Experiment-427 **S**

GALVANOMETER AND ITS CONVERSION INTO AN AMMETER AND VOLTMETER

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Abstract

Using a center-zero pointer galvanometer and a milli-volt power supply, coil resistance (R_G) and sensitivity (S) of the galvanometer are determined. The galvanometer is shunted with a low resistance to convert it in to a current meter and added a resistance in series to convert it in to a voltmeter and their figures of merits are also determined.

Introduction

Galvanometers (moving coil meters) were one of the first instruments used for measuring DC currents. The flow of a current through the galvanometer coil produces the corresponding deflection in a coil placed around permanent magnets. The most sensitive galvanometer gives 0-100μA full scale deflection. However, galvanometers with 500μA and 600μA full scale deflection are also available. Galvanometers were once considered novel and valuable instruments in Physics laboratories. A galvanometer can be converted into an ammeter (μA-A range) by shunting a small resistance, smaller than its coil resistance, across its terminals and converted into a voltmeter by connecting a large resistance in series with the coil.

Both the ammeter and voltmeter were the backbone of current and voltage measurement till 1980. Thereafter these have been replaced by digital ammeters and voltmeters. At present ammeters and voltmeters based on galvanometer are only for the purpose of exhibition in physics labs. In their present day digital version, one gets 200mV full scale display (FSD) digital panel meters (DPMs) which can be converted into an ammeter by shunting a low resistance across the input terminals and a voltage divider network work that is used to convert it into a voltmeter. The most important advantage in the DPMs is better accuracy in addition to the availability of calibration facility in the circuit, a feature which was not present in analog moving coil galvanometers.

In olden days three different types of galvanometers were used in physics labs, such as pointer galvanometer (or simply galvanometer), ballistic galvanometer (BG) and the spot reflecting galvanometers. All these galvanometers are now replaced by their respective digital versions which measure current over a wide range - from nano-ampere to ampere, and voltage from microvolt to thousands of volts [1].

Figures of merit of a pointer galvanometer

The coil resistance (R_G) and sensitivity (s) of a pointer galvanometer are called figures of merit of the galvanometer which can be determined experimentally. With the knowledge of these two parameters, one can convert a galvanometer into an ammeter as well as a voltmeter. The resistance R_G of the galvanometer can be determined by connecting a milli-volt power supply and load resistance (R_L) of the order of the coil resistance in series with the galvanometer, as shown in Figure-1.

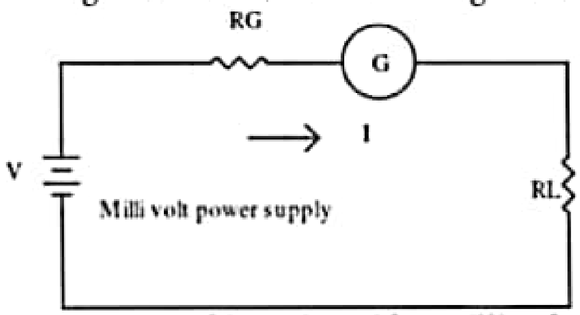

Figure-1: Galvanometer connected in series with a milli-volt power supply and a resistance box

If I is the current flowing through the circuit, then

$$V = (R_G + R_L)\, I \qquad ...1$$

If 'd' is the number of divisions of deflection of the needle and's' is the sensitivity of the galvanometer, then

$$I = s\, d \qquad ...2$$

where

s is the sensitivity of the pointer galvanometer, and
d is the number of divisions of deflection

$$V = (R_G + R_L)\, sd \qquad ...3$$

$$R_L = \frac{V}{sd} - R_G \qquad \ldots 4$$

Equation-4 represents a straight line between R_L and $\frac{1}{d}$ with

Slope = $\frac{V}{s}$, and

Y-intercept = $-R_G$

Hence by varying R_L, and noting down the number of divisions of deflection, the figures of merit of the galvanometer can be determined experimentally. This is a straight forward, graphical method.

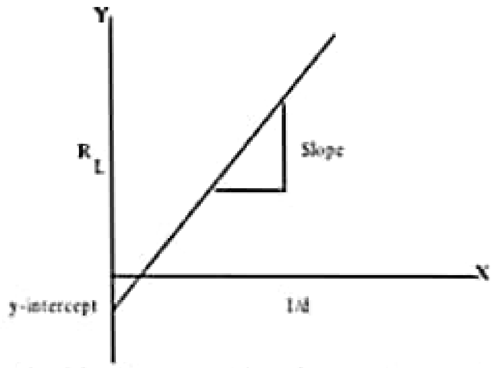

Figure-2: Variation of load resistance with 1/d

The half deflection method for determination of R_G

The coil resistance can be determined using the so called half deflection method. In this method keeping R_L= 0, the power supply voltage is increased so that the meter shows full scale deflection (30 divisions). The voltage corresponding to the full scale deflection, V_{full}, is noted.

