Lecturers In

Physics Lab Exercises (II)

Second Term

For First Year Students

Faculty of Basic Education

Prepared By

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Physics Laboratory instructions and safety

I. GENERAL INSTRUCTIONS

• Before starting a new Physics lab, you must always read the laboratory notes for that experiment and the instructor will discuss the experiment with you. If you don't know the experimental procedure, the Demonstrator may not let
you proceed with the experiment.

• Notes must be made during each laboratory exercise .

• Report to the Demonstrator or advisor if you find equipment that is out of order or you break something.

• If you run out of some reagent, let the Demonstrator know.

• Prepare the written laboratory report according to Sec. IV.

Note that this PDF file contains hyperlinks that can be activated by clicking on the underlined link -word.

II. LABORATORY SAFETY

The laboratory instructor will review the following safety rules and regulations with you and will point out the location and operation of the fire extinguisher, safety shower, eye wash, and other laboratory safety equipment available.

The safety rules:

1. While in the laboratory, you must wear approved safety goggles. Hair and easily combustible clothing must be confined at all times.
2. Do not smoke, eat, or drink in the laboratory.
3. Before beginning to work in the laboratory you should be familiar with the procedure you will be following, as well as with any special precautions or changes that the instructor may note. Report any unexpected events to the Demonstrator.
4. No unauthorized experiments may be performed. Violators will be subject to severe disciplinary action.
5. Before leaving the laboratory wash your hands carefully.
6. In case of an accident, the laboratory Demonstrator should be summoned. Furthermore:

(a) If you receive a chemical burn, immediately flood the area with cold water while another student summons the Demonstrator.

(b) Treatment for injuries may be obtained from the Student Health Center.

7. When conducting experiments:

(a) When cutting glass tubing or inserting tubing into stoppers, protect your hands by using a towel. Glass tubing should be lubricated with glycerol or water to aid insertion of the tubing into stoppers. To remove tubing from stoppers, cut the stoppers.
(b) When heating or carrying out reactions in a test tube, never point the mouth of the tube at your neighbor or yourself.
(c) Never taste or smell a chemical unless instructed to do so.
(d) When smelling a chemical, fan vapors toward your face and inhale *cautiously*.
(e) Never pour water into concentrated acid; slowly add the acid to the water with constant stirring in a pyrex beaker or flask, not in a graduated cylinder.
(f) Never pipet liquids by mouth; use a suction bulb.
(g) If objectional vapors are given off during an experiment, the experiment must be performed in a hood.
(h) Unless instructed otherwise, flammable solvents with boiling points less than 100 ^oC must be heated, distilled, or evaporated on a steam bath, not over or near an open flame. Flammable solvents should be contained in flasks rather than in open beakers.
(i) Each student is responsible for cleaning up all spilled chemicals at his desk, on the reagent shelves, in the hoods, and around the balances. Consult the instructor if uncertain about the method of cleanup.
(j) No chemicals should be disposed of in the sink unless instructed to do so. There are chemical solvent waste bottles in the hood. If chemicals are disposed in the sink, they should be washed down with ample water
for several minutes. Materials such as broken glass and towels should be placed in the receptacles beneath the sinks or in a waste jar. If in doubt, ask the instructor!
(k) Never dispose of sodium or potassium metal in the sinks as they react violently with water. Consult the instructor for the method of disposal.

III. PREPARATION OF THE LABORATORY NOTES

Your laboratory notebook is the primary record of your observations during the experiment. The central requirements for a notebook are completeness and comprehensibility, not organization and polish. Make the notes in such a way that others can read them too. Even though things may look obvious at the moment, they may not be so obvious after few weeks! Include at least the following in your laboratory notes:

- Your name, the name of the experiment and the date.
- Your "pre-lab" preparations – calculations of concentrations, required glassware etc.
- The equipment used and reagents including their purities.

• Include details about weighing of compounds, volumes of liquids, and the related errors. In the latter case the errors may originate, for example, from the accuracy of the volumetric flasks or pipettes used.
• Results from the measurement. Remember to label the numerical information you write down. In many cases, it is preferable to present results in tabular form.
• "Unexpected" events – like switching to another buffer solution, drift in instrumental readings, etc.

You will be asked to provide a photocopy of your laboratory notes to the instructor. Once the instructor has received the photocopy, he/she will sign your laboratory notes. The original laboratory notes must be submitted with each written laboratory report. *The original notes will not be accepted without the instructor signature!* If the experiment involves computer data files, be sure to store your data on floppy diskettes or a USB memory stick and make backups.

Remember to document the file names in your notes so that you will be able to connect the file names to the actual measurements later on. Note that your laboratory notes will also contribute to the overall grade.

Note: If you lose your laboratory notes, you will not be able to write the laboratory report and you will have to do the experiment again.

IV. PREPARATION OF A WRITTEN LABORATORY REPORT

A written laboratory report plays an equally important role as the experiment itself. The experimental results are usually meaningless unless they are not analyzed and interpreted properly. Furthermore such reports must provide the important details how the experiment was carried out. A general rule is that you should think that you are writing to another chemist (perhaps another chemistry student) who should after reading the report understand the experimental procedure and the meaning of the results. Do not include excessive amount of information or directly copy the laboratory instructions. The laboratory report format (see below) corresponds loosely to that of scientific research papers and part of the exercise is to learn how to write such documents. Every student must prepare their own written laboratory report, which should include the following sections: Abstract, Introduction, Experiment, Data analysis, Results, Discussion and References. The abstract must be preceded by a title, author and the date of the experiment. All equations, tables and figures must be numbered in sequence. In addition, tables and figures must include a caption that describes their content. All figures must have clearly specified axes (i.e.., axis label and unit; for example, Wavelength (nm)). A brief overview of the required sections is given below.

***Introduction*.** A brief introduction that summarizes the theoretical background, and the objective and approach of the experiment. (length typically ﹤ 1 page)

***Experiment*.** Describe the experimental setup and add notes of any special procedures that were carried out. For any instruments used, provide either the manufacturer and model or a schematic drawing of the setup. Indicate the possible error sources and accuracies for each instrument used. Chemicals and their purities must also be reported. Overall, the level of detail must be sufficient for others to repeat an equivalent experiment. Do not include irrelevant information, like what size flasks were used in preparing the solutions etc. (length typically ﹤ 1 page)

***Data analysis*.** Explain how the results were calculated using the experimental data. This would typically include data fitting and the related error estimates. Note also any computer programs and additional tools that were used. Do not include your prelab calculations here. (length typically ﹤ 1 page)

***Results*.** This section should contain the results from the experiments and how they were analyzed. Be sure to include the raw data in tabular form (or as graphs, if they take excessive amount of space). Remember that all numerical data must be supplied with proper units (SI) and accuracy. For example, you can first show the raw data and then proceed in describing the analysis and referring to the figures and tables. (length typically < 2 pages of text; may be longer when figures and tables are included).

***Discussion*.** Discuss your results and compare your results to literature values (theoretical and/or experimental), if available. If your results deviate from the literature values, explain why this is so and is the difference significant.

Remember to include reference numbers in the text for any literature values used.

Introduction to Measurement

1-Units and Measurement

One of the most important steps in applying the scientific method is *experiment*: testing the prediction of a hypothesis. Typically we measure simple quantities of only three types: mass, length, and time. Occasionally we include temperature, electrical charge or light intensity. It is amazing, but just about everything we know about the universe comes from measuring these six quantities. Most of our knowledge comes from measurements of mass, length, and time alone. We will use the standard used by the international scientific community for measuring these quantities: the SI metric system. *A measurement without a unit is meaningless!*

1-The scientific notation

In the scientific notation the base number and the exponent are written separately. For example, 3014.15 would be written in the scientific notation as 3.01415×10^3. Here 3.01415 is called the coefficient and it has to be a number greater than or equal to 1 and less than 10. The use of scientific notation is preferred because the prefixes indicating powers of ten can be used to simplify the exponent. For example, 10^3 would correspond to k (kilo) – see Table I for a complete list.

TABLE I: Prefixes indicating the powers of ten.

Prefix	Power	Prefix	Power
exa (E)	10^{18}	atto (a)	10^{-18}
peta (P)	10^{15}	femto (f)	10^{-15}
tera (T)	10^{12}	pico (p)	10^{-12}
giga (G)	10^{9}	nano (n)	10^{-9}
mega (M)	10^{6}	micro (μ)	10^{-6}
kilo (k)	10^{3}	milli (m)	10^{-3}
hecto (h)	10^{2}	centi (c)	10^{-2}
deca (da)	10^{1}	deci (d)	10^{-1}

2. Units

A scientific quantity is not complete unless both the value and the unit are given. SI units should be used in most cases. A list of SI units as well as the derived units are given tables II, III and Conversion between SI and other unit systems are given Tables IV and V. Some constants relevant to physical chemistry are listed in Table VI in SI units. VI.

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ABLE II: SI units are an international standard (MKS; 1960).

Quantity	Unit	Symbol	Definition
length	meter	m	Fixed to speed of light
mass	kilogram	kg	Weight of a reference cylinder
time	second	s	Fixed to Cs radiative lifetime
current	ampere	A	Fixed to current in reference system
temperature	kelvin	K	0 K = absolute zero, 273.16 K = triple point of H_2O
luminous intensity	candela	cd	Fixed to a black-body reference
amount of substance	mole	mol	The number of ^{12}C atoms in 0.012 kg. Avogadro's constant gives the number of molecules in one mole; $N_A = 6.022137 \times 10^{23}$ mol^{-1}

TABLE III: Derived units based on SI units.

Quantity	Unit	Symbol	Definition
force	newton	N	$1\ N = 1\ kg\ m\ s^{-2}$
energy	joule	J	$1\ J = 1\ kg\ m^2\ s^{-2}$
electric charge	coulomb	C	$1\ C = 1\ As$
pressure	pascal	Pa	$1\ Pa = 1\ N\ m^{-2}$
magnetic field	tesla	T	$1\ T = 1\ kg\ s^{-2}\ A^{-1}$
frequency	hertz	Hz	$1\ Hz = 1\ s^{-1}$
power	watt	W	$1\ W = 1\ J\ s^{-1}$
voltage	volt	V	$1\ V = 1\ W\ A^{-1}$
resistance	ohm	Ω	$1\ \Omega = V\ A^{-1}$

TABLE IV: Derived units based on SI units.

