpose:

To determine how a 3 way light bulb works.

Materials Needed:

1. Ohmmeter - digital autoranging preferred, such as the VWR P/N 26983-175
2. 50 W - 100 W - 150 W 3-way light bulb (or other type of 3 way light bulb)
3. 3 way switch socket (available at any hardware store, such as Home Depot)

Procedure:

1. Find the three electrical contacts on the base of the light bulb. Measure the electrical resistance between each of the 3 combinations of contacts. The connections are best made by contacting the ohmmeter probes to the silver blobs of solder. Note that one contact is the silvery dot on the bottom (contact 1), one is the copper colored annular disk surrounding the bottom dot (contact 2)), and one contact is the silvery threads on the side of the bulb (contact 3) .
2. Calculate the expected room temperature resistance of a filament for a 50 W bulb, a 100 W bulb and a 150 W bulb. Use the theoretical method described in experiment 1, steps 2 and 3.
3. Compare the experimentally determined values obtained in the first step of the procedure with the theoretically determined values in the second step of the procedure. What conclusions can be drawn? Can you determine which filaments are between which contacts? Draw a diagram showing your results.
4. Place the 3 way bulb in the socket. When they are used, 120 V is applied across the 2 screw terminals of the socket. Measure and record the resistance across the 2 screw terminals in the four different positions of the switch. You may also wish to examine how the switch works to obtain additional information.
5. Compare these data with the data above. What conclusions can you draw regarding what filaments are on when the switch is in the different positions?

Teacher's Guide to Experiment 3

1. The measured electrical resistances are
   contact 1 to contact 2 R = 35 ohms
   contact 2 to contact 3 R = 21 ohms
   contact 1 to contact 3 R = 11 ohms

2. a. 50 W bulb

When it is on, the hot filament resistance can be determined using

$R = V^2/P$ so $R = (120\ V)^2/50\ W = 288$ ohms.

The room temperature resistance is 15 times smaller, so the expected room temperature resistance is 288 ohms/15 = 19 ohms.

b. 100 W bulb

When it is on, the hot filament resistance can be determined using

$R = V^2/P$ so $R = (120\ V)^2/100\ W = 144$ ohms.

The room temperature resistance is 15 times smaller, so the expected room temperature resistance is 144 ohms/15 = 9.6 ohms.

c. 150 W bulb

When it is on, the hot filament resistance can be determined using

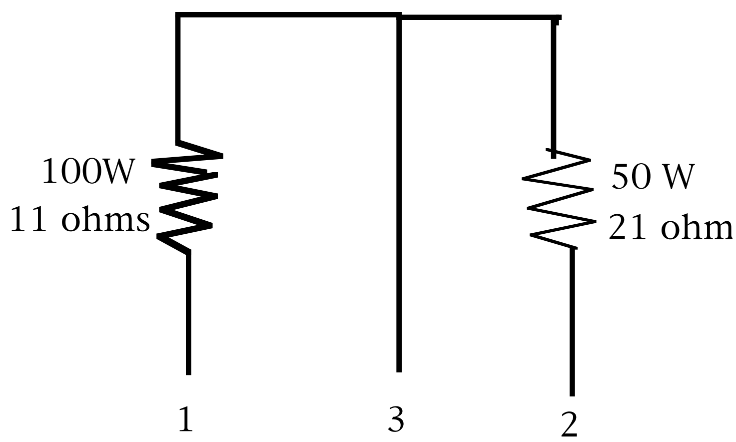
$R = V^2/P$ so $R = (120\ V)^2/150\ W = 96$ ohms.

The room temperature resistance is 15 times smaller, so the expected room temperature resistance is 96 ohms/15 = 6.4 ohms.

3. The 50 W filament is electrically connected to contacts 2 and 3 because 21 ohms is almost the same as 19 ohms - they are the same within experimental uncertainties.

The 100 W filament is electrically connected to contacts 1 and 3 because 11 ohms is almost the same as 9.6 ohms - they are the same within experimental uncertainties.

The electrical resistance between contacts 1 and 2 (35 ohms) is almost the same as the sum of the electrical resistance between contacts 1 and 3 (11 ohms) and contacts 2 and 3 (21 ohms). So contacts 1 and 2 must be connected across the series combination of the 50 W and the 100 W filaments.



