Principles of Physics II (PHY112)

Lab

Experiment no: 6

Name of the experiment: Determination of the ratio of the electromotive forces of two cells by using a potentiometer

Theory

Electromotive force of a cell is the amount of work performed by the cell to move one unit of positive charge (1 C, is SI unit), starting from a point of a circuit, through the whole circuit, and then bring it back to the starting point. We measure electromotive (‘emf’) force of a circuit in the unit of Volts (V). In this experiment we are going to measure the ratio of electromotive forces of two given cells. If the emf of a cell is known to us, then we can determine the emf of other one.

Potentiometer

Potentiometer is a device to measure potential difference and electromotive force. In this device a wire of 10 m length and uniform cross section is attached with a wooden frame. The wire has significant resistance. It has 10 segments. Each of the segments is of 1 m length. The segments are connected with each other in a series combination. The wire consists of a material, whose thermal coefficient of resistance is low, i.e., its specific resistance does not change much with the change of temperature. Usually, Manganin or Constantan is used.

By using a potentiometer the electric potential difference (“voltage difference”) across a component can be determined by applying the principle of a *potential divider*.

Potential Divider

Figure 1 shows a simple potential divider. Two resistors of resistances R_1, R_2 and a voltage source of electromotive force E are connected in series combination. Total I amount of current is passing through the closed loop. Voltage differences across the resistance R_1 and R_2 are V_1 and V_2 respectively. Therefore, according to Kirchhoff’s law, $E = V_1 + V_2$

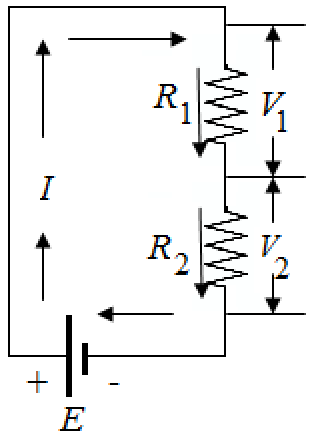

Figure 1: A simple potential divider

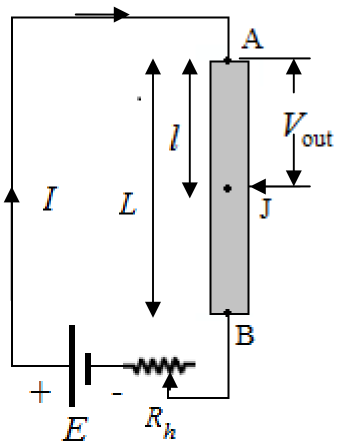

Figure 2: A conductor AB having uniform cross section connected with a cell in series serving as a potential divider.

According to Ohm's law, $V_1 = I\,R_1$ & $V_2 = I\,R_2$

Therefore, $E = I\,R_1 + I\,R_2 = I\,(R_1 + R_2) \Rightarrow I = \dfrac{E}{(R_1 + R_2)}$

Finally, we get rule of potential division between two resistors connected in series combination,

$$\boxed{\begin{aligned} V_1 &= \frac{R_1}{(R_1 + R_2)}E \\ V_2 &= \frac{R_2}{(R_1 + R_2)}E \end{aligned}} \qquad (1)$$

A conductor of uniform cross section and having significant resistance connected with a cell can serve as a potential divider, as shown in the Figure 2. The rheostat R_h is used to modulate the total current, I. A and B are the two ends of this conductor. A terminal is connected with the circuit at point A. Another terminal comes out from point J. We can slide it along the conductor. We get an output voltage difference of V_{out} between the A and J terminal. The resistances of the conductor's segments AJ and JB are R_{AJ} and R_{JB} respectively. Total resistance of the conductor, $R = R_{\text{AJ}} + R_{\text{JB}}$. Suppose, the length of the conductor is L and the length of the AJ segment is l. Since, the conductor has uniform cross section; the resistance of any of its segment is proportional to the length of that segment. If σ is the resistance per unit length of the conductor then $R_{\text{AJ}} = l\sigma$ and $R = L\sigma$. According to the potential division rule:

$$V_{out} = \frac{R_{AJ}}{R_{AJ} + (R_{JB} + R_h)}E = \frac{R_{AJ}}{R + R_h}E = \frac{l\sigma}{L\sigma + R_h}E = \frac{E}{L + R_h/\sigma}l$$