Non-SI unit	SI unit	Conversion factor
Ångström (Å)	meter (m)	1 Å$= 10^{-10}$ m
inch (in)	meter (m)	1 in = 2.54 cm = 0.0254 m
foot (ft)	meter (m)	1 ft = 12 in = 0.3048 m
mile (mi)	meter (m)	1 mi = 5280 ft = 1609.344 m
AMU	kilogram (kg)	1 AMU = 1.66054×10^{-27}kg
eV	joule (J)	1 eV = 1.602177×10^{-19} J
cal	joule (J)	1 cal = 4.1868 J
torr (Hgmm)	pascal (Pa)	1 torr = 1.33322×10^2 Pa
atmospheres (atm)	pascal (Pa)	1 atm = 1.01325×10^5 Pa
bar	pascal (Pa)	1 bar = 10^5 Pa
psi	pascal (Pa)	1 psi = 6.8948×10^3 Pa
gauss (G)	tesla (T)	1 G = 10^{-4} T

VI. ERROR ANALYSIS

Conversion Factors : TABLE V: Common conversion factors. For Kelvin units, the energy corresponds to kT. Note also that 1 K = 3.1669 × 10^{-6} Hartree (atomic units; a.u.) or 1 eV = 27.2114 Hartree. To get J mol−1 or kcal mol−1, multiply by Avogadro's number NA. For example, 1 eV = 1.602177×10^{-19} J and 1 atm = 760 torr.

Mass – Energy

kg	u	J	eV
1	6.022137×10^{26}	8.987552×10^{16}	5.609586×10^{35}
1.660540×10^{-27}	1	1.492419×10^{-10}	9.314943×10^{8}
1.112650×10^{-17}	6.700531×10^{9}	1	6.241506×10^{18}
1.782663×10^{-36}	1.073544×10^{-9}	1.602177×10^{-19}	1

Spectroscopic units

Hz	cm^{-1}	Ry	eV
1	3.335641×10^{-11}	3.039660×10^{-16}	4.135669×10^{-15}
$2.99792458 \times 10^{10}$	1	9.112671×10^{-6}	1.239842×10^{-4}
3.289842×10^{15}	1.097373×10^{5}	1	1.360570×10^{1}
2.417988×10^{14}	8.065541×10^{3}	7.349862×10^{-2}	1

Energy

K	kWh	kcal	J	eV
1	3.83516×10^{-30}	3.298×10^{-27}	1.38066×10^{-23}	8.61739×10^{-5}
2.60745×10^{29}	1	8.598×10^{2}	3.60000×10^{6}	2.24694×10^{25}
3.0325×10^{26}	1.1630×10^{-3}	1	4.1868×10^{3}	2.6132×10^{22}
7.24292×10^{22}	2.77778×10^{-7}	2.388×10^{-4}	1	6.241506×10^{18}
1.16045×10^{4}	4.45049×10^{-26}	3.827×10^{-23}	1.602177×10^{-19}	1

Pressure

Pa	bar	kp / cm^2	torr (mmHg)	atm
1	10^{-5}	1.020×10^{-5}	7.5006×10^{-3}	9.869×10^{-6}
10^{5}	1	1.020	7.5006×10^{2}	9.869×10^{-1}
9.807×10^{4}	9.807×10^{-1}	1	7.3556×10^{2}	9.678×10^{-1}
1.333×10^{2}	1.333×10^{-3}	1.360×10^{-3}	1	1.316×10^{-3}
1.013×10^{5}	1.013	1.033	760	1

Often it is necessary to convert from one unit to another. To do so, you need only multiply the given quantity by a conversion factor which is a ratio equal to 1, derived from definitions. For example, there are 100 centimeters in a meter. You can make a conversion factor out of that definition so that if you need to convert 89cm to meters, simply multiply by the conversion factor, which is equal to 1:

$$100\text{cm}=1\text{m} \longrightarrow \frac{1\text{m}}{100\text{cm}}=1$$

$$89\text{cm}\times\frac{1\text{m}}{100\text{cm}}=.89\text{m}$$

You can make conversion factors out of the definitions listed in the tables above and in your book.

Length Measurement
Vernier Caliper, Micrometer Screw, and Spherometer

Purpose of the Experiment

The purpose of this experiment is for **students** to understand the operating principles and usages of various length measurement instruments and to learn to address errors in the measurement. In general, the most frequently used length measurement instrument is the meter scale or rule. However, meter scales possess the following innate disadvantages:

1. Poor accuracy (the smallest scale marking or division is 1/10 cm, and any length below this scale can only be estimated).
2. Inability to measure the radius of curvature for spherical surfaces.

To overcome these drawbacks, we typically use more precise measurement instruments:

1. Vernier caliper
2. Micrometer screw
3. Spherometer

These instruments are used for various purposes and will be used frequently in other experiments.

Although the Vernier caliper and the micrometer screw have already been introduced briefly in high school curricula, we hope that students can use this experiment as an opportunity to develop a comprehensive understanding of length measurement.

Experimental Principle

A. **Vernier caliper**

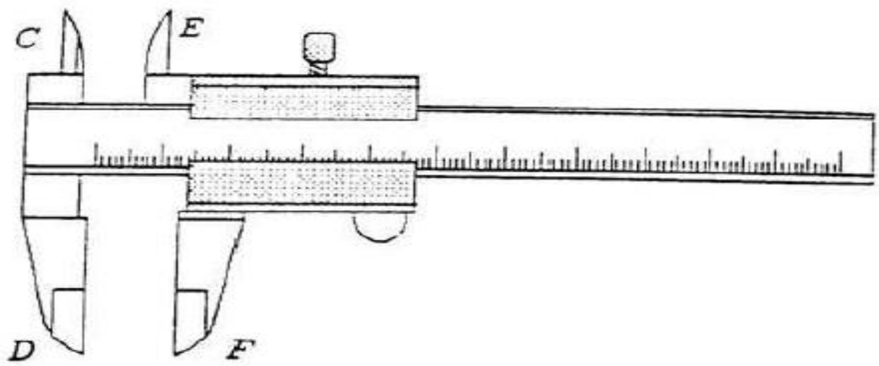


Figure 1

The Vernier caliper consists of a main scale and a vernier scale, and enables readings with a precision of 1/200 cm. Figure 1 shows that the main scale is fitted with Jaws C and D on either side, with the straight edges connecting C and D vertically to the main scale forming a right angle. Simultaneously, Jaws E and F are fitted on the Vernier scale, which moves over the main scale. When the jaws of the main and the Vernier scales contact each other, the zeros of both scales should coincide. If the zeros do not coincide, a zero point calibration must be performed instantly. The distance between C and E or between D and F is the length of the object that is being measured.

We first use an example to demonstrate how to read the Vernier caliper, followed by simple equation readings.

Figure 2

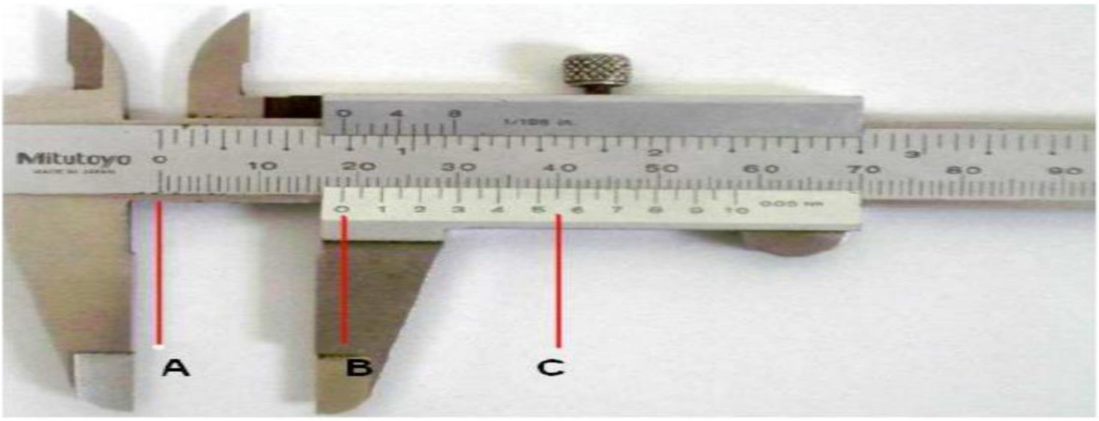


Figure 3

The Vernier scale in Figure 2 is graduated into 20 divisions or scale markings, which coincide with the 39 smallest divisions on the main scale (i.e., 39 mm). Assuming the length of one division on the Vernier scale is S, then S can be obtained as follows

S = 1.95 mm. (1)

In Figure 3, the zero on the Vernier scale is located between 18 and 19 mm on the main scale, whereas the 11th division on the Vernier coincides with the 40 mm on the main scale. Thus, AB is the length of the object, and : **AB = AC − BC (2)**

where the length of *AC* is 40 mm and *BC* is the length of the 11 divisions on the Vernier scale. Therefore, : **AB = 40 − 11 × S = 40 − 11 × 1.95 = 18.55. (3)**

However, although these calculations are easy, repeating them in each reading is time consuming. In fact, some contemplation enables Vernier caliper reading to be as direct and rapid as straight ruler reading. We hereby convert (3) into (4).

AB = 18 + 11 × _2 − 1.95_ = 18 + 11 × 0.05 (4)

Where 18 represents the division (i.e., 18 mm) on the main scale that precede the location where the zero on the Vernier scale points in Figure 3. Furthermore, 11 represents the division on the Vernier scale that coincides with a division on the main scale. A closer look indicates that 0.05 is marked on the Vernier caliper.

Thus, a reading of the Vernier caliper can be obtained rapidly following these steps:

1. Determine that the zero on the Vernier scale is located between divisions *n* and *n+1* on the main scale;
2. Identify division *m* on the Vernier scale as coinciding to a certain division on the main scale;
3. Determine how many units *M* one division on the Vernier scale is equivalent to. This unit is typically displayed on the Vernier scale. For example, Figure 3 shows that one division on the Vernier scale is equal to 0.05 mm. (Note: when we say that one division on the Vernier scale is equal to 0.05 mm, this does not mean that one division on the Vernier actually measures 0.05 mm. The actual length of one division on the Vernier scale shown in Figure 3 is in (1)). If the Vernier caliper does not show how many divisions a scale marking or divisions on the Vernier scale is equivalent to, we can obtain this information through calculations. The method is specified in a subsequent passage.

4. The reading should be n + m × M (A closer inspection shows that the value of m × M is displayed on the Vernier caliper. Therefore, a Vernier caliper reading is as simple as a straight ruler reading, and we can obtain the measurements instantly).

In labs, Vernier calipers possess various specifications. For example, the one shown in Figure 3 contains a Vernier scale, whose 20 divisions coincide with the 39 smallest divisions on the main scale.

We provide the following examples to demonstrate how to calculate how many divisions one marking on the Vernier scale equals.

Example 1: The 20 divisions on the Vernier scale coincide with the 39 smallest markings on the main scale (mm). Thus, the length of one division on the Vernier scale is

$$S = \frac{39}{20} = 1.95.$$

Therefore, one division on the Vernier scale is equal to 2 - 1.95 = 0.05 mm.

