Unit-02 Basic Electricity I

Objective：

In this experiment, we would like to get you familiar with the theorem, structure and use of multimeter and learn the measurement of Alternating Current (AC) / Direct Current (DC) signals.

Apparatus：

Digital multimeter, power supply, function generator, breadboard, resistance

Principle：

In physics experiments, we usually use precision instruments to measure the physics quantities, with the most common being in voltage and current measurement. The multimeter is a multipurpose tool for measuring the current, voltage, and resistance. With Ohm's law, we can know the resistance of a resistor by measuring the current under specific voltage. The design is based on D'arsonval galvanometer. The followings are principles of kinds of measurements.

A. D'arsonval galvanometer

The top view of D'arsonval galvanometer is shown in Fig.1, when current I passes through flexible coil, it generates magnetic field. This generated magnetic field, which interacts with the permanent magnet, would cause a clockwise torque L_1, in proportion to current I. It can be expressed as the following equation：

$$L_1 = K_1 I \qquad K_1 \text{ is the proportion constant}$$

This torque would cause the rotation of the coil. The twist of upper and lower springs causes the anticlockwise torque L_2. It can be expressed as the following equation：

$$L_2 = K_2 \theta \qquad K_2 \text{ is the proportion constan}$$

When the two torques L_1 and L_2 hit a balance, the coil would stay at a specific angle θ

$$L_1 = L_2 \quad \text{or} \quad K_1 I = K_2 \theta$$

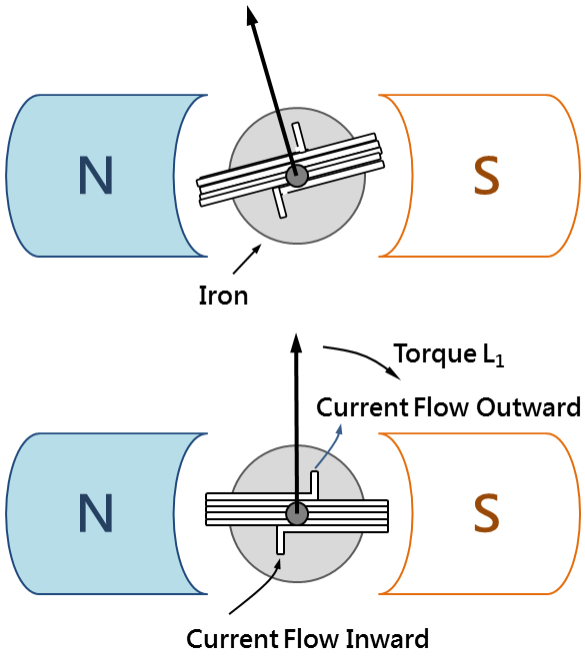

Figure 1. Principle of D'arsonval galvanometer

Assume $K = \frac{K_2}{K_1}$

So, we can get $I = K\theta$

Therefore, we can find the current value by measuring the angle of the indicator.

As is shown in Figure 2, there are two types of power supply: direct current (DC) and alternating current (AC). The current and voltage of direct current always stay constant. They would not vary with time. The current and voltage of alternating current would vary cyclically with time. Thus, the circuit would act differently when you supply these two kinds of power source.

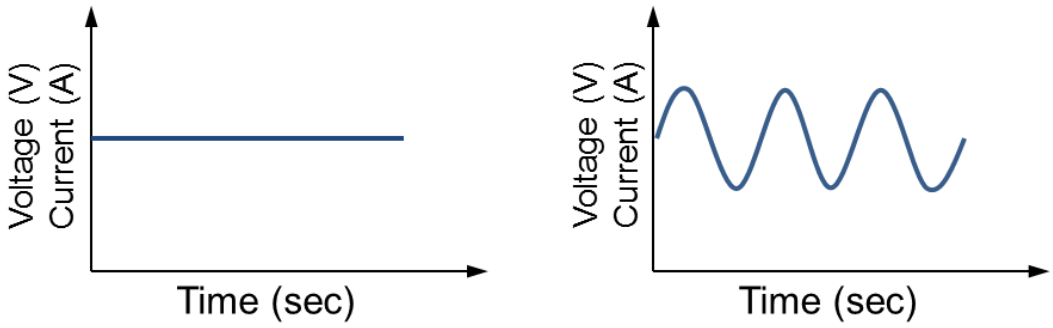

Figure 2. AC/DC signals in relation to time

To explicate the differences, take electric power as an example:

(a) Direct Current (DC)

If a resistor R is supplied by direct current I, the average power P would be

$$P = I^2 R$$

(b) Alternating Current (AC)