$$\Rightarrow \boxed{V_{out} = \frac{E}{L + R_h/\sigma}l} \qquad (2)$$

Let us connect a series combination of a cell of emf E_1 and a galvanometer G with the output terminals A and J (figure 3). **The positive electrodes of E_1 and E are connected with a same node, A.** The resistance R_o is the combined resistance of the galvanometer and the internal resistance of the cell, E_1. After reaching the junction A the current I gets divided into two flows: I_G and I_C. I_G passes through the E_1, R_o and G. On the other hand, I_C passes through the AJ segment of the conductor. According to Kirchhoff's current rule: $I = I_G + I_C$. Voltages at nodes A, C and J are V_A, V_C and V_J respectively.

I_G amount of current passes through the resistance R_o. According to Ohm's law,

$$V_C - V_J = I_G R_o \tag{3}$$

Voltage difference across E_1,

$$V_A - V_C = E_1 \tag{4}$$

By summing equations (3) and (4) we get,

$$V_A - V_J = E_1 + I_G R_o \tag{5}$$

However, that is the output voltage difference between terminals A and J provided by the potential divider. Hence, according to the equation (2) we can write,

$$\frac{E}{L + R_h/\sigma} l = E_1 + I_G R_o$$

$$\Rightarrow \frac{E}{L + R_h/\sigma} l - E_1 = I_G R_o$$

$$\Rightarrow I_G = \frac{1}{R_o}\left[\frac{E}{L + R_h/\sigma} l - E_1\right] \tag{6}$$

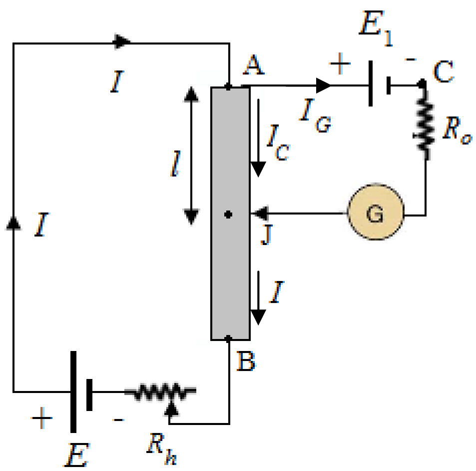

Figure 3: The output terminals A & J of the conductor AB of figure 5 are now connected with a cell of E_1 emf and a galvanometer, G. E_1 and G are in series combination. The resistance R_o is the combined resistance of the galvanometer and the internal resistance of the cell, E_1.

I_G can be positive or negative depending on the parameters which appear inside the square brackets of the right hand side of equation (6).

In Figure 3, both of the positive electrodes of E and E_1 are connected with A. However, instead of that if the negative electrode of E and the positive electrode of E_1 were connected with the junction A, then in equation (6), E would be negative and E_1 would be positive.). Eventually, I_G would be always negative. That means current would always pass through the E_1 & G opposite to our presumed direction as shown in the Figure 3, i.e., it would flow from C to A, instead of from A to C.

Again, if the positive electrode of E and the negative electrode of E_1 were connected with the junction A then in equation (6), E would be positive and E_1 would be negative. Therefore I_G would be always positive. That means current would always pass through the E_1 & G towards our presumed direction as shown in the Figure 3, i.e., it would flow from A to C.

If both of E and E_1 are either positive or negative then depending on l, I_G can be either negative or positive, i.e., the current through G can either flow from C to J or from J to C. Therefore, to make sure that the galvanometer's pointer can deflect towards both sides, the first condition is polarity of the electrodes of E and E_1 should be same which are connected with the junction A.

Suppose, both E and E_1 are connected as shown in Figure 3. If we slide the terminal J and keep it near A, then l will be sufficiently small and according to equation (6) the magnitude of the current I_G will be negative. Then the current I_G will actually flow toward the opposite to its presumed direction as shown in Figure 3. If we slide the terminal J and keep it near B, then l will be sufficiently bigger and according to equation (6) the magnitude of the current I_G may be positive. Then the current I_G will flow toward the direction as shown in the Figure 3. Depending on the position of J, direction & amount of the current passing through the galvanometer will be different and the galvanometer's pointer will deflect accordingly.

