# LAB 13 - BUILDING AN AMMETER AND VOLTMETER

#### Goals:

- Investigate characteristics of galvanometer.
- Use simple series and parallel circuit concepts to calculate resistance needed for ammeters and voltmeters to be created from the galvanometer.
- Build ammeters and voltmeters and test them (make a calibration curve).
- Determine the effect the meter has on the circuit how much resistance it adds, and how much power is lost because it is there.

It would be very helpful to look at the <u>online help page for this lab</u>.

### Part 1 - What is a Galvanometer

A galvanometer is a very sensitive coil meter. If there is a small voltage across the terminals of the galvanometer, there will be a deflection of the needle. The direction of the needle's deflection indicates the polarity of the voltage. If there is a small current through the galvanometer, there will also be a deflection, indicating the direction. Basically, there is just a coil of wire connected between the two ports on the galvanometer. The coil is in a magnetic field, so it will tilt when there is a current through it, or thus a voltage across it.



Figure 1 – Model of inner circuit of Galvanometer

There is one limitation to the use of a galvanometer - it is very sensitive to voltages and currents - too sensitive for most measurements. But, we can use this simple coil meter to create ammeters and voltmeters with any desired range. This will also help reinforce the series/parallel circuit concepts!

## Part 2 - Measuring the Characteristics of a Galvanometer

There is a maximum current allowed through the galvanometer (Ig) and a maximum voltage (Vg) - which combine to tell us the resistance of the galvanometer. Set up the circuit below:



Figure 2 - Circuit to measure maximum current of Galvanometer

<u>1. Preparing the meters.</u> Start with the ammeter setting on 200 mA DC. Set the decade box to a very high setting (over 20,000 ohms). This will create a very small current in the circuit, and the galvanometer shouldn't deflect much if at all. Push the tap switch to see if there is any reading on the galvanometer.

<u>2. Look for full-scale deflection</u>. Reduce the resistance on the decade box until you can get a full-scale deflection of the galvanometer. (Just "tap" the tap switch if you are not sure if the current is too high.) The maximum current of the galvanometer will probably be around 0.33 mA - so we should be fine on the 2 mA scale.

<u>3. Record the current.</u> Record the current in the ammeter when the galvanometer is deflected full-scale to one side (a reading of 35 on the galvanometer). Read from the lowest scale where you can get a reading! Record the information on the Data/Question sheet.

<u>4. Measure the voltage.</u> Disconnect the multimeter from the circuit, and switch it to the 200 mV scale (DC voltage). (You will have to switch the probes also.) Connect the voltmeter across the terminals of the galvanometer as shown below:



Figure 3 - Circuit to measure maximum voltage of Galvanometer

(The maximum voltage for the Galvanometer should be around 35 mV). We should already have the perfect circuit resistance to give us a maximum voltage across the galvanometer, but just to be sure, increase the resistance on the decade box by about 100 ohms (100 ohms plus what you already have). Tap the switch and look for a deflection.

<u>5. Full-scale deflection of meter.</u> Lower the resistance until you find the same full-scale deflection of the galvanometer. This voltage reading on the multimeter is the maximum voltage of the galvanometer. Record the information on the Data/Question sheet.

We can now use these characteristics of the galvanometer to construct a simple ammeter and voltmeter, but first we need to look at the circuit concepts.

### Part 3 -Calculating the Resistance for a Voltmeter

A voltmeter measures the potential difference across two points in a circuit. To do this, it must be connected **ACROSS** the circuit, and a little bit of current has to run through the meter. A voltmeter should not affect the circuit greatly, so it must have a high resistance (to limit the current that it siphons off from the main circuit). With our galvanometer (which can register very small currents) we will put a large resistance in series. The constructed voltmeter would look like this:



Figure 4 - Conceptual diagram to create "voltmeter" from galvanometer

Comparing the voltage in the main part of the circuit ( $V_{meas}$ ) with the sums of the voltages inside the constructed voltmeter, we see the following:

$$V_{meas} = V_g + I_g R_V$$
  $R_V = \frac{V_{meas} - V_g}{I_g}$  (Should be ~ 15,000 ohms)

1. Power supply voltage. Thus, knowing the characteristic voltage and current for the galvanometer, and putting in a value for the voltage that we wish to measure (in our case, the voltage of our power supply), we can calculate the resistance that we would need to make the voltmeter. So, measure the voltage across the power supply with the multimeter, and record the information on the Data/Question sheet.