If a resistor R is supplied by alternating current $I = I_m \sin(2\pi t / T)$, the average power P would be

$$P = \frac{1}{T}\int_0^T R\left(I_m \sin\left(\frac{2\pi t}{T}\right)\right)^2 dt = \frac{RI_m^2}{T}\int_0^T \left(\frac{1-\cos\left(\frac{4\pi t}{T}\right)}{2}\right) dt$$

$$= \frac{RI_m^2}{T}\left(\frac{t}{2} - \frac{T\sin\left(\frac{4\pi t}{T}\right)}{8\pi}\right)_0^T = \frac{RI_m^2}{T}\cdot\frac{T}{2} = \frac{RI_m^2}{2} = R(I_{rms})^2$$

I_m is the maximum current and T is the period

In figure 3, we can see that the average power of alternating current has an additional factor 1/2. In order to unify the formula of alternating current and direct current, we define an effective current I_{rms} (root mean square of current) to describe the total effect of alternating current. Similarly, we can define an effective voltage (root mean square of voltage).

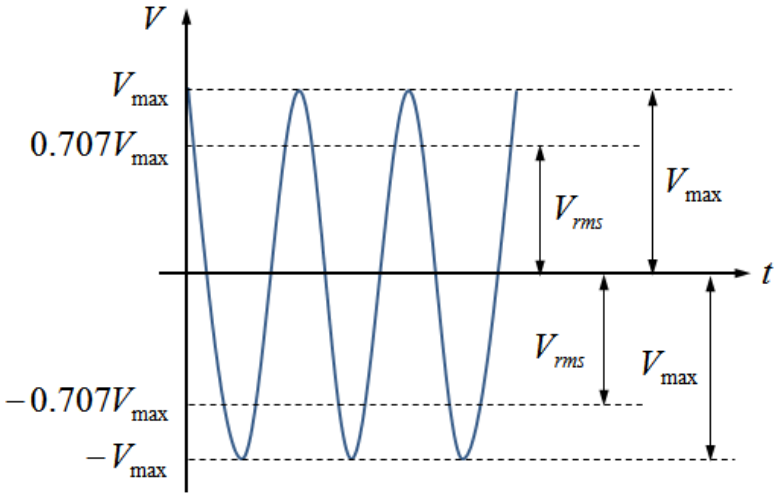

Figure 3. Root mean square of voltage

When measuring the alternating voltage and alternating current, the values on multimeter are V_{rms} and I_{rms}.

Root mean square of voltage $$V_{rms} = \frac{V_{\max}}{\sqrt{2}} = 0.707 V_{\max}$$

Root mean square of current $$I_{rms} = \frac{I_{\max}}{\sqrt{2}} = 0.707 I_{\max}$$

B. Ammeter – current measurement

As shown in Figure 4, when a galvanometer is used as an ammeter, a shunt resistor *R* is connected in parallel with the galvanometer. Assume the internal resistance of galvanometer is R_g, the maximum direct current which passes through the ammeter is *I*, and the maximum direct current which passes through the galvanometer is I_f. According to Ohm's Law, the value of the shunt resistance *S* is determined by

$$R_g I_f = (I - I_f) S \Rightarrow S = \frac{I_f}{I - I_f} \times R_g$$

Thus, the measurement gear of the DC ammeter varies in accordance with shunt resistance *S*.

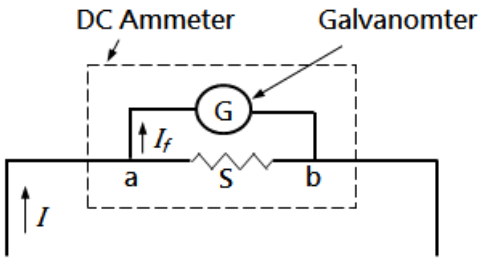

Figure 4. DC Ammeter

For AC ammeter, it is formed with a galvanometer, a small resistor, and a rectifier. (A diode has the characteristic of low resistance under forward bias and high resistance under reverse bias.) Since D'arsonval galvanopmeter can only work with direct current, a rectifier is required to transform alternative current into direct current. Insert a rectifier into the left side of node *a* in figure 5 and it can be an AC ammeter. But please remember that the dial scale of an AC ammeter is the peak current times $0.707 (= 1/\sqrt{2})$.