Now the resistance R_L in the box is slowly increased so that the deflection becomes half (i.e., 15 divisions). The resistance in the box corresponding to half deflection is noted, which equals R_G. At this point the voltage drop and current flowing through R_G and R_L are equal, hence

Resistance in box at the half deflection point = R_G

Conversion of a galvanometer into an ammeter

In the first part of the experiment, with the knowledge of the coil resistance and sensitivity of the galvanometer, one can convert a galvanometer into an ammeter by shunting a low resistance (smaller than the coil resistance) across its terminals as shown in Figure-3.

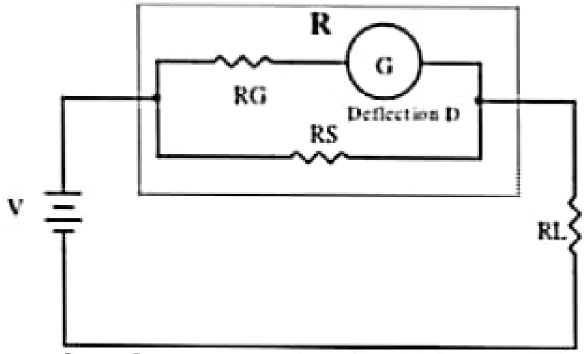

Figure-3: Conversion of a galvanometer into an ammeter using a shunt resistance

Taking R_G =100Ω and sensitivity, s, as 20μA/div, the full scale current (FSC) = 20μAx30= 600μA.

This current can be converted to higher scale by the shunting resistance as shown in Figure-3, as given in Table-1.
Hence depending on the desired range of the ammeter, one can choose the shunt resistance value from this table and convert the galvanometer into an ammeter. The panel carrying the graduation marks can be suitably calibrated in terms of amperes or milli-amperes.

Table-1: Current meter range and sensitivity

Shunt resistance (R_S)Ω	R= (R_G//R_S) Ω	Current meter range	Sensitivity (S)
infinity	100	0-600μA	20μA/Div
10	9.09	0-6mA	200μA/Div
1	0.99	0-60mA	2mA/Div
0.1	0.099	0-600mA	20mA/Div
0.01	0.0099	0-6A	0.2A/Div

Figures of merit of the ammeter

When a resistance is shunted across the terminals of the galvanometer, its effective coil resistance changes as shown in Table-1. Hence the sensitivity (S_A) and effective coil resistance (R_A) also change.

If R_A is the effective resistance of the current meter coil then

$R_A = R_S // R_G$ ...5

If V is voltage and I is current flowing in the circuit, then by the Ohm's law

$V = (R_A + R_L)\, I$ ...6

If S_A is the sensitivity of the current meter and D_A is the number of divisions of deflection in current meter (in terms of number of divisions), then

$I = D_A S_A$ ...7

Substituting for I from the above in Equation-6, we get

$V = (R_A + R_L)\, S_A D_A$ ...8

$\frac{V}{S_A D_A} = R_A + R_L$ ...9

Rearranging the terms in (9) gives

$R_L = \frac{V}{S_A D_A} - R_A$ ...10

This equation represents a straight line between R_L and $1/D_A$, with

Slope = $\frac{V}{S_A}$; Y intercept = $-R_A$

Hence figures of merit of the ammeter can be determined.

By varying R_L, the number divisions of deflection in current meter are noted, from which the figures of merit of the current meter, R_A and S_A can be determined from which the coil resistance R_G and sensitivity s of the galvanometer also can be determined.

Conversion of a galvanometer into a voltmeter

A 0-600μA galvanometer can be converted into a voltmeter with different ranges. A 0-3V voltmeter is obtained by adding a resistance R_X in series, as shown in Figure-4. Table-2 shows different series resistances, voltmeter range and their sensitivity.