To observe galvanometer's pointer can deflect towards both directions, depending on the value of l, I_G should be either positive or negative. When l is zero then clearly, I_G (= $-E_1/R_o$) is negative. However, the maximum value of l can be L. So, to get I_G positive,

$$\frac{E}{L+R_h/\sigma}L - E_1 > 0 \Rightarrow \frac{1}{L+R_h/\sigma} > \frac{E_1}{LE} \Rightarrow L + R_h/\sigma < \frac{LE}{E_1} \Rightarrow R_h < \frac{\sigma LE}{E_1} - L\sigma$$

$$\Rightarrow R_h < R\frac{(E-E_1)}{E_1} \text{ [Since, } L\sigma = R\text{]}$$

Therefore, to get the galvanometer's pointer to deflect towards both directions, depending on the position of J, the value of the rheostat should be lower that this cut off value $R\frac{(E-E_1)}{E_1}$.

For a particular position of J on the conductor AB, no current will pass through the galvanometer, i.e., I_G = 0. This is called '*null point*'. The pointer of the galvanometer will not deflect. If I_G = 0 then from equation (6) we get,

$$E_1 = \frac{E}{L+R_h/\sigma}l$$

Here, l is the length of the segment of the conductor between the *null point* and the end A of the conductor where the electrodes of same polarity (in our example, positive electrodes) of E and E_1 are connected. Let's put a subscript 1 under l to denote that this corresponds to E_1.

$$\boxed{E_1 = \frac{E}{L+R_h/\sigma}l_1} \qquad (7)$$

Suppose, now we connect a cell of emf E_2 instead of cell E_1. Now, the length of the segment of AB is found l_2 distance away from A. Therefore,

$$E_2 = \frac{E}{L + R_h / \sigma} l_2 \tag{8}$$

If we divide equation (7) by equation (8) then we get,

$$\boxed{\frac{E_1}{E_2} = \frac{l_1}{l_2}} \tag{9}$$

By using this equation we can compare two voltages, using a potentiometer.

Circuit Construction

A potentiometer works as a potential divider. The schematic diagram of the circuit construction of this experiment is shown below (Figure 4):

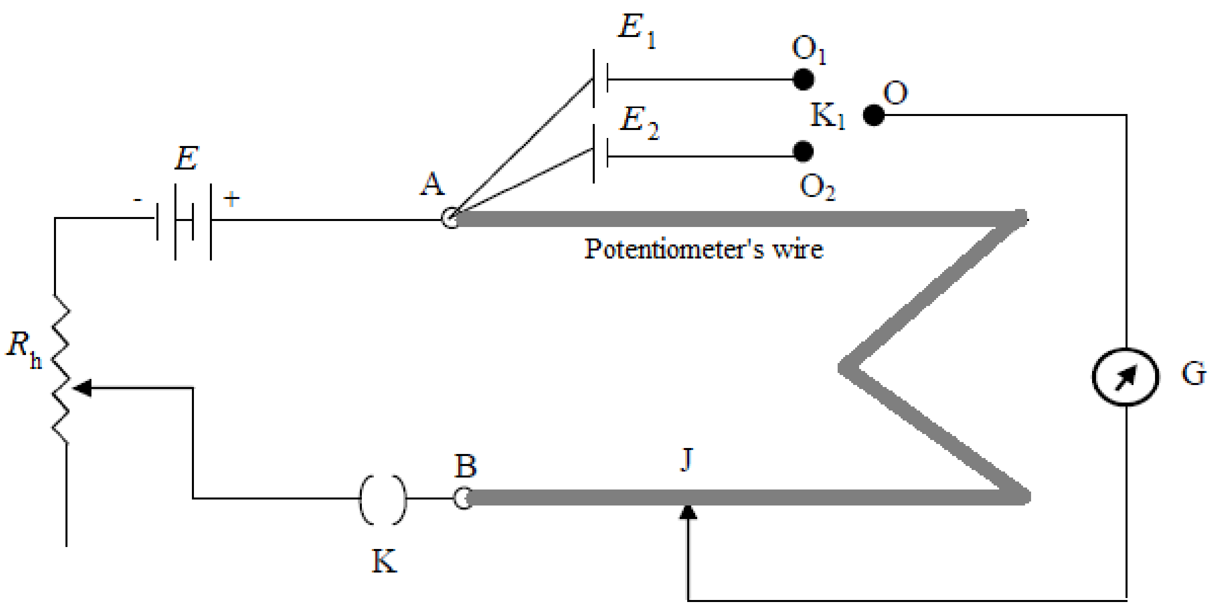

Figure 4: Schematic diagram of the circuit construction to determine the ratio of electromotive forces of two cells by using a potentiometer