Example 2: Ten divisions on the Vernier scale coincide with 9 smallest divisions on the main scale (mm). Thus, the length of one division on the Vernier scale is

$$S = \frac{9}{10} = 0.9.$$

Therefore, one division on the Vernier scale is equal to 1 - 0.9 = 0.1 mm.

Regarding the Vernier calipers in this lab, we have summarized the following rules by which we can obtain what one division of the Vernier scale equals.

1. When the smallest division on the main scale is *M* and *n* divisions on the vernier scale are equal to *m* divisions on the main scale, the actual length of the smallest division on the Vernier scale is S = M{m/n}
2. $\frac{m}{n}$ is not an integer, and the value of $\frac{m}{n}$ is between integers *R*-1 and *R*, that is, $R - 1 < \frac{m}{n} < R$.
3. One division on the vernier scale is equal to $D = \left(R - \frac{m}{n}\right) \times M$.

B. Micrometer screw

Figure 4 shows a micrometer screw, where A is an anvil fixed to the frame (F), and the spindle (B) channels through F and the sleeve (S) to connect to a revolution thimble (T) and a ratchet (H). S is marked with precise divisions, and the periphery of T is graduated into 50 equal parts. For one revolution of T, it moves forward or backward half a division on the sleeve, that is, 0.05 cm (metric micrometer screw). Therefore, one division on the periphery of T equals 0.05/50 = 0.001 cm

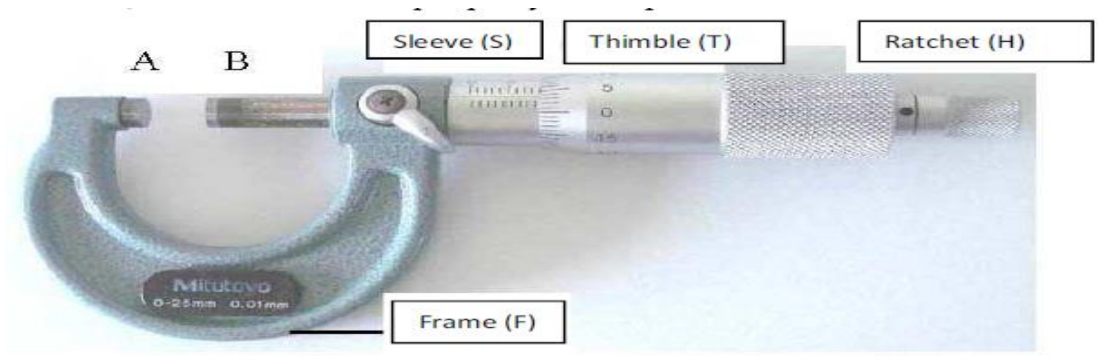


Figure 4

The ratchet is designed to ensure that the object that is placed between the anvil and the spindle undergoes a certain amount of pressure, but that the pressure does not cause significant object deformation, which would affect the precision of the measurement. Therefore, rather than directly turning the thimble to compress the object during measurement, we should turn ratchet (H) for adjustments. We will use an example to demonstrate the usage of micrometer screws. Figure 5 shows the positions of S and T when the length of an object is *Y.* The edge of T is located between 9.5 and 10.0 mm on S, and the reading on T is 33.5. Therefore, the distance between the edge of T and the 9.5 mm on S is.

$33.5\ x\ \frac{1}{100}\mathrm{mm} = 0.335\ \mathrm{mm}$ Thus, the length of the object is: $\mathrm{Y} = 9.5 + 33.5\ x\ \frac{1}{100} = 9.\mathbf{8}35\ \mathrm{mm}$

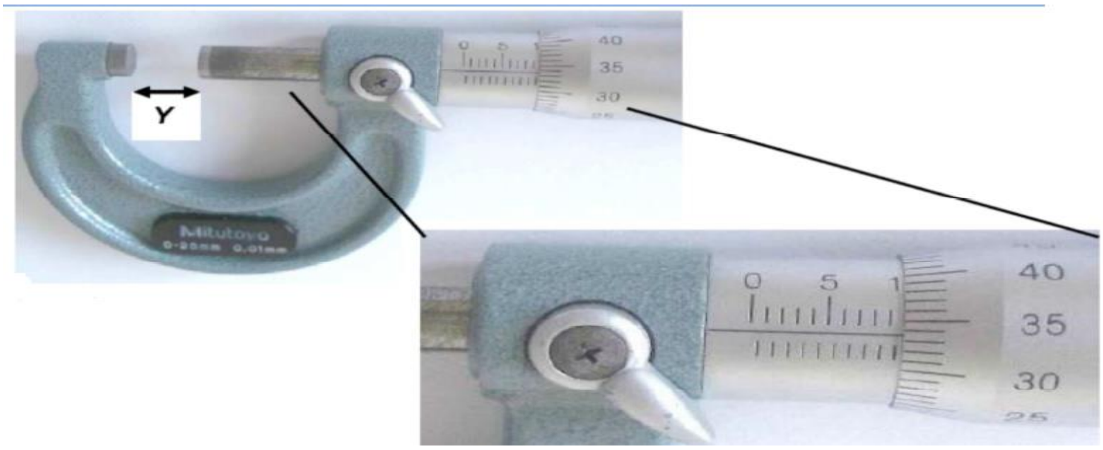


Figure S

C. Spherometer

Spherometers are used to measure the thickness of thin objects or the radius of curvature of objects. Its structure and operating principles are similar to those of a micrometer screw. Figure 6 shows that a straight ruler (S) is placed on a tripod (T) and a circular disc is located on top of the screw (I). The circular scale (G) is graduated into 100 equal parts or divisions. For one rotation of the circular scale, it
advances or recedes by 0.1 cm on S. Therefore, each division of G is equal to P{1/100}x 0.1 equals 0.001 cm.

To measure a spherical surface, first place the three legs (ABC) of the spherometer on the surface, and adjust the screw so that F is in contact with and fixes the surface. If the spherical glass being measured is positioned as shown in Figure 7, assuming its radius of curvature is *R*, the spherometer is located at points A, B, C, and D, and the tip of the central angle is at D. We assume that *h* is the distance between D and D', which is the center of the equilateral triangle formed by A, B, and C, the sides of Triangle ABC are *s*, and the distances between D' and A, B, and C are all *r.*

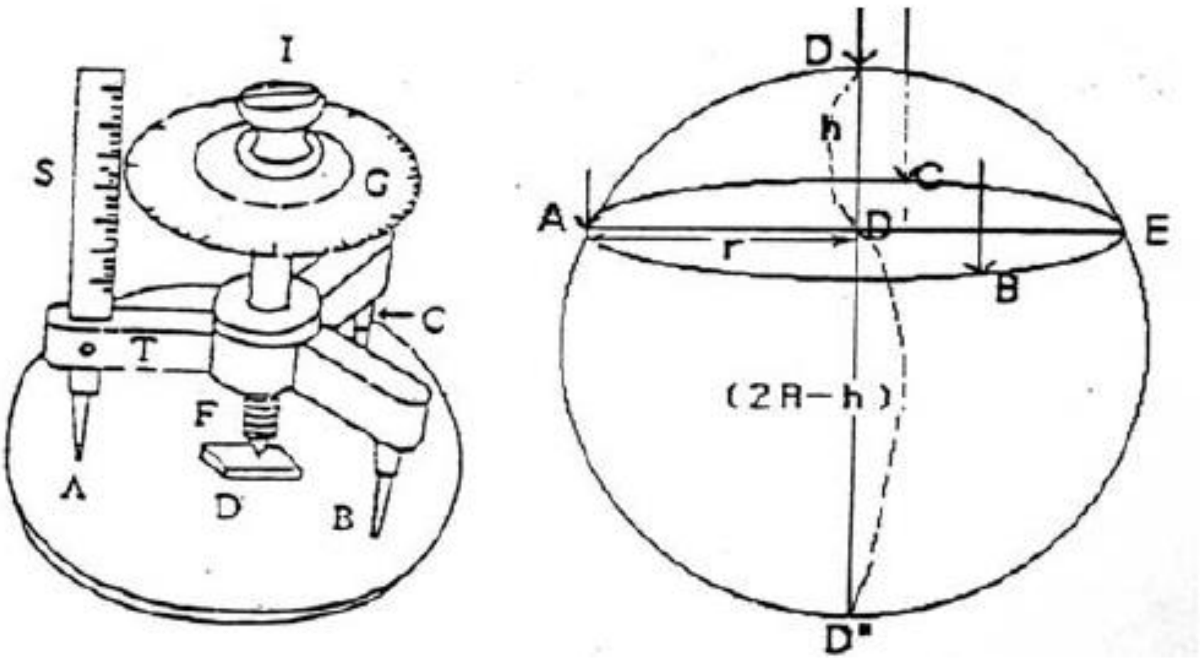


Figure 6

Based on the relationship of similar triangles, we obtain

$$\Delta ADD' \sim \Delta D''AD'$$

$$AD' : DD' = D''D' : AD' \rightarrow r : h = (2R - h) : r$$

$$\therefore R = \frac{h}{2} + \frac{r^2}{2h}.$$

Furthermore, ΔABC is an equilateral triangle, the side length of which is s; therefore

$$\frac{s}{2} = r \sin 60^o = \frac{\sqrt{3}}{2} r \rightarrow r^2 = \frac{s^2}{3}$$

$$\therefore R = \frac{h}{2} + \frac{s^2}{6h}.$$

Laboratory Instruments

1. Vernier caliper 2. Micrometer screw 3. Spherometer 4. Hollow cylinders (several)
5. Watch glass (several) 6. Plate glass 7. Coins (self-prepared)

Experimental Procedure

A. Vernier Caliper

1. Zeroing

a. Close the jaws of the vernier caliper and read the zeros;

b. Repeat the action five times and calculate the means of the errors and the standard deviations.

2. Measure the thicknesses and diameters of the coins five times, respectively, and calculate the means of the measurements and the mean standard deviations.

3. Use the results from Steps 1 and 2 to calculate the volume of the coins (including the means and mean standard deviations).

4. Select a random hollow cylinder and measure its outer and inner diameters and depths five times, respectively, and calculate the means and mean standard deviations.

5. Use the results from Steps 1 and 4 to calculate the volume of the hollow cylinder (including the means and mean standard deviations).

B. Micrometer Screw

1. Perform zeroing, same as Step A.-1, and identify the means of the errors and standard deviations.

2. Same as Step A.-2. (Measure the same coin as the one used in Step A)

3. Same as Step A.-3.

C. Spherometer

1. Zeroing: Place the spherometer on plate glass and ensure that A, B, C, and F are all contacting the glass. Read the zeros. Repeat the measurement five times and calculate the means of the errors and standard deviations.