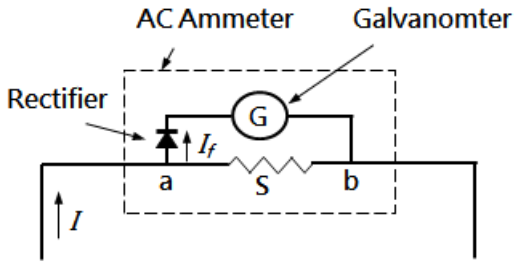

Figure 5. AC Ammeter

C. Voltmeter – voltage measurement

As shown in Figure 6, when a galvanometer is used as a voltmeter, a resistor R is connected in series with the galvanometer. Assume the highest voltage measured by galvanometer is V_m, the current at this time is I_m, the internal resistance of the galvanometer is R_g and the highest voltage to measure is $V(=V_m N)$, the resistor R we need to connect in series can be determined by

$$V_m = R_g I_m$$

$$V = NV_m = (R + R_g) I_m$$

then

$$NR_g I_m = (R + R_g) I_m$$

$$R = (N - 1) R_g$$

For AC voltmeter, it would be the same as DC voltmeter except that it requires one more rectifier and the dial scale is defined by multiplying 0.707.

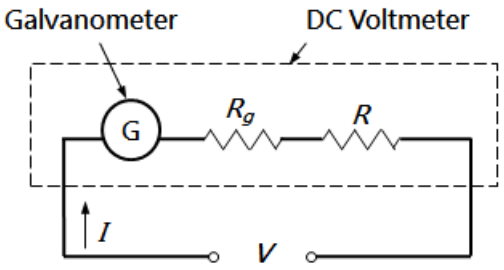

Figure 6. DC Voltmeter

D. Resistance measurement

With Ohm's law, we can know the resistance by measuring the current under specific voltage. The amount of resistance can be determined as the following

$$R = \frac{V}{I} \quad \text{(Ohm's Law)}$$

Remarks：

1. The rotary switch should be placed in the right position and no any changeover off of range shall be made during measurement is conducted to prevent damage of the Meter.
2. When measuring voltage, the multimeter should be in parallel with the circuit.
3. When measuring current, the multimeter should be in series with the circuit.
4. Never measure the voltage by current gear. If you do, it will cause fire and people might get hurt.
5. To avoid damage to the equipment, the output voltage of the power supply must not exceed 10.0 V.

Procedure：

➢ **Preparation**

1. Before measurement, read user guide of power supply, function generator and breadboard.
2. Scale switch：Switch to the proper gear when measuring voltage or current. You should start with the maximum gear down to the minimum.
3. Turn the multimeter off when it is not in use to prevent the battery from dying.

A. DC voltage, current and resistance measurement

1. Choose any two resistances and connect in series on the breadboard. Record R_1 and R_2 resistance values.
2. Set the multimeter to resistance gear, make sure that the sensor is properly connected, use the senor to touch the two ends of the resistance, and record the values of R_1 and R_2 based on color code table.
3. Set up the circuit in series and parallel on Breadboard, as indicated in Figure 7.
4. Supply direct voltage power (< 10.0V) to series circuit and parallel circus respectively.
5. Turn on the multimeter and press blue button, and then switch to DC measurement.
6. Set the multimeter to voltage gear and record the total voltage and the shunt voltage with the Meter connected in parallel.
7. Set the multimeter to current gear (from high to low) and record the total current and the shunt current with the multimeter connected in series.

8. Calculate the total voltage, shunt voltage, total current, and shunt current by Ohm's Law.

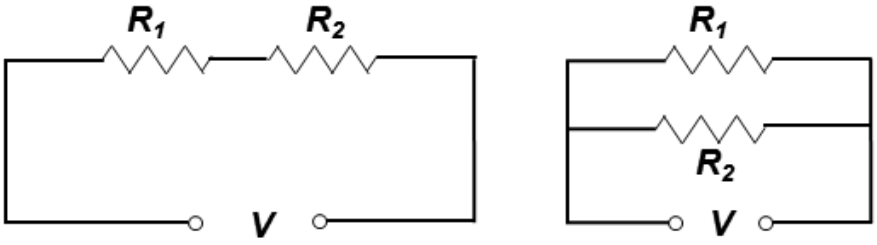

Figure 7. Series and parallel circuit

[Note] Color Code

Black	Brown	Red	Orange	Yellow	Green	Blue	Violet	Grey	White
0	1	2	3	4	5	6	7	8	9
Gold	Silver								
±5%	±10%								

B. AC voltage measurement

1. Turn on the Meter and press Function (AC/DC) (blue button), and then switch to AC measurement.
2. Connect two leads separately to anode and cathode of Meter, and then connect the other side of both leads to the anode and **COM** of function generator.
3. Fix output frequency 60 Hz sine wave, adjust the amplitude (AMPL switch), and observe the variation of AC voltage.
4. Fix the output amplitude, adjust output frequency (60 Hz, 120 Hz, 1 kHz, 10 kHz, 100 kHz, 1 MHz) and measure voltage.

Questions：

1. Are the measured values and calculated values the same in DC voltage measurement? What is the reason for the difference? Please explain.
2. Are the measured AC voltage values the same when the output amplitude is fixed with varying output frequency? What is the reason for the difference? Please explain.