Compare this circuit construction with Figure 3. The potentiometer's wire, which has a significant resistance, plays the role of the conductor AB. K_1 is a 'single pole double throw' switch. Positive electrodes of the cells (E_1 and E_2) and the DC voltage source E, are connected with end A of the potentiometer's wire. Negative electrodes of E_1 and E_2 are connected with the throws O_1 and O_2, of the switch K_1, respectively. The pole O is connected with one terminal of a Galvanometer, G. Other terminal of the galvanometer is connected with a jockey. The point of contact between the jockey and the potentiometer's wire is J. The negative electrode of E is connected with one end of a Rheostat. Other end of the rheostat is connected with a key, K. The key K is connected with the end B of the potentiometer's wire.

When O & O_1 are connected then E_1 is connected with the galvanometer in series combination and E_2 remains disconnected. We find the null point on the potentiometer's wire, measure the length, l_1 of the wire's segment between end A and the null point. Similarly, when O & O_2 are connected then E_2 is connected with the galvanometer in series combination and E_1 remains disconnected. Then we find the null point and the length, l_2 of the wire's segment between end A and the null point which correspond to E_2 in the same way.

Finally, we work out the ratio of the electromotive forces of the two given cells using equation (9).

Potentiometer as an electromotive force measuring device

We can measure the voltage of a cell by using a voltmeter or a digital multi-meter. However, to cause the deflection of the voltmeter's pointer or to cause an electric impulse in the digital multi-meter, a tiny amount of current should be allowed to flow through the voltmeter's coil or the multi-meter's internal circuit. That will certainly cause a potential drop between the two electrodes of the cell, since that amount of current will also flow through the electrolyte(s), inside the cell between its two electrodes. This current inside the cell has to overcome the cell's internal resistance which results the little potential drop. That is why what we observe in a voltmeter or a digital multi-meter when we measure the electromotive force of a cell, is slightly lower than its actual value. On the other hand, when we use the potentiometer to measure the cell's electromotive force, no current passes through the galvanometer assuring that no current passes through the cell (connected in series combination with the galvanometer), as well. Hence no potential drop occurs across the internal resistance of the cell. This is an advantage of a potentiometer as a measuring device of electromotive force.

However, to make the assumption that- 'resistance of a certain portion of the potentiometer's wire is proportional to its length'; the cross sectional area of this wire should be same everywhere. Left and right ends of every segment of the wire should coincides with the 0 and 100cm marks of the meter-scale respectively, otherwise an 'end correction' should be made. Connections of the wires should be tight. Weak connections may cause the fluctuations of the galvanometer's pointer. Voltage of the DC voltage source, E should be same while taking the measurement of l_1 and l_2. When current passes through the wire, it will increase its temperature. Resistance of a body changes with temperature. The potentiometer's wire should consist of a material whose thermal coefficient of resistance is very low, so that the resistance of the wire will not change much due to the change of the temperature.

Apparatus

A potentiometer, a DC voltage source, two cells, a rheostat, a 'single pole double throw' switch, a 'single pole single throw' switch, a galvanometer, copper wires (of insignificant resistance).

Procedure

1. Construct the circuit as shown in the Figure 4. Make sure that the galvanometer's pointer deflects towards opposite directions when you make contact between the jockey and the potentiometer's

wire near end A and end B. Do it for both cells when they are connected with the galvanometer separately.

2. Connect O and O_1. Cell E_1 is connected with the galvanometer. Find out the null point. Record the length of the wire-segment between end-A and the null point, i.e., l_1.
3. Connect O and O_2. Cell E_2 is connected with the galvanometer. Find out the null point. Record the length of the wire-segment between end-A and the null point, i.e., l_2.
4. Find out E_1/E_2 ($=l_1/ l_2$).
5. Slightly change the resistance of the rheostat. Repeat the steps 2-4.
6. Repeat step 5 for 4 times.
7. Finally work out the average of E_1/E_2.

