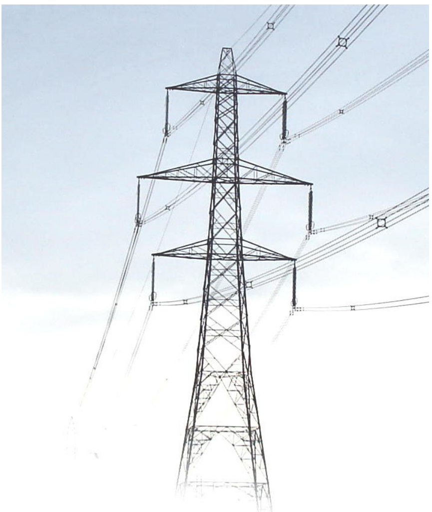
| EXPERIMENT 6 | MEASUREMENT OF LOW RESISTANCE USING CAREY FOSTER'S BRIDGE |
|---|---|

# EXPERIMENT 6

# MEASUREMENT OF LOW RESISTANCE USING CAREY FOSTER'S BRIDGE

## Structure





## 6.1 INTRODUCTION

So far you have learnt to measure mechanical quantities. We now take up the measurement of electrical quantities and begin with resistance measurement. You may logically ask: Why measure resistance? Let us discover the answer. You must be familiar with electrical appliances such as electric heater, electric iron or boiler at your home. Have you ever thought as to what makes these appliances work? Which material is used in their heating element and why? In all these appliances, current flows in the heating element and produces heat. You know that every material offers some resistance to the flow of current. How does this resistance arise and what factors determine it? Is it the same for all materials? You must have learnt answers to some of these questions in your school physics course.

In commercially produced resistors, resistance is provided in the form of a thin layer of carbon or metal films.

Suppose, we wish to regulate temperature in an electric iron. For this we change the flow of current in it. Which physical parameter do we vary? We are sure that your answer is the resistance of the circuit. Depending on the circuit/device, the resistance values can vary from a fraction of an ohm to several million ohms. For instance, one metre of copper wire, normally used in electric connections in physics laboratory, has a resistance of about 0.02Ω. In power transmission, current carrying cables have resistance as low as a few milliohm per kilometre so that power loss is minimal. On the other hand, in a radio or a TV circuit, the resistance is a few kilo-ohm or more because the current required in these circuits is low. Therefore, it is important to know the methods to measure resistance over the entire range from MΩ down to mΩ.

Ohm's law states that the current flowing through a conductor is directly proportional to the potential difference across it, provided its temperature, pressure, shape and size remain the same.

The resistance of the order of a few ohm (1– 100Ω) is usually measured by methods which depend on the direct application of Ohm's law. (You have learnt Ohm's law in your earlier classes.) For low resistance, we use methods based on the principle of Wheatstone's bridge, which essentially involves comparison of resistances. A post office box, a meter bridge, and a Carey Foster's bridge are based on this principle. In this experiment, you will learn to use a Carey Foster's bridge to measure low resistance. Now you may logically ask: Why do we prefer the method of comparison of resistances over direct measurement? Among the options available in comparison mode, which one should we use and when? You should be able to answer these and other related questions after performing this experiment.

### Objectives

After performing this experiment, you should be able to:

- make electrical connections on the basis of a circuit diagram;
- acquire the skills of making measurement using null (zero deflection) method;
- explain why contact resistance (or loose connection) does not play any role in the Carey Foster's bridge circuit; and
- determine the value of a low unknown resistance.

## 6.2 MEASUREMENTS USING A BRIDGE

Low Resistance measurement by comparison of resistances is more reliable. You may, therefore, like to first understand, how this principle works in a Wheatstone Bridge.

### 6.2.1 Wheatstone's Bridge

A Wheatstone's bridge circuit diagram is shown in Fig. 6.1. Here *P*, *Q*, *R* and *S* are resistances in the arms *AB*, *BC*, *AD* and *CD*, respectively. A low voltage dc power supply of about 2V, a key $K_1$ and a rheostat *Rh* are connected as shown in the circuit. *G* is a galvanometer connected between points *B* and *D*. Note that the galvanometer has no positive or negative terminal marked on it. The flow of current in the arm *BD* is indicated by the thin needle fixed in the galvanometer. The needle shows deflection on either side of the zero, marked at the centre of the scale. You should note that in this circuit, the rheostat is being used as a resistor to control the current in the circuit.