2. Select a random watch glass, place the spherometer on the spherical surface of the glass, and ensure that the tips of the four legs are in contact with the surface. Read the scale measurement. The difference between zero and this value is *h.* Repeat this action five times and calculate the means of *h* and mean standard deviations.

3. Place the four legs of the spherometer on flat paper simultaneous. Apply a little pressure to press the tips to leave marks on the paper. Use these marks to obtain the side length *s* of Equilateral Triangle ABC. Repeat the measurement five times and calculate the means of *s* and standard deviations.

4. Based on these results, calculate the radius of curvature of the watch glass (means and mean standard deviations).

Questions for Reflection

1. Using the vernier calipers and the micrometer screw to measure the same object, which method will yield a more precise result? Why?

2. Can we use the spherometer to measure the radius of curvature of a concave mirror? If yes, please demonstrate how to modify the equations.

3. Based on the statistics of the experiments, please explain how to determine the significant figures of the results.

Experiential Exercises On Straight Line Equations

The equation of a straight line is usually written this way:

$$y = mx + b$$

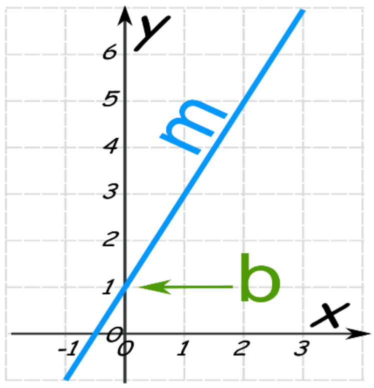
(or "y = mx + c" in the UK)

What does it stand for?

$$y = mx + b$$

Slope or Gradient

y when x=0 *(see Y Intercept)*



y = how far up

x = how far along

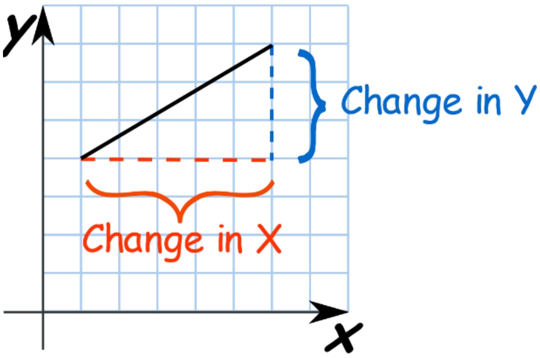
m = Slope or Gradient (how steep the line is)

b = value of **y** when **x=0**

How do you find "m" and "b"?

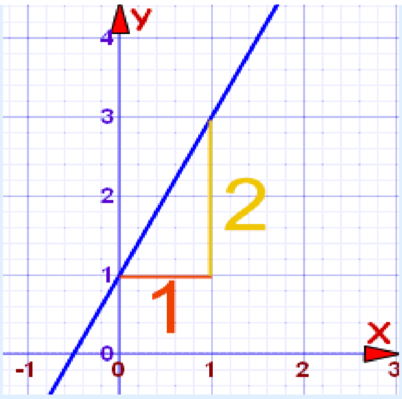
- b is easy: just see where the line crosses the Y axis.
- m (the Slope) needs some calculation:

m = *Change in Y*/ **Change in X**



Knowing this we can work out the equation of a straight line:

Example 1



m = 2**1** = 2

b = 1 *(value of **y** when x=0)*

So: y = 2x + 1

With that equation you can now ...

... choose any value for x and find the matching value for y

For example, when x is 1:

y = 2×**1** + 1 = 3

Check for yourself that x=1 and y=3 is actually on the line.

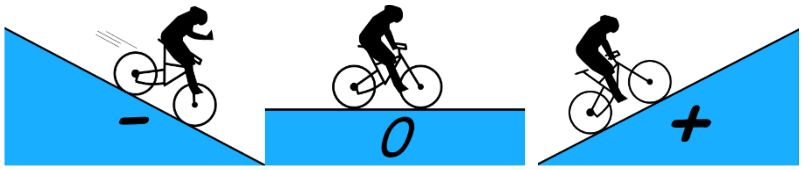
Or we could choose another value for x, such as 7:

y = 2×**7** + 1 = 15

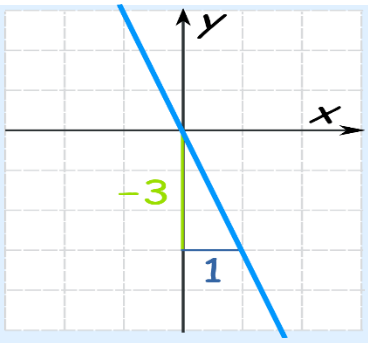
And so when x=7 you will have y=15

Positive or Negative Slope?

Going from left-to-right, the cyclist has to **P**ush on a **P**ositive Slope:



Example 2



m = −*3*/**1** = −3

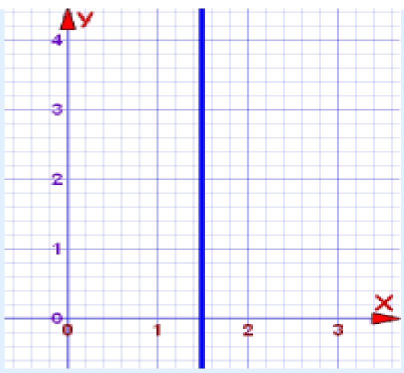
b = 0

This gives us **y = −3x + 0**

We do not need the zero!

So: y = −3x

Example 3: Vertical Line



What is the equation for a vertical line?
The slope is **undefined** ... and where does it cross the Y-Axis?

In fact, this is a **special case**, and you use a different equation, not "**y**=...", but instead you use "**x**=...".

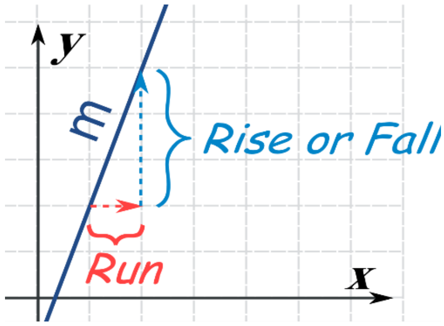
Like this:

x = 1.5

Every point on the line has **x** coordinate **1.5**,
that is why its equation is **x = 1.5**

Rise and Run

Sometimes the words "rise" and "run" are used.



- Rise is how far up
- Run is how far along

And so the slope "m" is:

m = *rise*/**run**

You might find that easier to remember.

EXERCISES 2

1. (a) On a single graph plot the following curves:

$$y = 1.5x + 3$$

$$y = x^2$$

$$y = \frac{1}{3}x^3$$

for values of x between - 3 and + 3.

(b) By observing the points of intersection of the curves in (a) find the roots of each of the equations:

$$x^2 - 1.5x - 3 = 0$$

$$\frac{1}{3}x^3 - 1.5x - 3 = 0$$

(Note that in order to obtain reasonably accurate values for the roots, the grid Δx should not exceed 0.1 in the regions near the solutions).

2. The relation between the time of swing or period, T, of a pendulum and its length L is given by

$$T = 2\pi\sqrt{L/g}$$

where g is a constant.

The value of L and T obtained from an experiment are:

L(cm) :	24	49	74	105	150
T(sec) :	1.02	1.45	1.80	2.07	2.48

(a) Determine g by the following way. Substitute each pair of the values for L and T into the above formula to obtain a value for g, then find the mean $\bar{g}$.

(b) Determine g from the graph of T^2 vs L.

(c) State which method you would consider to give the more accurate value of g, and why.

3. To obtain the coefficient of friction between two wooden surfaces the following formula was used:

$$coefficient\ of\ friction = \frac{mass\ of\ pan + mass\ in\ pan}{mass\ of\ tray + mass\ in\ tray}$$

Or $$\mu = \frac{p + w}{T + W}$$

where

p = mass of pan, w = mass in pan

T = mass of tray, W = mass in tray

The values of w and W obtained by experiment were as follows:

W(gm) :	0	200	400	600
w(gm) :	21	86	143	208

What is the value of the coefficient of friction, μ?

4. The relation between the current i sent through a galvanometer of resistance G by a cell of constant e.m.f. E, when the external resistance is R, is given by

$$i = \frac{E}{R+G}$$

The relation between the current i and the deflection θ it produces in a tangent galvanometer is given by $i = k \tan \theta$

where k is a constant.

Determine graphically the resistance G of the galvanometer from the experimental results:

R (ohm) :	1	5	14	26	38	61
θ (degree) :	71	63	51	40	32	23

5. A ball rolls down a slope. The distances s covered at different times t are given below.

t (sec) :	0	1	2	3	4	5	6
s (m) :	0	2	8	18	32	50	72

Plot the graph of s against t.

(a) The velocity, v, of the ball is the instantaneous rate at which distance is covered, (i.e. the velocity is the rate of increase of s with respect to t). What is the velocity after 1 sec., 2 secs., 3 secs., 4 secs., and 5 secs.?

(b) The acceleration, a, of the ball is the instantaneous rate at which the velocity increases, (i.e. the acceleration is the rate of increase of v with respect to t). Draw the velocity - time graph and from it find the acceleration after 1 sec., 3 secs., and 5 secs. Is the acceleration constant? What is the relation between v and t?

(c) Find the area (in velocity - time units) under the (v, t) curve between the third and the fourth seconds. Compare your answer with the distance covered during the fourth second as read off from the (s, t) graph. What conclusion can you draw from your observations?

6. Using the values of s and t of Problem 5, plot log s against log t. Hence determine the relationship between s and t.

7. The data below refer to the amplitudes of successive swings of the pendulum vibrating in a viscous medium.

Number of swings (x) :	1	2	3	4	5	6	7	8	9	10
Amplitude of swings (θ):	7.6	6.3	5.2	4.3	3.6	2.9	2.5	2.0	1.7	1.4

The relation between θ and x is of the form $\theta = ae^{bx}$

where θ is in radians.

(a) Show that the above relation can be converted to

$$\log \theta = \log a + 0.4343\, bx$$

(b) Plot log θ vs x and determine the constants a and b from the graph.

8. (a) Using the method of "Points in Pairs", find the slope and its error for the best line that passes through the experimental points:

x :	0	1	2	3	4	5	6	7	8	9
y :	0.2	1.0	1.9	2.9	4.2	4.8	6.2	7.1	8.0	8. 8

(b) Plot the experimental points and the best line determined in (a) on the same sheet.

Questions:

1- For the straight-line $\mathbf{y = -2x + 3}$, what are:
a) the slope
b) the y-intercept?