<u>2. Voltmeter resistance recipe.</u> Now we can input that value to our voltmeter recipe formula (make sure units match). Record the information on the Data/Question sheet.

Putting this resistance in series with the galvanometer will turn it into a "voltmeter" that can read from 0 to  $V_{meas}$  volts. (This will basically make a 5-volt scale voltmeter ... if we put in a different  $V_{meas}$ , we can calculate a different voltage. Thus, when we switch scales on the multimeter, we are basically switching which resistance is in series with the galvanometer!)

## Part 4 - Using the "voltmeter" and calibrating it

Set up the circuit as shown below. The voltmeter resistance that we calculated in the previous section will be added with another decade resistance box. [There will now be two decade boxes in the circuit ... one is the "voltmeter" resistance - that will be set and left alone - the other is the "circuit" resistance ... that allows us to change the external current in the circuit, and thus the voltage across the 220 ohm resistor.] Set the resistance box to the calculated resistance for the voltmeter and connect it in series with the galvanometer to create the "voltmeter". Once set, *leave that "voltmeter" resistance box alone* and only change the circuit resistance box.



Figure 5 - Circuit diagram for "voltmeter" across the 220-ohm resistor

<u>1. Prepare circuit.</u> Start with about 100 ohms on the circuit decade resistance box. Connect the Multi meter leads across the 220-ohm resistor. We can use the ULI to record the actual voltage across the 220-ohm resistor, and we can compare that with the "reading" on the galvanometer. Tap the tap switch. You should get a deflection that is not quite full-scale.

<u>2. Look for full-scale deflection</u>. Lower the resistance to near zero on the circuit decade box, but watch for the scale reading to peak. We might not be able to reach the full-scale deflection (if our meter is too "weak"), or we might reach full-scale deflection with less than the maximum power supply voltage.

[At this point, we want to test our "voltmeter" by comparing it with a real voltage measurement {the Multi meter}. We will change the current in the system, thus changing the voltage across that resistor (220 ohms). We change the current by changing the circuit decade resistance box. Do what is necessary (increase or decrease the resistance) to get the various scale readings in the chart on the Data/Question sheet ... record the multi meter voltage for that particular scale reading in Vmeas.] The scale on the Data/Question sheet is the reading from the face of the galvanometer. Record the information on the Data/Question sheet. (If you can't reach full scale deflection – change the "35" to whatever the maximum scale is.)

### Part 5 - Calculating the Resistance for an Ammeter

An ammeter measures the current that flows through a particular point in a circuit. To do this, it must be connected **INTO** the circuit, and all of the current will flow through it. An ammeter also should not affect the circuit it is reading, so it should have a low resistance (so it won't increase the total resistance very much). With our galvanometer (which can register very small currents) we will put a very small resistance across the terminals of the galvanometer (thus most of the current runs through that resistance, and not into the galvanometer. The constructed ammeter would look like this:



Figure 6 - Circuit diagram for new "ammeter"

Considering the current that flows into the constructed ammeter, we see the following:

$$(I_0 - I_g)R_A = I_gR_g = V_g$$
  $R_A = \frac{V_g}{I_0 - I_g}$  (Should be ~ 1.5 ohms)

<u>1. Maximum current.</u> Knowing the characteristic voltage and current for the galvanometer, and putting in a value for the current that we wish to measure (in our case, the maximum current will be the power supply voltage divided by 220 ohms), we can calculate the resistance that we would need to make the ammeter. So, calculate the maximum current that will be in the system and record the information on the Data/Question sheet. (Maximum current should be ~ 22 mA - thus we should use the 200 mA scale)

<u>2. Ammeter recipe formula.</u> Now we can input that value to our ammeter recipe formula and record the information on the Data/Question sheet.

Putting this resistance in parallel (across the leads of the galvanometer) with the galvanometer will turn it into an "ammeter" that can read from 0 to  $I_0$  amps.

### Part 6 - Using the "AMMETER" and Calibrating It

The ammeter resistance that we calculated in the previous section will be added with a smaller resistance box (three dials - 10's, 1's and 0.1's). **Turn the dials of the mini decade box until it reads the value of your "ammeter" resistance.** Then connect this "ammeter" resistance in parallel with the galvanometer to create the "ammeter". <u>Once set, leave that "ammeter" resistance alone</u>, only change the circuit resistance box. Set up the circuit as shown below:



Figure 7 - Circuit diagram for "ammeter" in the circuit

<u>1. Prepare the meters.</u> Start with about 100 ohms on the circuit decade resistance box. We need to measure the current in the system. Disconnect the multi meter from ACROSS the resistor, and put it IN SERIES with the resistor (as shown above).