In case a low voltage dc power supply is not available in your laboratory, you can use a storage cell/battery.

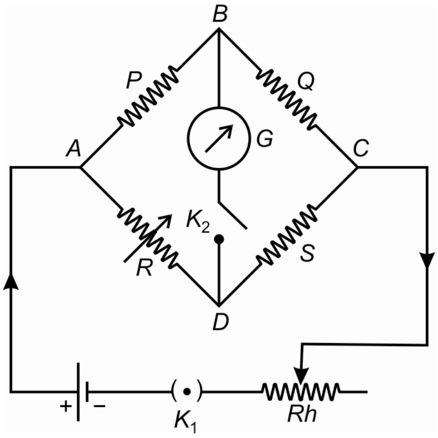
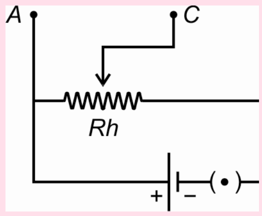



**Fig.6.1: Circuit diagram of Wheatstone's bridge**

A rheostat can also be used as a potential divider. To do so, we apply the battery/dc power supply across the fixed terminals of the rheostat, and a variable voltage is obtained at *C* from the slider terminal as shown below:




Note that *R* is a variable resistance (as indicated by an arrow on it) and *S* is an unknown resistance. The principle of the experiment is that for fixed values of *P* and *Q*, *R* is varied in such a way that no current flows through the galvanometer when key $K_2$ is pressed. Zero current through the path *BD* means that the junctions *B* and *D* are at the same potential. This is seen as zero deflection in the galvanometer. The bridge is then said to be **balanced**. For a balanced bridge, the following condition holds good:

$$\frac{P}{Q} = \frac{R}{S}. \qquad (6.1)$$

For low resistance measurements, the bridge should be sensitive, which means that even for an infinitesimal change in *R*, the balance condition should be disturbed.

For maximum sensitivity, it is important to ensure that all four resistances are of the same order of magnitude. This means that if the unknown resistance is low, the bridge will be most sensitive only when other resistances are also low.

During the experiment, the resistors *P* and *Q* are kept constant. The unknown resistor (*S*) is connected in one of the two remaining arms (say *DC*) and the value of *R* is changed in order to balance the bridge, i.e. to get zero deflection in the galvanometer. Note that key $K_1$ should be kept inserted only while you are adjusting *R* to obtain the balance. If you keep it inserted for the entire duration of the experiment, flow of current can cause heating and may change the value of resistances.

Let us now pause for a minute and ask: Why do we use Wheatstone's bridge to measure low resistance? This is essentially because it is a **null method**. This means that when the bridge is balanced, the galvanometer registers no current, that is, we are not *measuring* any current. We have to only change a known resistance to balance the bridge. Thus, the accuracy of measurement depends only on the precision of the known resistors; the galvanometer does not influence experimental accuracy in any way.

*Spend 4 min.*

### SAQ 1 : Measurements with Wheatstone's bridge

Are the following statements true? Justify your answer.

i) The key $K_1$ in Fig. 6.1 should always be kept inserted in the circuit.

ii) If we know the values of resistances in any three arms of a Wheatstone's bridge, the fourth one can always be found. It does not matter that the bridge is balanced or unbalanced.

iii) The Wheatstone's bridge is more sensitive when the resistances in the four arms are nearly equal.

As you know, in Wheatstone's bridge, the bridge is balanced by changing resistance in the known arm. This can be done by using standard resistance boxes. However, there is always a limit to the minimum value of the resistance available in the resistance box and it is sometimes difficult to balance the bridge accurately. This problem is more prominent if the unknown resistor is of very small value. In order to overcome this difficulty, a modified form of Wheatstone's bridge is used. This is called **Carey Foster's Bridge**. You will now learn the working principle of this bridge.