Read carefully and follow the following instructions:

- **Please READ the theory carefully, TAKE printout of the 'Questions on Theory' and ANSWER the questions in the specified space BEFORE you go to the lab class.**

- **To get full marks for the 'Questions on Theory' portion, you must answer ALL of these questions CORRECTLY and with PROPER UNDERSTANDING, BEFORE you go to the lab class. However, to ATTEND the lab class you are REQUIRED to answer AT LEAST the questions with asterisk mark.**

- **Write down your NAME, ID, THEORY SECTION, GROUP, DATE, EXPERIMENT NO AND NAME OF THE EXPERIMENT on the top of the first paper.**

- **If you face difficulties to understand the theory, please meet us BEFORE the lab class. However, you must read the theory first.**

- **DO NOT PLAGIARIZE. Plagiarism will bring ZERO marks in this WHOLE EXPERIMENT. Be sure that you have understood the questions and the answers what you have written, and all of these are your own works. You WILL BE asked questions on these tasks in the class. If you plagiarize for more than once, WHOLE lab marks will be ZERO.**

- **After entering the class, please submit this portion before you start the experiment.**

Name: ______________________ ID: ______________ Sec: ___ Group: __ Date: __________

Experiment no: ___

Name of the Experiment: ____

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Questions on theory (all diagrams should be drawn by using a pencil and a scale)

*1) What is electromotive force of a cell? [0.25]

Ans:

*2) See Figure 1. Draw it and work out the rule of voltage division for this circuit. [0.25]

Ans:

*3) See Figure 2. Draw it and work out an expression of V_{out} in terms of E, l, L, R, R_h and σ. σ is the resistance per unit length of the conductor AB. R is the total resistance of the conductor. [1]

Ans:

*4) See Figure 3. Draw it and work out an expression of the current passing through the galvanometer, I_G as shown in equation (6). [2]

Ans:

*5) When I_G is zero, then show that, $E_1 = \frac{E}{L + R_h / \sigma} l$ [0.25]

Ans:

*6) If l_1 and l_2 are the length of the segment of the potentiometer's wire and the null point, correspond to E_1 and E_1, then show that $\frac{E_1}{E_2} = \frac{l_1}{l_2}$ [0.25]

Ans:

*7) Draw the schematic diagram of the circuit construction to determine the ratio of the electromotive forces of two given cells by using a potentiometer. [0.5]

8) See the Figure 5 which shows the circuit construction to compare the emf of two cells with a potentiometer. When OO_1 is connected then the null point of the galvanometer is found at J_1. When OO_2 is connected then the null point of the galvanometer is found at J_2. What is the approximate value of $\frac{E_1}{E_2}$? [0.5]