2. Comparing our ammeter to the actual current. Now we can use the multi meter to record the actual current in the system, and we can compare that with the "reading" on the galvanometer. Tap the tap switch. You should get a deflection that is not quite full-scale. Lower the resistance to near zero on the circuit decade box, but watch for the scale reading to peak. We might not be able to reach the full-scale deflection (if our meter is too "weak"), or we might reach full-scale deflection with less than the maximum current. Record the current values for when the galvanometer shows the given values from the chart on the Data/Question sheet (change the resistance in the circuit decade box to change the current in the circuit, as we did before). Record this on the chart on the Data/Question sheet. (If you can't reach full scale deflection – change the "35" to whatever the maximum scale is.)

## Part 7 - How Does the Voltmeter Affect the Circuit?

<u>1. Effective resistance.</u> When putting the voltmeter into the circuit across the 220-ohm resistor, we are adding some resistance in parallel to the 220 ohms. (The total resistance added in parallel would be the sum of the "voltmeter" resistance and the galvanometer resistance.) Calculate the total resistance of the voltmeter across the 220-ohm resistor, and record it on the Data/Question sheet.

2. Power change due to meter. How much electrical power is taken away from the circuit? (We need to make some assumptions here ... let's look at the worst case, when the meter is full-scale, so the galvanometer has Ig passing through it. Let's ignore the slight decrease in resistance {which would affect the current in the overall system} as calculated above.) So, we can now account for electrical power that will be from the current through  $R_v$  and the current going through  $R_g$  can be calculated on the Data/Question sheet. (The meter thus creates a slight drain of power that would not be there without the meter.)

## Part 8 - How Does the Ammeter affect the Circuit?

<u>1. Effective resistance.</u> When putting the ammeter into the circuit in series with the 220-ohm resistor, we are adding some resistance in series to the 220 ohms. (The total resistance added in series would be the parallel (effective) resistance of the "ammeter" resistance and the galvanometer resistance.) Calculate the total resistance of the ammeter, and record it on the Data/Question sheet.

<u>2. Power change due to meter.</u> How much electrical power is taken away from the circuit? (Again, we need to make some assumptions ... let's look at the worst case, when the meter is full-scale, so the galvanometer has  $I_g$  passing through it. This means that  $(I_0 - I_g)$  passes through the "ammeter" resistor (R<sub>A</sub>). Let's ignore the slight increase in resistance {which would affect the current in the overall system} as calculated above.) So, we can now account for electrical power that will be from the current through R<sub>A</sub> and the current going through R<sub>g</sub> can be calculated on the Data/Question sheet. (The meter thus creates a slight drain of power that would not be there without the meter.)

### Part 9 - Are our meters too strong or two weak?

Based on our calculations (and possibly the limits of the decade boxes), our meters might not be "perfect". Either we might hit the full-scale deflection at less than the  $V_{meas}$  (for the voltmeter) or  $I_0$  (for the ammeter), or we might not be able to get to full-scale deflection. In the former case, our meters are too strong (we won't reach the full-scale deflection until we have more voltage or current); in the latter case, our meters are too weak.

<u>1. Strength of the meter.</u> Consider the values in the ammeter and voltmeter charts. For each meter, discuss whether the meter is too strong or too weak, and explain your claim with respect to the numbers in the chart. Report your results on the Data Question sheets.

# **DATA/QUESTION SHEET / LAB 13 - BUILDING AN AMMETER AND VOLTMETER**

# Part 2 - Measuring the Characteristics of a Galvanometer

<u>3. Record the current.</u> Record the current in the ammeter when the galvanometer is deflected full-scale to one side (a reading of 35 on the galvanometer). Record the information on the Data/Question sheet.

 $I_g = \_\__m M$ 

<u>5. Full-scale deflection of meter.</u> Lower the resistance until you find the same full-scale deflection of the galvanometer. This voltage reading on the multimeter is the maximum voltage of the galvanometer. Record the information on the Data/Question sheet.