## 6.2.2 Carey Foster's Bridge

Refer to Fig. 6.2, which shows the circuit diagram of Carey Foster's bridge. The jagged part is a copper strip with four gaps (*m*, $x$, *y* and *n*). These act as four arms of Wheatstone's bridge. Two known resistances *P* and *Q* (equal and small) are connected in the inner gaps at $x$ and *y*. A galvanometer is attached between the terminal *B* and the sliding tapping key (or the jockey) at *D*. A variable resistance box *R* with fractional resistances is placed in the outer gap at *m*. The unknown (low) resistance *S*, which is to be determined, is put in the outer gap at *n*. A battery, a key and a rheostat are connected between the terminals *A* and *C*. A one metre long wire *EF* of uniform resistivity (resistance per unit length) is mounted along side a metre rod, and is soldered to the two ends of the copper strip.



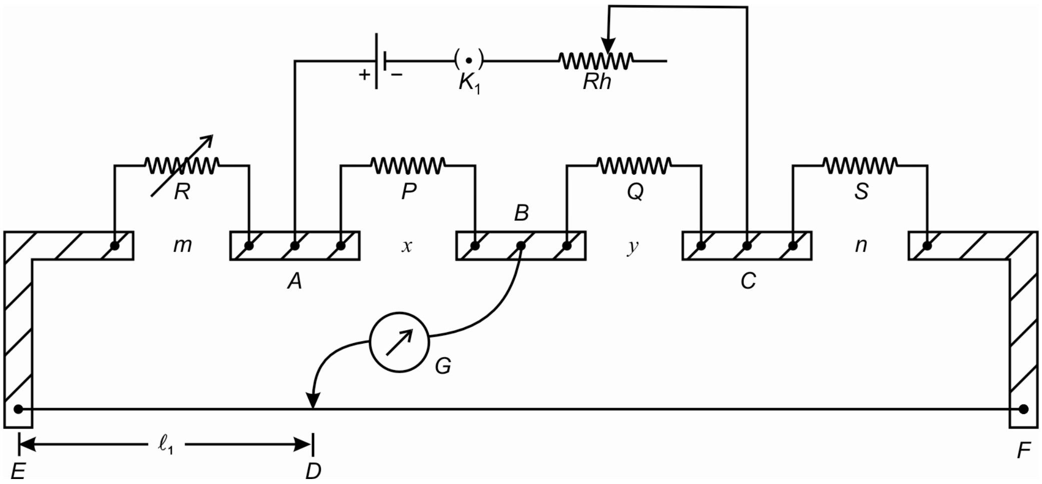



**Fig.6.2: Carey Foster's bridge**

Since the tapping key can be slided along the wire *EF*, the point *D* can be anywhere between *E* and *F*. **It defines the position at which there would be *no deflection* in the galvanometer.** It is located by tapping the jockey over the wire.

Since the wire *EF* is uniform, we can assume that it has a constant resistance per unit length. Let it be $r\,\Omega\ \text{cm}^{-1}$. If the length of the wire *ED* is $\ell_1$ cm, the resistance between *E* and *D* is equal to $\ell_1 r\,\Omega$. The resistance between *D* and *F* would be equal to $(100 - \ell_1) r\,\Omega$.

The points *A*, *B*, *C* and *D* here correspond exactly to those of the Wheatstone's bridge shown in Fig. 6.1. Therefore, you can write the condition of balance as

$$\frac{P}{Q} = \frac{R + \alpha + \ell_1 r}{S + \beta + (100 - \ell_1) r}, \qquad (6.2)$$

where $\alpha$ and $\beta$ are the **end-resistances** at the left and the right ends.

To account for end-resistances, we interchange resistances *R* and *S* : the fractional resistance box is put in gap *n*, and the unknown resistance in gap *m*. Let us assume that the balance point is obtained at a distance $\ell_2$ from *E*. Since the errors at the ends *E* and *F* stay the same, irrespective of the resistances in the gaps *m* and *n*, you can write the condition of balance as

$$\frac{P}{Q} = \frac{S + \alpha + \ell_2 r}{R + \beta + (100 - \ell_2) r}. \qquad (6.3)$$

To eliminate $\alpha$ and $\beta$, first equate Eqs. (6.2) and (6.3):

$$\frac{R + \alpha + \ell_1 r}{S + \beta + (100 - \ell_1) r} = \frac{S + \alpha + \ell_2 r}{R + \beta + (100 - \ell_2) r}.$$

When the contact between the two wires (or between a screw and a wire) is not good, the area of cross section at the contact becomes very small. *This introduces some resistance in the circuit*, which we call the **contact resistance**. In Carey Foster's bridge, the contact resistances are usually referred to as **end-resistances** or **end-errors**. Usually, these are low, of the order of milliohm. The contact resistances assume considerable importance in low resistance measurements because the effective value of unknown resistance can change. It is for this reason that (i) you should clean heads of the connecting wires with sand paper, and (ii) the connections must be tight.