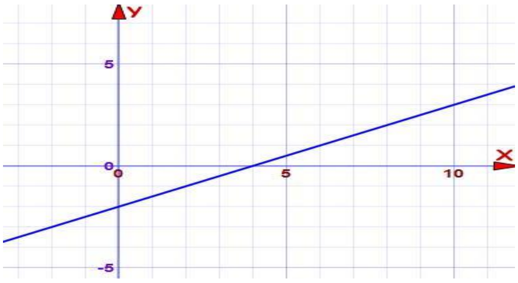
A): a) Slope = 2   b) y-intercept = (0, -3)

B): a) Slope = -2   b) y-intercept = (0, 3)

C): a) Slope = 3   b) y-intercept = (0, -2)

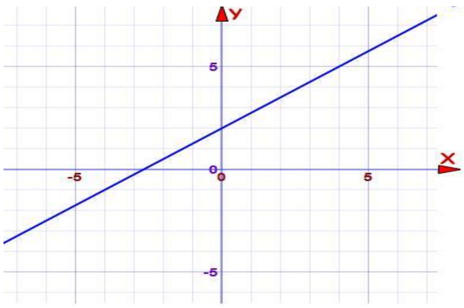
D): a) Slope = -3   b) y-intercept = (0, 2)

2- What is the equation of the straight line shown in the diagram?



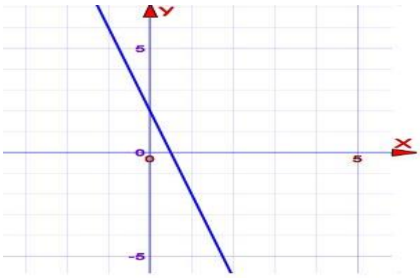
A): y = 2x – 2 B): y = -2x + ½ C): y = -(½) x + 2 D): y = (½)x - 2

3- What is the equation of the following line?



A): y = -1.33x + 2 B): y = 1.33x + 2 C): y = -0.75x + 2 D): y = 0.75x + 2

4- What is the equation of the following graph?



A): y = -4x + 2 B): y = 4x + 2 C): y = -0.25x + 2 D):y = 0.25x + 2

5- For the straight- line **x = 2y - 3**, what are:
a) the slope
b) the y-intercept?

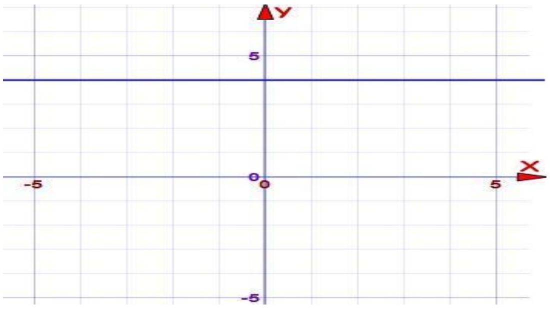
A) Slope = 2 and y-intercept = (0, -3)

B) Slope = ½ and y-intercept = (0, 1½)

C) Slope = -½ and y-intercept = (0, 1½)

D) Slope = ½ and y-intercept = (0, -1½)

6- What is the equation of the straight line shown in the diagram?



A): y = 4x + 4 B): y = -4x + 4 C): y = 4 D): x = 4

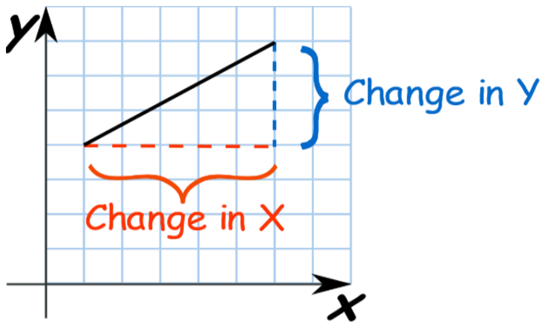
Gradient (Slope) of a Straight Line : The Gradient (also called Slope) of a straight line shows **how steep** a straight line is.

Calculate

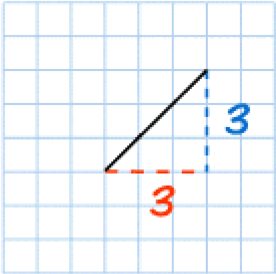
To calculate the Gradient:

Divide the change in height by the change in horizontal distance

Gradient = *Change in Y/* Change in X

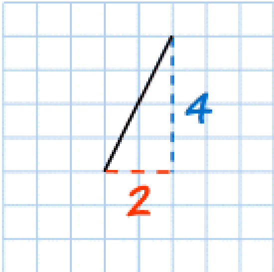


Examples:



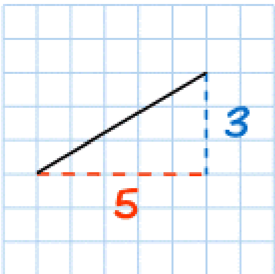
The Gradient = *3*/**3** = 1

So the Gradient is equal to 1



The Gradient = *4*/**2** = 2

The line is steeper, and so the Gradient is larger.



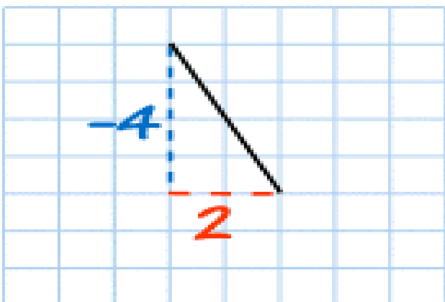
The Gradient = *3*/**5** = 0.6

The line is less steep, and so the Gradient is smaller.

Positive or negative

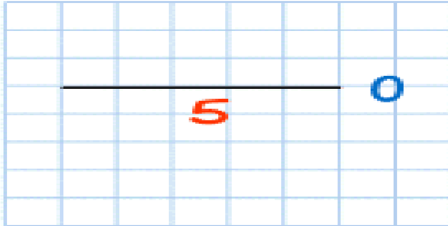
Going from left-to-right, the cyclist has to **P**ush on a **P**ositive Slope: When measuring the line:

- Starting from the left and going across **to the right is positive** (but going across to the left is negative).
- **Up is positive**, and down is negative



Gradient = *−4*/**2** = −2

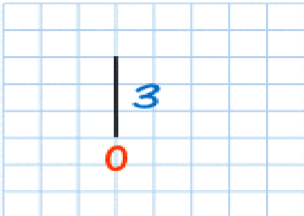
That line goes **down** as you move along, so it has a negative Gradient.



Gradient
= *0*/**5** = 0

A line that goes straight across (Horizontal) has a Gradient of zero.

Straight Up and Down



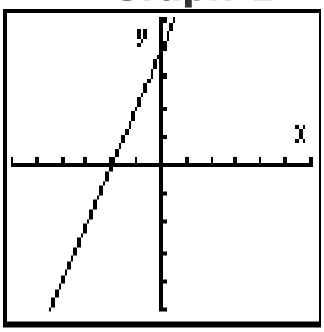
Gradient = *3*/**0** = undefined

That last one is a bit tricky ... you can't divide by zero,
so a "straight up and down" (vertical) line's Gradient is "undefined".

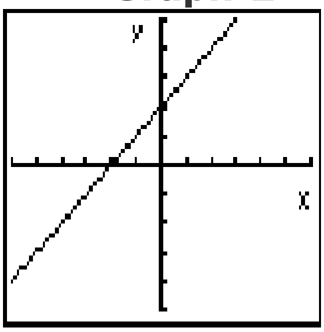
Sometimes the horizontal change is called "run", and the vertical change is called "rise" or "fall":

Which graph shows the line y = 2x + 4

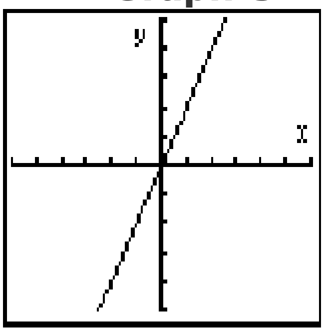
Graph 1



Graph 2

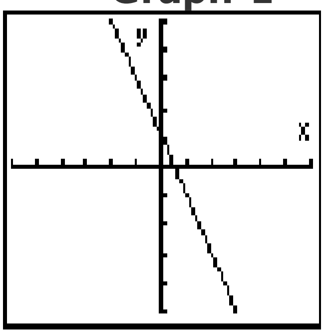


Graph 3

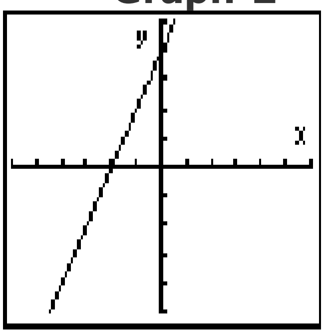


Which graph shows the line y = 3 - x

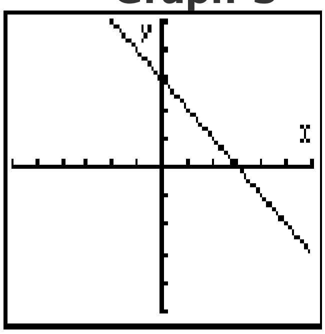
Graph 1



Graph 2



Graph 3



Practical Exercises On Plotting And Graphing Data

1. INTRODUCTION

Graphing is one of the basic techniques used in experimental physics. The following are some of the common uses of graphs:

(a) Determination of the value of some physical quantity, usually represented by the slope or the intercept of a straight line.

(b) Graphs may be used as visual aids. Experimental data are usually recorded first in tabulated form. The variation or trend of the data as a function of some experimentally controlled parameter is most easily seen when plotted in a graph. Also, the experimental data can be easily compared with a theoretical curve when both are plotted in the same graph.

(c) An empirical equation may be obtained from experimental data by curve fitting.

2. GENERAL RULES

The following general rules should be observed in plotting graphs:

(a) Choice of Scales

In drawing graphs, choose scales such that the data points are spread over the graph paper. Do not cramp your graph into one corner or a small section of the sheet (See Fig. 1(a) and Fig. 1(b)). The scale need not be the same for both axes, but make them convenient, i.e. have each division equal to 1, 2, 5, 10, etc. units. Do not use 3, 7, 9, etc. The numbers increase from left to right and from bottom to top. It is customary to plot the independent variable as abscissa (x-axis) and the dependent variable as ordinate (y-axis).