Vg =\_\_\_\_\_ mV Rg = Vg/Ig =\_\_\_\_\_ ohms (~ 100 ohms)

## Part 3 -Calculating the Resistance for a Voltmeter

<u>1. Power supply voltage</u>. Measure the voltage across the power supply with the multimeter, and record the information below:

 $V_{power\_supply} = V_{meas} = \_____ volts$ 

2. Voltmeter resistance recipe. Now we can input that value to our voltmeter recipe formula (make sure units match). Record the information below:

 $R_{V} = \frac{V_{meas} - V_{g}}{I_{g}} = \underline{\qquad} \text{ohms} \qquad \text{(should be ~15,000 }\Omega\text{)}$ 

## Part 4 - Using the "voltmeter" and calibrating it

2. Look for full-scale deflection. Record the information below:

You will be measuring the values for the middle row. For the bottom row, use the following equation:

$$V_{theoretical} = V_{powersupply} \left( \frac{scale}{35} \right)$$

You would plug in the power supply voltage, and then the various scale readings from the chart (0, 5, 10, etc) to get the corresponding scaled theoretical voltage (from 0 up to the power supply voltage).

Scale	0.0	5	10	15	20	25	30	35
V (meas)								
V (theo)								

# Part 5 -Calculating the Resistance for an Ammeter

<u>1. Maximum current.</u> So, calculate the maximum current that will be in the system and record the information below:

 $I_0 = V_{power supply} / (220 \text{ ohms}) = \____A = \___mA$  (Should be on the order of 22 mA)

<u>2. Ammeter recipe formula.</u> Now we can input that value to our ammeter recipe formula and record the information below:

 $R_A = \frac{V_g}{I_0 - I_g} = \underline{\qquad} \text{ohms} \qquad (\text{around } 1.5 \text{ ohms})$ 

Putting this resistance in parallel (across the leads of the galvanometer) with the galvanometer will turn it into an "ammeter" that can read from 0 to  $I_0$  amps.

# Part 6 - Using the "AMMETER" and Calibrating It

<u>2. Comparing our ammeter to the actual current.</u> Now we can use the multi meter to record the actual current in the system, and we can compare that with the "reading" on the galvanometer. Record this information in the chart below:

The I<sub>theo</sub> row can be calculated by using the formula:  $I_{theo} = I_0 \left(\frac{scale}{35}\right)$ 

Scale	0.0	5	10	15	20	25	30	35
I (meas)								
I (theo)								

# Part 7 - How Does the Voltmeter Affect the Circuit?

1. Effective resistance. Record this below:

$$\frac{1}{R_{V\_eff}} = \frac{1}{220\Omega} + \frac{1}{\left(R_V + R_G\right)} \qquad \qquad R_{V\_eff} = \underline{\qquad} \text{ohms}$$

(should be <220  $\Omega$ )

This means a % decrease in resistance of:

% decrease = 
$$\frac{220 - R_{V_{eff}}}{220} x 100 =$$
\_\_\_\_\_

2. Power change due to meter.

Power lost to circuit =  $R_V I_G^2 + R_G I_G^2$  = \_\_\_\_\_ Watts

Total Power  $\cong$  Power in 220 ohm resistor =  $(220\Omega)I_0^2$  = \_\_\_\_\_ Watts

% loss of total power =  $\frac{\text{power lost}}{\text{power total}} x100 =$ \_\_\_\_\_

### Part 8 - How Does the Ammeter affect the Circuit?

1. Effective resistance.

$$\frac{1}{R_{A_{-eff}}} = \frac{1}{R_A} + \frac{1}{R_G} \qquad \qquad R_{A_{-eff}} = \underline{\qquad} \text{ohms} \quad (\text{under } R_A)$$

This means a % increase in resistance of:

% increase = 
$$\frac{R_{A_{-eff}}}{220} x 100 =$$
\_\_\_\_\_

2. Power change due to meter.

Power lost to circuit =  $R_G I_G^2 + R_A (I_0 - I_G)^2$  = \_\_\_\_\_ Watts

Total Power  $\cong$  Power in 220 ohm resistor =  $(220\Omega)I_0^2$  = \_\_\_\_\_ Watts

% loss of total power =  $\frac{\text{power lost}}{\text{power total}} x100 =$ \_\_\_\_\_

### Part 9 - Are our meters too strong or two weak?

1. Strength of the meter. Discuss results here:

### How do I write up this lab? ... What is required for this lab report?

Consult the Rubric for this experiment and the "Lab Report Instructions" document (both found on the Lab Schedule page).

Questions/Suggestions -> Dr. Scott Schneider - <u>S\_SCHNEIDER@LTU.EDU</u>

Portions of this laboratory manual have been adapted from materials originally developed by Priscilla Laws, David Sokoloff and Ronald Thornton for the Tools for Scientific Thinking, RealTime Physics and Workshop Physics curricula. You are free to use (and modify) this laboratory manual only for non-commercial educational uses.