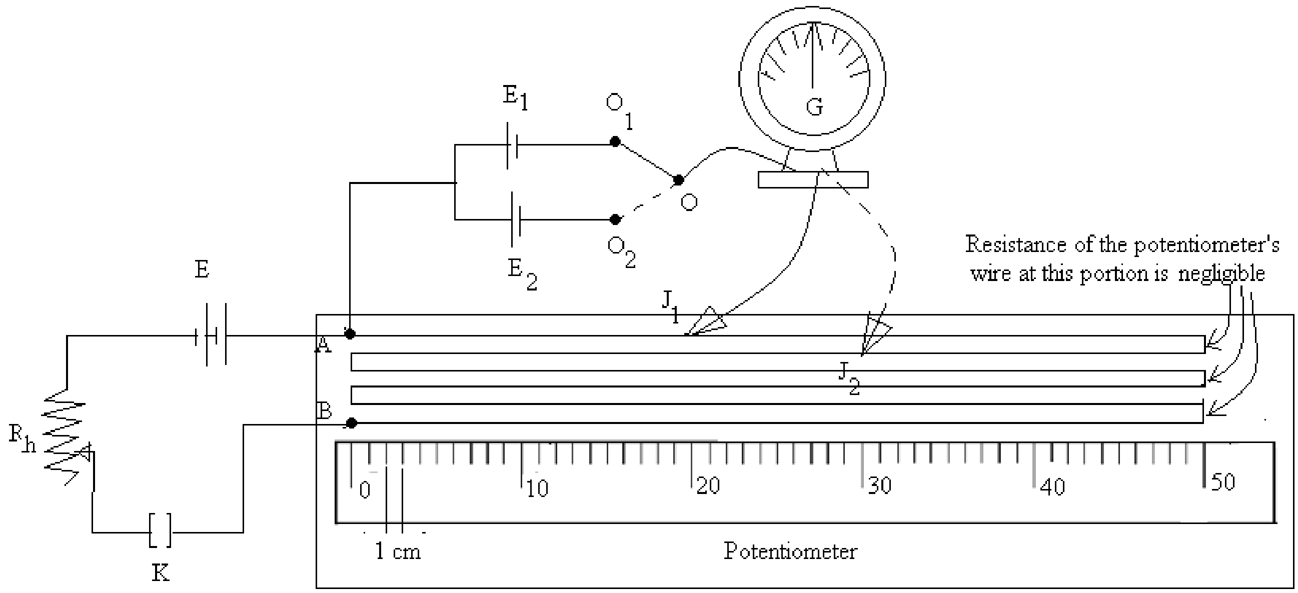


Figure 5: Figure for question 8

Ans:

- **Draw the data table(s) and write down the variables to be measured shown below (in the 'Data' section), using pencil and ruler BEFORE you go to the lab class.**

- **Write down your NAME and ID on the top of the page.**
- **This part should be separated from your Answers of "Questions on Theory" part.**
- **Keep it with yourself after coming to the lab.**

Data

Table: Data for calculating the ratio of emf of two cells

No. of obs.	Cell	Null points			Total length (cm)	$E_1/E_2 = l_1/l_2$	Mean E_1/E_2
		Wire - segment number	Scale reading (cm)	Mean scale reading (cm)			
1	First (E_1)						
	Second (E_2)						
2	First (E_1)						
	Second (E_2)						
3	First (E_1)						
	Second (E_2)						
4	First (E_1)						
	Second (E_2)						
etc.							

- **READ the PROCEDURE carefully and perform the experiment by YOURSELVES. If you need help to understand any specific point draw attention of the instructors.**
- **DO NOT PLAGIARIZE data from other group and/or DO NOT hand in your data to other group. It will bring ZERO mark in this experiment. Repetition of such activities will bring zero mark for the whole lab.**
- **Perform calculations by following the PROCEDURE . Show every step in the Calculations section.**
- **Write down the final result(s)**

Calculations

Results

- **TAKE printout of the 'Questions for Discussions' BEFORE you go to the lab class. Keep this printout with you during the experiment. ANSWER the questions in the specified space AFTER you have performed the experiment.**
- **Attach Data, Calculations, Results and the Answers of 'Questions for Discussions' parts to your previously submitted Answers of 'Questions on Theory' part to make the whole lab report.**
- **Finally, submit the lab report before you leave the lab.**

Name: ___________________________ ID: __________________

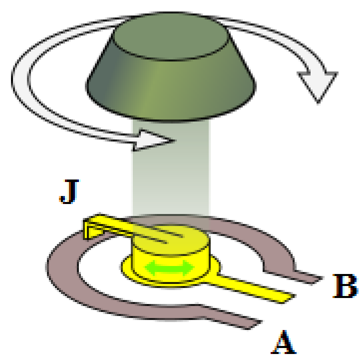
Questions for Discussions

1) If you see the galvanometer's pointer always deflects towards same direction when you make the contact between the jockey and the wire, near end A and end B; what might be the possible reason(s) for this? [0. 5]
   Ans:

2) We can use a voltmeter or a multi-meter to measure the emf of a cell. What might be a drawback of using a voltmeter or a multi-meter for this purpose? How can a potentiometer be useful to avoid this drawback? [0.5]
   Ans:

3) The Figure 6 shows a typical single turn potentiometer, but its structure is quite different from the potentiometer which you have used in the lab. You can see three terminals, and a knob which can be rotated. In the right side, you see its internal structure. The grey colored circular object is a conductor of significant resistance having uniform thickness. Yellow colored object is a good conductor whose resistance can be neglected, an L shaped portion of which touches the circular conductor a point J as shown in the Figure 6. By rotating the knob we can slide this L shaped portion around the circular conductor. Explain how you can use this single turn potentiometer as a potential divider. [1]

(a) External view



(b) Internal structure

Figure 6: Single turn potentiometer (Courtesy: Wikimedia)

Ans:

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