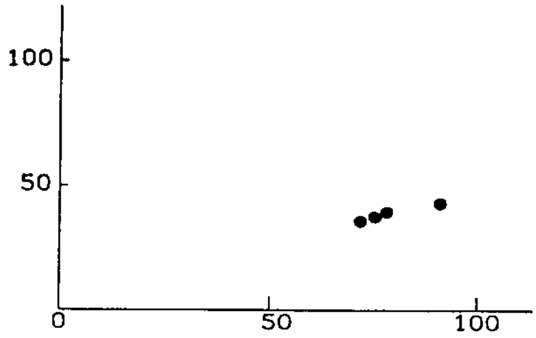


Fig. 1(a)

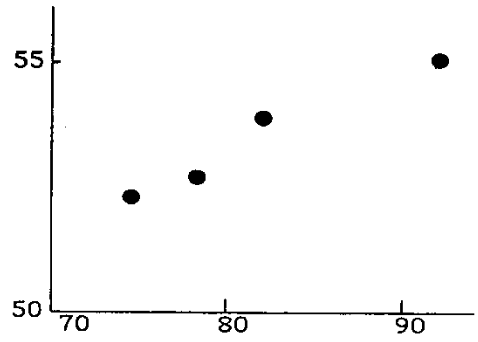


Fig. 1(b)

Fig. 1(a) is not a very useful graph. The results are plotted on an expanded scale in Fig. 1(b) which is more informative.

(b) <u>Plotting</u>

Locate experimental points by small, sharp dots. Draw around each point a small circle in ink. A cross and other symbols may also be used. Draw a smooth curve, first in pencil and then in ink, passing through (or near) as many points as possible, but do not draw the final line <u>through</u> the circles. The curve should indicate the average trend of the data (See Fig. 2). The "smoothness" of a curve can be tested by looking along with the eye on the same level as the

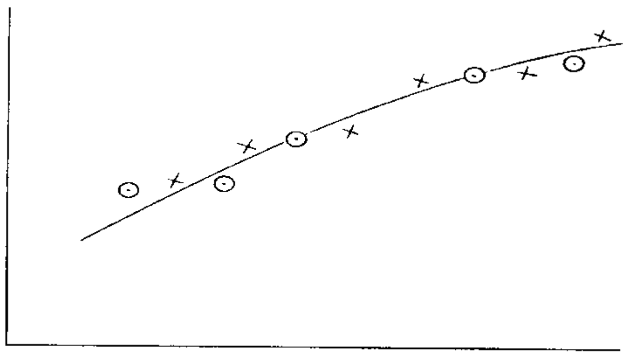


Fig. 2

graph paper. Any sudden bends or kinks in the curve will show up from this angle and <u>must</u> be smoothed out.

(c) <u>Labelling Curve and Coordinates</u>

Write the title of the curve on the sheet. Along each axis label the coordinates, stating the quantity plotted and the units in which it is expressed (See Fig. 3). When two or more curves are plotted on one sheet, use different colors of ink if possible for the different scales and corresponding curves, or else use dotted or broken lines.

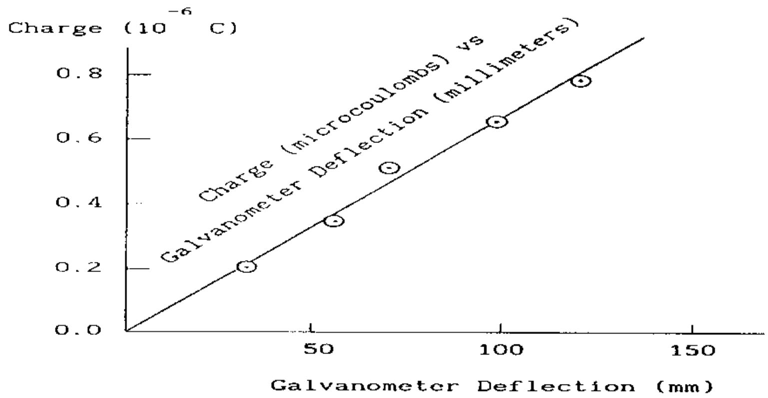


Fig. 3

(d) <u>Interpretation of Curves</u>

Try to find out what physical law or conclusions may be drawn from such a curve. For example, if a curve of distances (covered by a body falling from rest) against squares of the time is plotted, and this comes out as a straight line passing through the origin, the conclusion would be that the distance covered by a falling body is directly proportional to the square of the time.

3. <u>CURVE FITTING AND EMPIRICAL EQUATIONS</u>

Sometimes in a physical problem the dependence of one quantity upon another can be deduced theoretically, and sometimes it must be arrived at experimentally. The mathematical relationship between two quantities may be determined experimentally by observing a series of values of one of them corresponding to various arbitrary values of the other (all other factors being kept constant). And then the data can be <u>fitted</u> into a curve. At this stage an equation which describes the curve may be obtained. An equation established in this way is called an <u>empirical equation</u>.

In the graphical analysis of experimental data, the straight line assumes a fundamental role since it can readily be recognized, whereas the exact nature of a nonlinear graph is often difficult to identify.

If data plotted on rectangular graph paper results in a straight line, the variable y is linear in x, then the graphical plot is a straight line of the form : $\mathbf{y = mx + c}$

where m is the slope of the curve and c is the y intercept.

Many equations which are not linear can be made so by changing the variables which are actually being plotted. This can be seen by a few examples given below:

(i) If the equation is of the form : $y = x^2$

a plot of y vs x yields a parabola but a plot of y vs x^2 yields a straight line (See Fig. 4(a) and Fig. 4(b)).

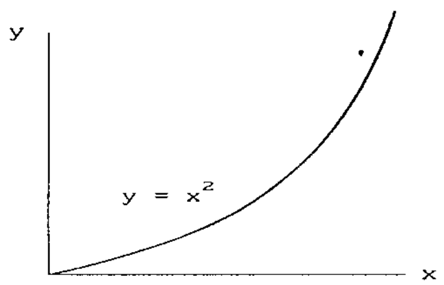


Fig. 4(a)

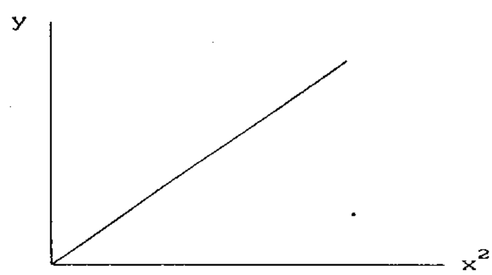


Fig. 4(b)

(ii) For $y = \frac{1}{x}$, a plot of y vs x yields a hyperbola but a plot of y vs $\frac{1}{x}$ yields a straight line (See Fig. 5(a) and Fig. 5(b)).

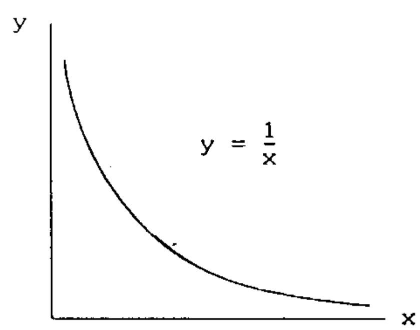


Fig. 5(a)

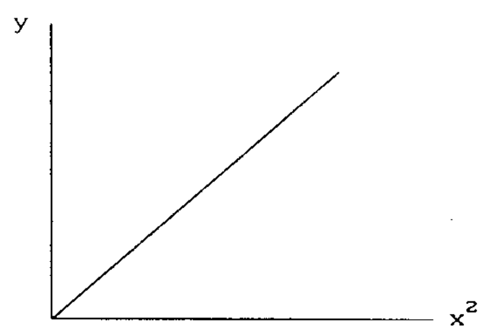


Fig. 5(b)

(iii) The mathematical statement of a power function is

$$y = cx^n$$

where c and n are constant. Taking the logarithms of both sides of the above equation yields

$$\log y = \log c + n \log x \, .$$

A plot of log y vs log x gives a straight line. Its slope is the value of the constant n and the constant c can be determined from the intercept along the log y axis.

4. FITTINGS OF A STRAIGHT LINE

We give two methods for fitting the best, i.e. most probable, line through a set of points:

(a) The Method of Least Squares

Suppose there are n pairs of measurements (x_1, y_1), (x_2, y_2), ….., (x_n, y_n) and the errors are entirely in the y values. We want to fit them into a straight line

$$y = mx + c \, .$$

For a given pair of values for m and c, the deviation of the ith reading is (See Fig. 6)

$$y_i - mx_i - c \, .$$

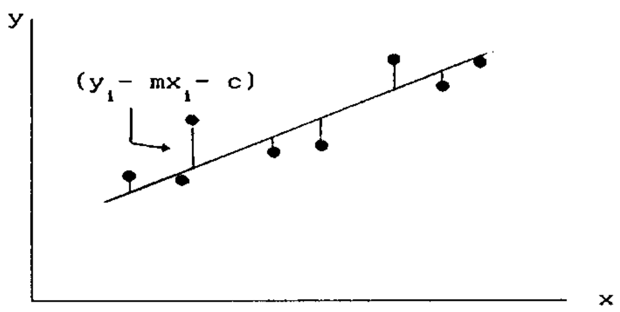


Fig. 6

The best values of m and c are taken to be those for which

$$\Delta = \Sigma(y_i - mx_i - c)^2$$

is a minimum - hence the name method of least squares. In the above summation, the subscript i runs from 1 to n. The required values of m and c are obtained by solving simultaneous equations

$$\frac{\partial \Delta}{\partial m} = 0 \tag{4.1}$$

$$\frac{\partial \Delta}{\partial c} = 0 \tag{4.2}$$

which are the same as

$$m\Sigma x_i^2 + c\Sigma x_i = \Sigma x_i y_i \tag{4.3}$$

$$m\Sigma x_i + cn = \Sigma y_i \tag{4.4}$$

respectively. Eq. (4.4) shows that the best line passes through the point

$$\bar{x} = \frac{1}{n}\Sigma x_i, \qquad \bar{y} = \frac{1}{n}\Sigma y_i \tag{4.5}$$

On solving eq. (4.3) and eq. (4.4) simultaneously we have

$$m = \frac{\Sigma\left(x_i - \bar{x}\right)y_i}{\Sigma\left(x_i - \bar{x}\right)^2} \tag{4.6}$$

$$c = \bar{y} - m\bar{x} \tag{4.7}$$

It can be shown that the standard errors in m and c are given by

$$\left(\Delta m\right)^2 \approx \frac{1}{D}\frac{\Sigma d_i^2}{n-2} \tag{4.8}$$

$$\left(\Delta c\right)^2 \approx \left(\frac{1}{n} + \frac{\bar{x}^2}{D}\right)\frac{\Sigma d_i^2}{n-2} \tag{4.9}$$

Where , $D = \Sigma\left(x_i - \bar{x}\right)^2$ and $d_i = y_i - mx_i - c$

(b) **Points in Pairs**

Without the help of a calculator, the method of the least squares is laborious. The following method is much simpler in practice and is often adequate for the purpose.