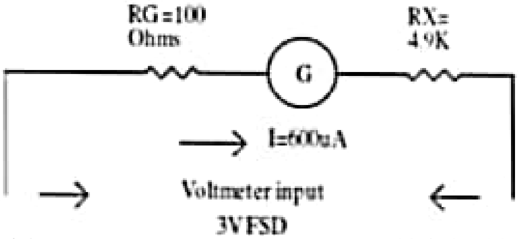

Figure-4: A 0-600μA galvanometer converted into a 0-3V voltmeter

Table-2: Voltmeter range and sensitivity

Series resistance $(R_S)K\Omega$	$R_V = (R_G+R_S)\ K\Omega$	Volt meter range	Sensitivity (S_V)
4.9	5	0-3V	0.1V/Div
49.9	50	0-30V	1V/Div
499.9	500	0-300V	10V/Div

The circuit shown in Figure-4 is a linear circuit with passive components; hence one can apply Ohm's law to it, viz.

$V = RI$

To design a 0-3V voltmeter, we have

$3V = (R_G+R_X)\ 600\mu A$

$R_G+R_X = 5000\Omega$, since $R_G = 100\Omega$

$R_X = 4900\Omega = 4.9K\Omega$

By using a 4.7KΩ, MFR resistor, and 200 Ω trim-pots, one can achieve this. The trim-pot acts like a full scale calibrator.

Instruments used

Milli-volt power supply, 30-0-30 pointer galvanometer, shunt resistance 1Ω/2W, DMM and 0-30V power supply. The apparatus used is shown in Figure-5.

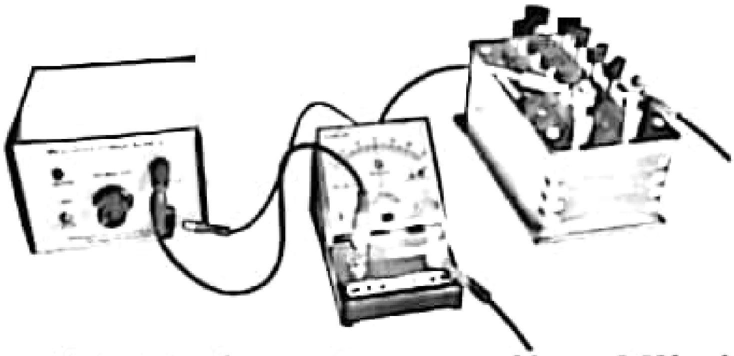

Figure-5: A 0-600μA galvanometer converted into a 0-3V voltmeter

Experimental procedure

The experiment consists of three parts:

Part-I: Determination of figures of merit of a galvanometer (R_G, s)
Part-II: Determination of R_G by the half deflection method
Part-III: Conversion of a galvanometer into an ammeter and determination of its figures of merit (R_A, S_A)
Part-IV: Conversion of a galvanometer into a voltmeter and determination of its figures of merit (R_V, S_V)

Part-I: Determination of figures of merit of a galvanometer (R_G, s)

1. The milli-volt power supply, galvanometer and resistance boxes are connected in series as shown in Figures-1 and 5. The resistance in the box is set to 0Ω.

2. The voltage in the milli-volt power supply is slowly increased till the galvanometer shows full scale deflection (i.e. 30 divisions). The voltage that produces full scale deflection is noted using DMM.

   V_{full} = 57 mV

3. The resistance (R_L) in the box is now set to 200Ω and the deflection in the galvanometer is noted.

   R_L = 200 Ω;
   d = 10 divisions

4. The experiment is repeated by decreasing the resistance R_L in the box and corresponding value of the galvanometer deflection is noted and recorded in Table-3.

5. A graph is drawn with 1/d along X-axis and R_L along the Y-axis, as shown in Figure-6. From the graph the slope and Y-intercepts of the straight line are noted.

   Y-intercept = $-R_G$ = -100Ω

   Slope = $\frac{V}{s}$ =3025.12

   Sensitivity of the galvanometer $s = \frac{V}{slope} = \frac{0.057}{3025.12} = 18.8\mu A/div$

Table-3: Load variation and the deflection observed in the galvanometer

Load resistance R_L (Ω)	Deflection (No. of divisions) d	1/d
200	10	.1
100	15	.06
90	16	.062
80	17	.058
70	18	.055
60	19	.052
50	20	.05
40	21.5	.046
30	23	.043
20	25	.04
10	27	.037
5	28.1	.035
0	30	.033