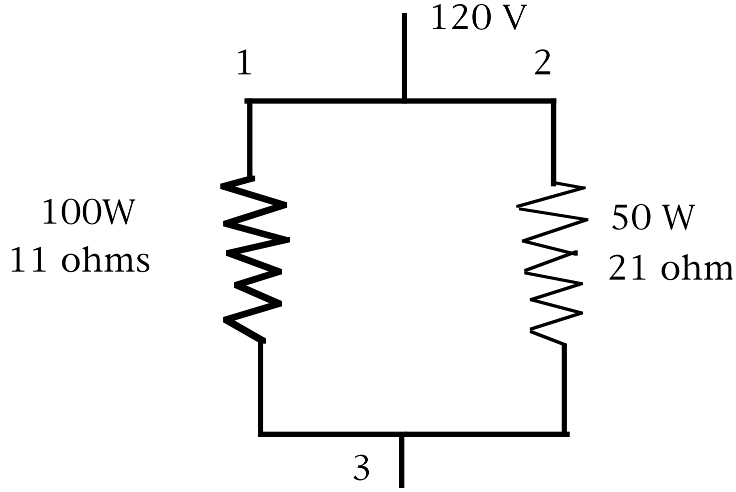
4. switch position 1 R = open
switch position 2 R = 23 ohms
switch position 3 R = 11 ohms
switch position 4 R = 8.2 ohms

5. In switch position 1, no voltage is applied to any of the filaments.

In switch position 2, 120 V is applied across contacts 2 and 3 (the 50 W, 21 ohm resistor) because 23 ohms is just slightly higher than the 21 ohms measured across positions 2 and 3 previously. The switch apparently contributes a couple of ohms of series resistance.

In switch position 3, 120 V is applied across contacts 1 and 3 (the 100 W, 11 ohm resistor) because 11 ohms is in agreement with the previously measured resistance across positions 2 and 3. The switch apparently contributes almost no series resistance in this position.

In switch position 4, 120 V is applied across the parallel combination of the 50 W and 100 W filaments. In other words, 120 V is applied to contacts 1 and 2 and contact 3 is ground, as shown below.



This can be determined in 2 ways. First, note that the parallel combination of the 2 resistances of 11 ohms and 21 ohms is

$$R_P = \frac{(R_1 \times R_2)}{(R_1 + R_2)} = \frac{21 \text{ ohms} \times 11 \text{ ohms}}{32 \text{ ohms}} = 7.2 \text{ ohms.}$$

The value of 7.2 ohms is very close to the value of the resistance measured when the switch was at position 4 of 8.2 ohms. Apparently, the switch contributes about 1 ohm of resistance in this position.

The second way that this can be determined is by examining the switch itself using the ohmmeter. In switch position 4, the switch terminals inside the housing, which connect to contacts 1 and 2 on the bulb, are shorted together and are connected to one of the screw terminals. The other screw terminal is connected to the threaded part of the housing, which in turn electrically connects to contact position 3 on the bulb.

In fact, the second screw terminal is always connected to the threaded part of the housing, which is connected to contact position 3 on the bulb. Note that the first screw terminal is connected to the following contacts as the 3-way switch is turned:

- switch position 0 (off) - no contact
- switch position 1 - connected to contact 2
- switch position 2 - connected to contact 1
- switch position 3 - connected to contacts 1 and 2.

Advanced Topic

You might point out to the students that a 4 way bulb is possible by utilizing the series equivalent of the filaments, by using contacts 1 and 2 only. In this case the bulb wattage would be

$$P = \frac{V^2}{R} = \frac{(120\ V)^2}{288\ \text{ohms} + 144\ \text{ohms}} = 33.3\ W.$$

Note that the highest wattage of a 3-way bulb is always the sum of the 2 lower wattage settings. The reason is that at the highest setting, 120 V is applied across both of the filaments, so that the light output is the sum of the filaments at the two lower settings.

It is interesting to note that if our electrical system operated on constant current instead of constant voltage, the three way bulb would place the filaments in series in the highest wattage setting. Along this line of thought, you might ask your students to consider what an electrical distribution system would be like if it operated on constant current instead of constant voltage.

Let's review this topic in a slightly different way. If we have a constant voltage system and we want to make a 3-way light bulb where the power produced at the highest setting P is the sum of the power produced at the 2 lower settings: P_1 and P_2 using resistors R_1 and R_2, then

$$P = P_1 + P_2 = \frac{V^2}{R_1} + \frac{V^2}{R_2} = V^2 \left[\frac{1}{R_1} + \frac{1}{R_2}\right].$$

So the resistors should be arranged in parallel.

If instead we have a constant current system and we want to make a 3-way light bulb where the power produced at the highest setting P is the sum of the power produced at the 2 lower settings: P_1 and P_2 using resistors R_1 and R_2, then

$$P = P_1 + P_2 = I^2R_1 + I^2R_2 = I^2 [R_1 + R_2].$$

So the resistors should be arranged in series.