In order to illustrate the method, suppose that we have 8 points (x_1, y_1), (x_2, y_2), . . . , (x_8, y_8) that lie approximately on a straight line and we require the best value of the slope m and its error. Let the points be numbered in order from 1 to 8 (See Fig. 7). Divide the points into pairs:

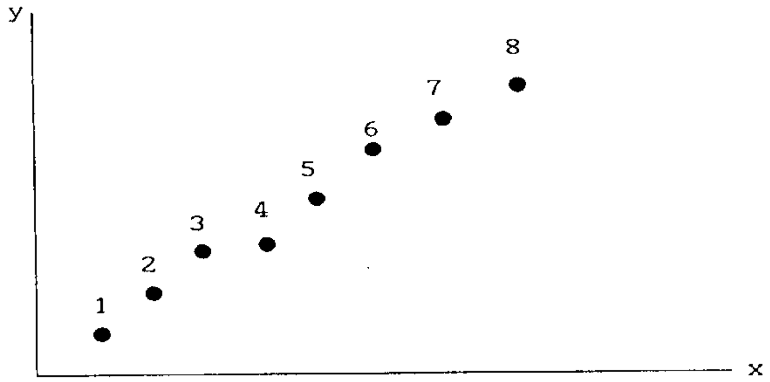


Fig. 7

(x_1, y_1) and (x_5, y_5),

(x_2, y_2) and (x_6, y_6),

(x_3, y_3) and (x_7, y_7),

(x_4, y_4) and (x_8, y_8),

Next find the slopes corresponding to each pair:

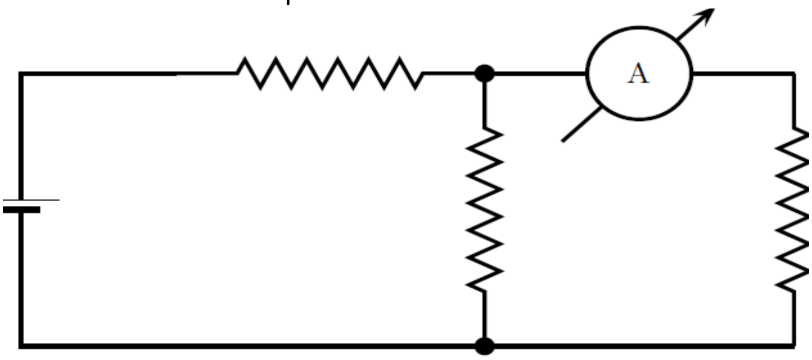
$$m_1 = \frac{y_5 - y_1}{x_5 - x_1}, \qquad m_2 = \frac{y_6 - y_2}{x_6 - x_2}, \qquad \text{etc.}$$

We take their mean $\overline{m}$ as the best value of m and find its error by the common sense approach. The best line given by this method is the one with the slope $\overline{m}$ that passes through the point $(\overline{x}, \overline{y})$.

Electrical Measuring Instruments

1-An ammeter:

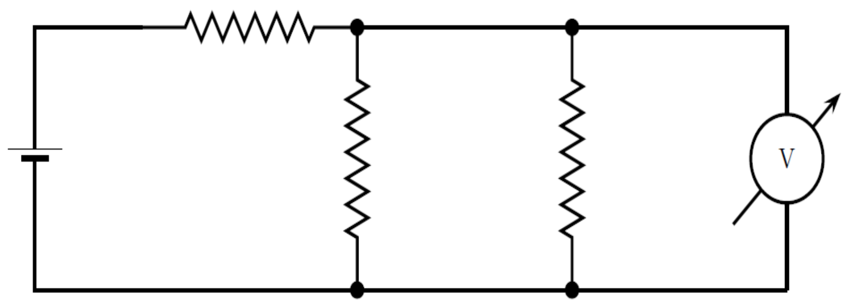
An ammeter (the name is a contraction of 'ampere-meter') is a device for measuring the electric current through a wire or a circuit element. *An ammeter is always connected in* series with the element in question:



Note: the voltage drop across the ammeter itself disturbs the circuit into which it is plugged in, and such disturbance may change the very current the ammeter is used to measure. To minimize the disturbance, *the voltage across the ammeter should be as small as possible*, which requires that *the electric resistance of the ommeter should be as small as possible.*

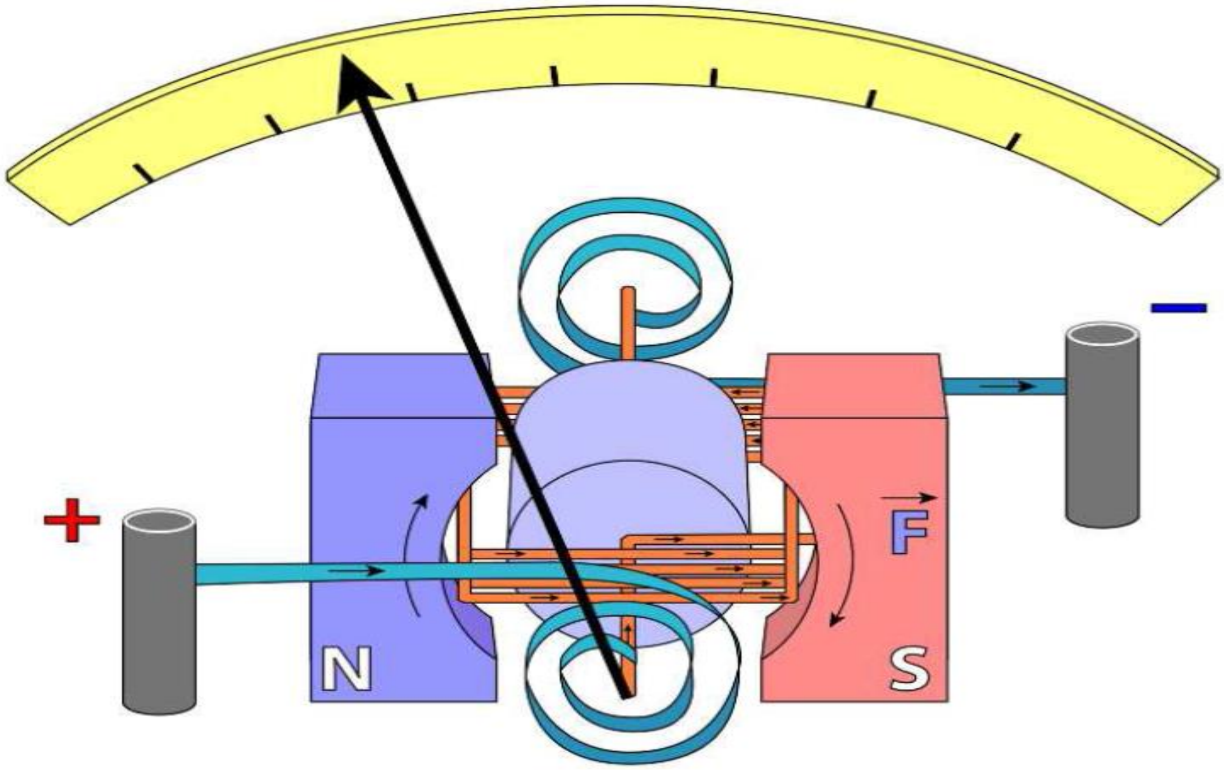
2-A voltmeter

A voltmeter is a device for measuring potential difference (the voltage) between two wires, usually across a circuit element or a group of elements. *A voltmeter is alwasys connected in parallel with the element(s) in question:*



Note: the current flowing through the voltmeter itself disturbs the circuit into which it is plugged in, and such disturbance may change the very voltage the voltmeter is used to measure. To minimize the disturbance, *the current through the voltmeter should be as small as possible,* which requires that *the electric resistance of the ommeter should be as large as possible.*

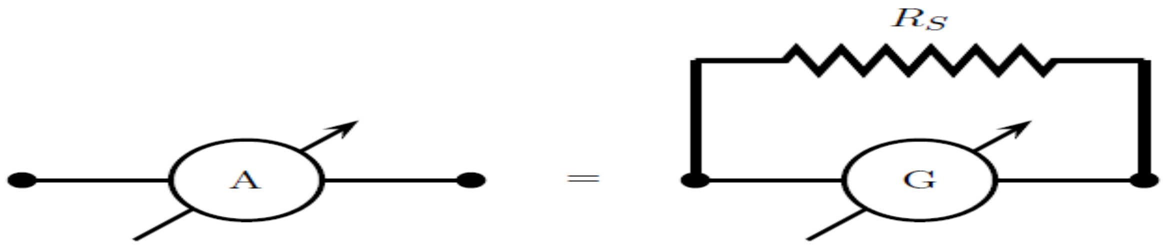
At the core of any analog ammeter or voltmeter is a galvanometer. By itself, a gal-vanometer is a very sensitive ammeter: typically, it takes only 100 μA to make the gal-vanometer arrow move all the way across the scale. The picture below gives the schematics of the D'Arsonval / Weston type of a galvanometer:



The electric current flows through a wire coil placed in a magnetic field of a permanent magnet. The magnetic forces on the current-carrying wires create a net torque on the coil. But when the coil turns, the torsion spring attached to the coil cancels the torque. The arrow attached to the coil indicates the angle through which they turn. In a properly made galvanometer, this angle is proportional to the current through the coil, so the scale behind the arrow may be labeled in units of the current.

In more sensitive **mirror galvanometers**, the arrow is replaced with a mirror reflecting a beam of light onto a distant scale This way, even a small-angle turn of the coil and the mirror can make the reflection move through easily notable distance.

To turn a galvanometer into a less sensitive ammeter, one connects a low-resistance shunt in parallel with the galvanometer:



The shunt takes most of the currents through the ammeter, so only a small fraction flows through the galvanometer,

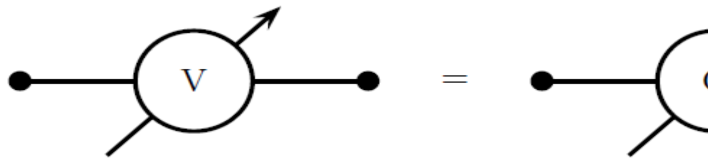
$$I_{\text{galvanometer}} = \frac{R_S}{R_G + R_S} \times I_{\text{ammeter}}^{\text{net}}$$

where RG is the galvanometer's resistance — typically 500 or 1000 — while RS is the much smaller shunt resistance. For example, if RS = 500.0 while RS = 0.5005 is 999 times smaller, then 99.9% of the current measured by the ammeter flows through the shunt while only 0.1% flows through the galvanometer. So if it takes 100 μA to turn the galvanometer's arrow through full scale, the net current through the ammeter is 1000 times larger, *i.e.*, 0.1 A. In general :

$$I^{\text{full scale}}[\text{ammeter}] = \left(1 + \frac{R_G}{R_S}\right) \times I^{\text{full scale}}[\text{galvanometer}].$$

In many ammeters one may switch between several different shunt resistances to choose the full-scale current of the ammeter to the value appropriate to the circuit in question. Besides making the ammeter less sensitive, the shunt resistance lowers its overall resis- tance from RG down to $\frac{R_G R_S}{R_G+R_S}$ =R_S which reduces the ammeter's effect on the measured circuit. However, the voltage across the ammeter is the voltage across the galvanometer, typically 50 mV for the full-scale arrow deflection. If this voltage significantly disturbs the circuit in question, you would need an ammeter with a more sensitive galvanometer.