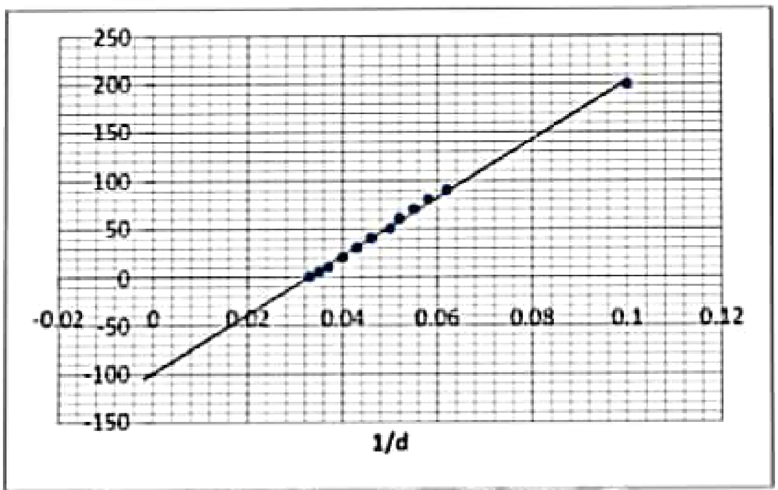

Figure-6: Variation of R_L with 1/d for $R_S = \infty$

Part-II: Determination of R_G by the half deflection method

6. The resistance in the box is set to '0' and the value of the full scale deflection is observed.

   $R_L = 0$;

   Full scale Deflection =30 divisions

7. The resistance in the box is increased so that deflection in the galvanometer becomes 15 divisions (i.e. half of the original value of deflection)

   $R_L = 100\Omega$, d =15divisions
   Hence resistance of the coil $R_G = 100\ \Omega$

Part-III: Conversion of a galvanometer into an ammeter and determination of its figures of merit (R_A, S_A)

8. A 10Ω resistance now shunted across the galvanometer terminal as shown in Figure-7 and keeping $R_L=0$, the milli-volt power supply is adjusted to the full scale.

   $R_L=0$;

   Full scale deflection =30 divisions

   The full scale display voltage is measured using a DMM.

   $V_{full} = 60mV$

Figure-7: $R_S=1\Omega$ shunted across the input terminal of the galvanometer

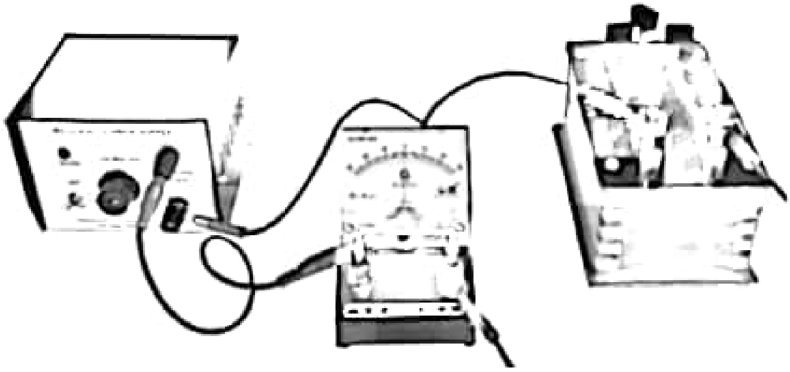

Figure-8: Conversion of a galvanometer in to a milli ammeter

9. By varying the resistance R_L in box, the corresponding deflection is noted in Table-4.

R_L =100Ω; D_A =2.5divisions

Table-4: Load variation and the observed deflection in a galvanometer

Load resistance R_L (Ω)	Deflection (No. of divisions) D_A	$1/D_A$
100	2.5	0.4
70	3.5	0.28
40	5.2	0.192
20	9	0.111
10	14.5	0.074
4	20	0.05
3	22	0.045
2	22.5	0.044
1	26	0.038
0	30	0.033