Now add one on both sides and simplify. This gives

$$\frac{R+\alpha+\ell_1 r}{S+\beta+(100-\ell_1)\,r}+1 = \frac{S+\alpha+\ell_2 r}{R+\beta+(100-\ell_2)\,r}+1$$

$$\frac{R+S+\alpha+\beta+100\,r}{S+\beta+(100-\ell_1)\,r} = \frac{R+S+\alpha+\beta+100\,r}{R+\beta+(100-\ell_2)\,r}. \qquad (6.4)$$

You will note that in this equation, the numerators are equal. So the denominators must also be equal. Therefore, you can write

$$S+\beta+(100-\ell_1)\,r = R+\beta+(100-\ell_2)\,r. \qquad (6.5)$$

On simplification, you will get

$$S = R + (\ell_1 - \ell_2)\,r. \qquad (6.6)$$

Note that this value is independent of the end-corrections.

Let us pause for some time and ask: How does this relation help us to determine the value of a low resistance accurately? It shows that the difference between the known resistance $R$ and the unknown resistance $S$ is equal to the resistance of the bridge wire between the two balance points. Once we know $(\ell_1 - \ell_2)$, $r$ and $R$, the unknown resistance can be easily determined.

Now you may like to know: Is there any limitation of this method? Yes, there is one. **The difference between the known and the unknown resistance cannot be more than the total resistance of the bridge wire.** When this condition is not satisfied, the method fails because you cannot obtain the balance point on the wire. For more accurate measurements, you should use a wire of length greater than one metre, i.e. 3-4 wires, each of length 1 m, as in case of a potentiometer.

*Spend 6 min.*

## SAQ 2 : Balancing the Carey Foster's bridge

Write whether the following statements are *True* or *False*, giving reason:

i) To locate the balance point ($D$) on the Carey Foster's bridge, we should slide the tapping key along the bridge wire with heavy pressure on it.

ii) The bridge wire could be of non-uniform cross-section.

iii) If the soldering of the bridge wire with copper strip is weak, the contact resistance is large.

Before we describe the procedure to determine the value of low resistance, let us list the apparatus with which you will work.

**Apparatus**

Carey Foster's bridge, two resistors each of about 2Ω (or two resistance boxes), a thick copper strip, fractional resistance box, low voltage power supply or storage battery, one-way key, rheostat, galvanometer and the unknown low resistance.



## 6.3 SETTING UP THE APPARATUS

1. Place Carey Foster's bridge apparatus on the table and keep it in such a way that the gaps in copper strips are away from you.
2. Clean the ends of the connecting wires with a sand paper.
3. Identify and mark the various terminals of the Carey Foster's bridge by comparing them with Fig. 6.2.
4. Connect the galvanometer between *B* and the sliding key.
5. Connect the two known standard resistors (or the resistance boxes) in gaps $x$ and *y*.
6. Connect the fractional resistance box and the unknown low resistance in the gaps *m* and *n*, respectively.
7. Connect the battery, one-way key and rheostat between *A* and *C*. For connecting the rheostat, you should use its upper terminal and its lower terminal on the other side.
8. Check that the connections (and the keys in the resistance boxes, if used) are tight.
9. Move the slider of the rheostat towards its lower terminal, which is connected to the key and the battery.
10. If resistance boxes are used, take out resistance of, say 2 Ω each from the boxes in the inner gaps at $x$ and *y*.
11. If a fractional resistance box is used in gap *m*, take out a resistance of, say, 0.1 Ω from the box.
12. Insert the key in the battery circuit. Gently tap the jockey of the sliding key near the end *E*. The galvanometer should show deflection on one side of the zero mark.
13. Now move the jockey to the other end (*F*) and again tap it. The galvanometer should now show a deflection on the other side of the zero mark.