10. A graph is now drawn taking R_L along Y-axis and $1/D_A$ along X-axis as shown in Figure-9

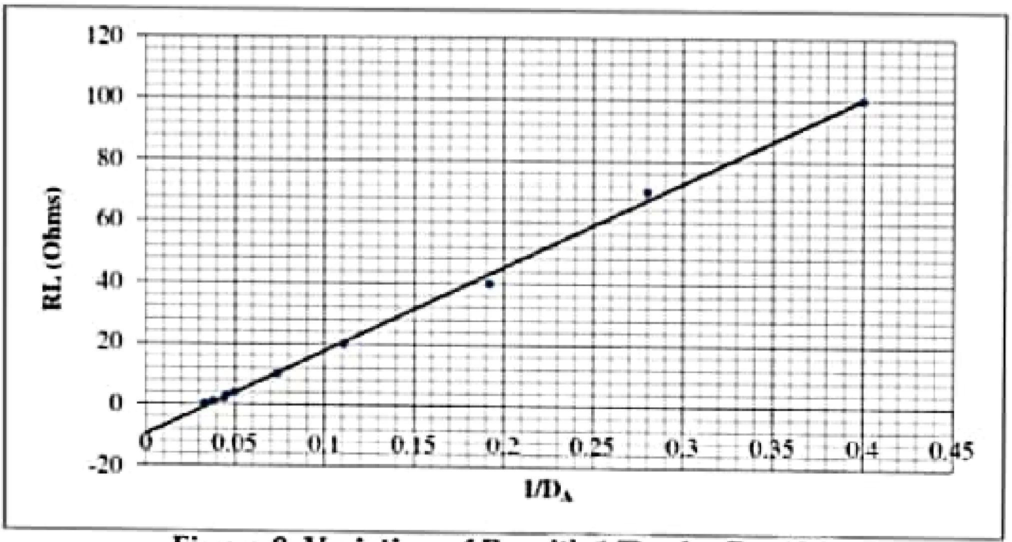

Figure-9: Variation of R_L with $1/D_A$, for R_S=10Ω

The slope of the straight line and the Y-intercept are noted from Figure-9.

Y-intercept = $-R_A$ = - 9.1 Ω $=R_S//R_G$

$$\frac{1}{R_G} = \frac{1}{R_A} - \frac{1}{R_s} = \frac{1}{9.1} - \frac{1}{10} = 9.89\text{x}10^{-3}$$

R_G = 101 Ω

which agrees with the value obtained in Part-1 .

Slope = $\frac{V}{S_A}$ =275.75

Sensitivity of the milli-ammeter $S_A = \frac{V}{slope} = \frac{0.060}{275.75}$ = 217.58μA/div

FSD of the meter 217.58x30= 6.5mA
Hence by using the shunt resistance R_s=10 Ω, we have changed it into a milli-ammeter of 0-6.5mA range, and the

Sensitivity = 0.217mA/div. This value corresponds to R_s=10 Ω in Table-1.

Part-IV: Conversion of galvanometer into a voltmeter and determination of its figures of merit (R_V, S_V)

11. The galvanometer is connected to a resistance box (DRB-206, 1Ω-1.11MΩ range) and resistance in the box is set to 4.9KΩ, as shown in Figure-5.

Hence the total resistance $R_V = R_G + R_X = 100\Omega + 4.9K\Omega = 5K\Omega$

12. The input of the voltmeter is now connected a 0-30V DC regulated power supply for measuring the supply voltage.

13. The power supply voltage is set to 0.0V and the galvanometer shows '0' reading.

Table-5: Number division of deflection of the voltage for different input voltage

Observed deflection (No. of divisions)	Input voltage (V)	Corresponding voltmeter reading (=5000sDᵥ)
0	0	0.0
5	0.5	0.5
10	1.0	1.0
15	1.5	1.5
20	2.0	2.0
25	2.5	2.5
30	3.0	3.0

For a 0-3V FSD voltmeter, R_X=4.9KΩ, R_G=100Ω

Table-6: Number division of deflection of the voltage for different input voltage

Deflection(No. of divisions)	Input voltage (V)	Calibrated voltmeter reading
0	0	0
5	5	5
10	10	10
15	15	15
20	20	20
25	25	25
30	30	30

For a 0-30V FSD voltmeter meter, R_X=49.9KΩ, R_G=100Ω

14. Now the power supply voltage is varied so that the deflection in the galvanometer shows 5 divisions.

    Deflection = 5 divisions;
    Input voltage = 0.5V

15. The experiment is repeated by increasing the deflection in steps of 10, 15, 20, 25, 30 divisions and the corresponding input voltage in the power supply is noted and recorded in Table-5.

16. By setting the resistance to 49.9K Ω in DRB, the experiment is repeated to convert it into a 0-30V range voltmeter. Table-6 shows the observed readings.

Results

The results obtained are tabulated in Table-7

Table-7: Experimental results

Parameter	Graphical method	Half deflection method
Sensitivity (s) μA/division	21.7	20.00
Galvanometer resistance (R_G)	100Ω	101Ω

Conclusions

1. In the process of converting a galvanometer in to a milli-ammeter or ammeter, one essentially changes effective resistance of the ammeter. Hence its sensitivity (see Table-1) also change so that FSD $=D_AS_A$ and effective coil resistance $R_A=(R_G//R_S)$.

2. In the process of converting a galvanometer in to a voltmeter, one essentially adds a series resistance with coil resistance. Hence its sensitivity (see Table-2) also change so that FSD $=D_VS_V$ also change. The effective coil resistance then becomes $R_V=(R_G+R_X)$.

References

[1] Jeethendra Kumar P K, Digital nano-ammeter, LE Vol-8, No-3, Sept.-2008