Only when you have ensured this, you can be sure that your circuit connections are correct and you can begin to take observations. If you do not get deflection on both sides, you should check your connections again and repeat the above procedure. If you succeed, fine. Otherwise, you should take help of your counsellor without spending any further time. You should however proceed further, only when you are fully confident about the correctness of the circuit.

## 6.4 EXPERIMENTAL PROCEDURE

You have to perform this experiment in two parts. In the first part, you have to find $r$, the resistance of the bridge wire per unit length. In the second part, you will determine the lengths $\ell_1$ and $\ell_2$. These two measurements will give you the unknown low resistance.

### 6.4.1 Measurement of Resistance per Unit Length

1. Connect a known low value resistance or fractional resistance box in the left outer gap $m$ and a thick copper strip in the right outer gap $n$. (If you are using a fractional resistance box, take out a resistance of 0.1 Ω.) Let it be $R$ Ω. When we are connecting thick copper strip in the right gap, we are short circuiting $n$ and then $S = 0$ Ω.
2. Locate the balance point by moving the sliding key over the bridge wire and tapping it gently at different points. The deflection will become zero at some point on the wire. (At the balance point, the galvanometer needle should not move at all.)
3. Note the position of the balance point and measure its length from the end $E$ with the help of the metre scale mounted along the bridge wire. Let it be $\ell_1'$. Record your reading in Observation Table 6.1.
4. Now interchange the position of the copper strip and the fractional resistance box and again determine the balancing length. Let it be $\ell_2'$. By substituting $S = 0$ Ω in Eq. (6.6), you can determine the resistance per unit length of the wire from the relation

$$r = \frac{R}{\ell_2' - \ell_1'}. \tag{6.7}$$

5. Repeat this procedure at least four times by taking out different values of resistance from the fractional resistance box. Calculate the mean value of $r$.

**Observation Table 6.1: Determination of resistance per unit length of the wire**

| S.No. | Fractional resistance $R$(Ω) | Balancing lengths when $R$ is in gap | | Difference in balancing lengths $(\ell_2' - \ell_1')$ cm | $r = \frac{R}{\ell_2' - \ell_1'}$ (Ω cm$^{-1}$) |
|---|---|---|---|---|---|
| | | $m$ | $n$ | | |
| | | $\ell_1'$ (cm) | $\ell_2'$ (cm) | | |
| 1. | | | | | |
| 2. | | | | | |
| 3. | | | | | |
| 4. | | | | | |
| 5. | | | | | |
| 6. | | | | | |
| 7. | | | | | |
| 8. | | | | | |
| . | | | | | |

Mean value of $r$ = ............ Ω cm$^{-1}$.

## 6.4.2 Determination of Unknown Resistance

1. Keep the fractional resistance box *R* in the gap *m* and the unknown resistance *S* in the gap *n*, to start with.

2. Repeat all steps given in the sub-section 6.4.1 in the same order. Prepare your own Observation Table 6.2 and record the data. Compute *S* using Eq. (6.6).

As mentioned earlier, you will not be able to locate the balance point if the difference in the known and unknown resistances is more than the resistance of the bridge wire. To avoid such a situation, you should **change the known resistance in small steps**.

**Observation Table 6.2**

| | | | | | |
|---|---|---|---|---|---|
| 1. | | | | | |
| 2. | | | | | |
| 3. | | | | | |
| 4. | | | | | |
| . | | | | | |

Mean value of unknown resistance, *S* = ......................Ω

Do you get consistent values of unknown resistance *S* in each case?

**Result:** The low resistance determined by using a Carey Foster's bridge

= ........................Ω

Now you may answer an SAQ.

### *SAQ 3 : Graphical estimation of low resistance*

*Spend 15 min.*

(i) Can you determine *r* by plotting a graph with the measurements recorded in Table 6.1?

(ii) If yes, plot this graph.

(iii) If not, say why?

(iv) If you have plotted the graph, what is the shape of the curve?

(v) Estimate the value of *r* from the slope.

(vi) How does the value obtained from graph compare with the one obtained above?

(vii) Does Eq. (6.6) tell us anything about the nature of this curve?

*Spend 5 min.*

## *SAQ 4 : Error analysis*

Imagine that the values marked on standard resistance are not correct. What possible errors do you expect in your result?