A galvanometer may also be turned into a voltmeter by connecting a large *multiplier resistance* in series with the galvanometer:



The multiplier resistance RM and the galvanometer's own resistance RG form a *voltage divider*, so the net voltage on the galvanometer is only a small fraction of the net voltage on the voltmeter,

$$V[\text{galvanometer}] = \frac{R_G}{R_M + R_G}$$

For example, for RG = 500 and RM = 49, 500 , the galvanometer gets only 1% of the net voltage on the voltmeter. Consequently, the full-deflection voltage of the voltmeter is 100 times larger than the full-deflection voltage of the galvanometer, V full = 100×50 mv = 5 V. More generally,

$$V^{\text{full scale}}[\text{voltmeter}] = \left(1 + \frac{R_M}{R_G}\right) \times V^{\text{full scale}}[\text{galvanometer}].$$

The name 'multiplier resistance' for the RM is due to its appearence in this formula. In terms of the full-deflection current of the galvanometer,

$$V^{\text{full scale}}[\text{voltmeter}] = (R_M + R_G) \times I^{\text{full scale}}[\text{galvanometer}].$$

In many voltmeters one may switch between several different multiplier resistances to choose the full-scale voltage of the voltmeter to the value appropriate to the circuit in question.

Besides making the voltmeter less sensitive, the multiplier resistance RM increases the overall electric resistance of the voltmeter to RM +RG _ RM, which reduces the voltmeter's effect on the measured circuit. However, the current flowing through the voltmeter is the current through the galvanometer, typically 100 µA for the full-scale arrow deflection. If this current significantly disturbs the circuit in question, you would need a voltmeter with a more sensitive galvanometer.

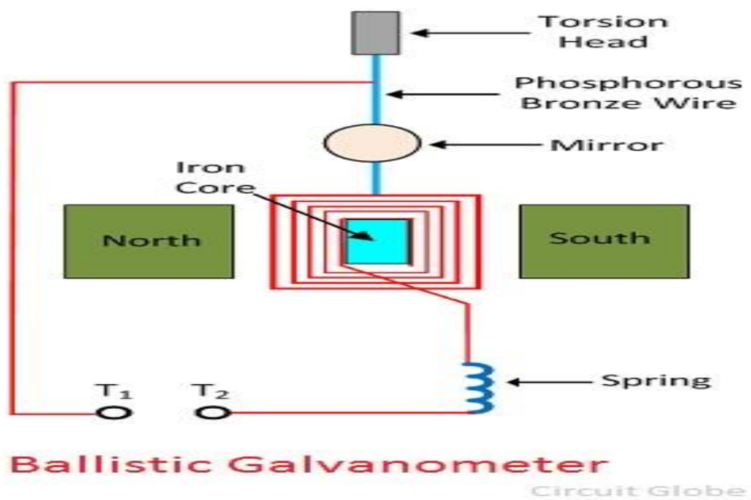
<u>٣-Ballistic galvanometer</u>

Definition: The galvanometer which is used for estimating the quantity of charge flow through it

Is called the ballistic galvanometer. The working principle of the ballistic galvanometer is very simple. It depends on the deflection of the coil which is directly proportional to the charge passes through it. The galvanometer measures the majority of the charge passes through it in spite of **current.**

Construction of Ballistic Galvanometer

The ballistic galvanometer consists coil of copper wire which is wound on the non-conducting frame of the galvanometer. The phosphorous bronze suspends the coil between the north and south poles of a magnet. For increasing the magnetic flux the iron core places within the coil. The lower portion of the coil connects with the spring. This spring provides the restoring torque to the coil.



When the charge passes through the galvanometer, their coil starts moving and gets an impulse. The impulse of the coil is proportional to the charges passes through it. The actual reading of the galvanometer achieves by using the coil having a high moment of inertia. The moment of inertia means the body oppose the angular movement. If the coil has a high moment of inertia, then their oscillations are large. Thus, accurate reading is obtained.

Theory of Ballistic Galvanometer

Consider the rectangular coil having N number of turns placed in a uniform magnetic field. Let **l** be the length and **b** be the breadth of the coil. The area of the coil is given as :

$$A = l \times b \ldots\ldots equ(1)$$

When the current passes through the coil, the torque acts on it. The given expression determines the magnitude of the torque

$$\tau = NiBA \ldots\ldots equ(2)$$

Let the current flow through the coil for very short duration says dt and it is expressed as

$$\tau dt = NiBAdt \ldots\ldots equ(3)$$

If the current passing through the coil for t seconds, the expression becomes

$$\int_0^t \tau dt = NBA \int_0^t idt = NBAq \ldots \ldots equ(4)$$

The q be the total charge passes through the coil. The moment of inertia of the coil is given by **I,** and the angular velocity through **ω.** The expression gives the angular momentum of the coil

$$Angular\ momentum\ = \ l\omega \ldots \ldots . equ(5)$$

The angular momentum of the coil is equal to the force acting on the coil. Thus from equation (4) and (5), we get. **:** **L ω =NBAq………………equ(6)**

The Kinetic Energy (K) deflects the coil through an angle θ, and this

deflection is restored through the spring

$$\text{Restoring torque} = \frac{1}{2} c\theta^2$$

$$\text{Kinetic energy K} = \frac{1}{2} l\omega^2$$

.

The resorting torque of the coil is equal to their deflection. Thus,

$$\frac{1}{2}c\theta^2 = \frac{1}{2}l\omega^2$$

$$c\theta^2 = l\omega^2 \ldots \ldots \ldots . equ(7)$$

The periodic oscillation of the coil is given as

$$T = 2\pi\sqrt{l}/c \quad \text{or} \quad T^2 = \frac{4\pi^2 l}{c} \quad \text{or} \quad \frac{T^2}{4\pi^2} = \frac{l}{c} \quad \text{or} \quad \frac{cT^2}{4\pi^2} = l$$

By multiplying the equation (7) from the above equation we get

$$\frac{c^2T^2\theta^2}{4\pi^2} = l^2\omega^2 \quad \text{or} \quad \frac{ct\theta}{2\pi} = l\omega \ldots \ldots \ldots . equ(8)$$

On substituting the value of equation (6) in the equation (8) we get

$$\frac{ct\theta}{2\pi} = NBAq$$

$$q = \frac{ct\theta}{NBA2\pi} \ldots\ldots\ldots equ(9) \text{ or } q = \frac{ct}{2\pi BNA} \times (\theta) \text{ or } Let, k = \frac{ct}{2\pi BNA} \text{ or } q = k\theta$$

Advantages and Disadvantages

Advantages

- Sensitivity increases as the value of n, B, A increases and value of k decreases.
- The eddy currents produced in the frame bring the coil to rest quickly, due to the coil wound over the metallic frame.

Disadvantages

- Its sensitivity cannot be changed at will.
- Overloading can damage any type of galvanometer.

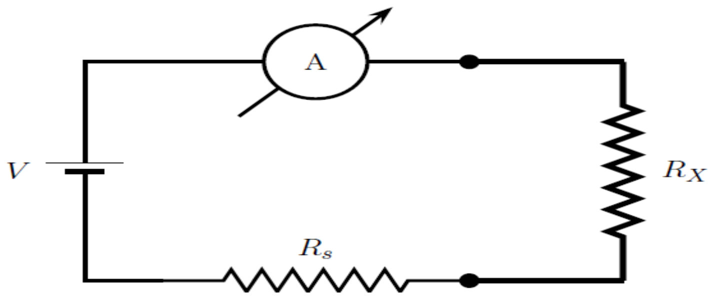
Learn more about Magnetism:

- AC Generator: Parts, Working Mechanism, Phases, Videos, and Examples
- Domestic Electric Circuits

Motion in Combined Electric and Magnetic Fields

4-An Ohmmeter

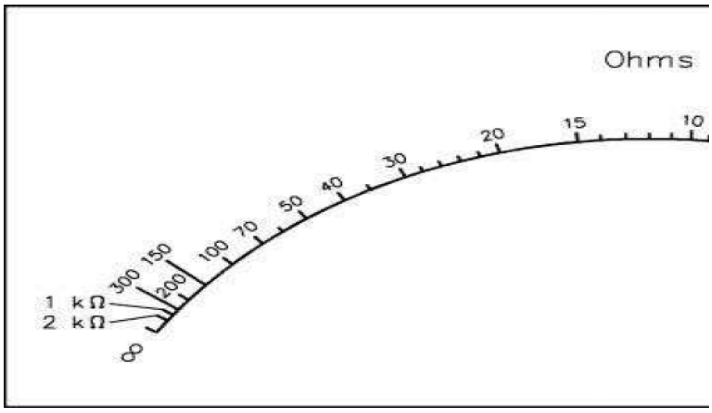
An ohmmeter is a device for measuring electric resistance of an isolated circuit element or of a simple circuit without any active power sources. A simple ohmmeter consists of a battery, an ammeter, and a safety resistance Rs, all connected in series with the resistance being measured:

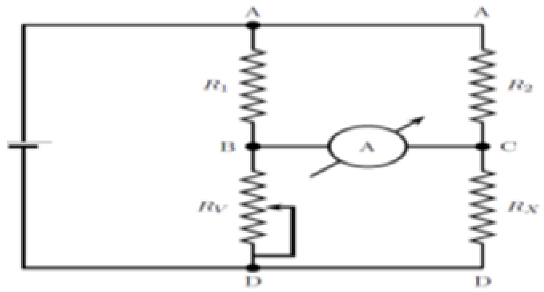


The ammeter here itself consists of a galvanometer and a shunt resistor. It also has an inverted non-linear scale calibrated in Ohms according to :

$$I = \frac{V}{R_s + R_X} \implies R_X = \frac{V}{I} - R_s \,.$$

Graphically, the scale looks like





For small resistances RX ≤1 simple ohmmeters have poor accuracy since they do not separate the RX from the resitance of the wires, or the internal resistance of the battery, or an error in the safety resistance Rs. To avoid these problems, one may use a Wheatstone bridge to compare the RX to a precisely calibrated variable resistor RV . Besised the RX and the RV , the Wheatstone bridge involve two fixed well-calibrated resistors R1 and R2, a sensitive ammeter, and a battery, connected as follows:

The ammeter in this circuit should be able to handle current flowing in both directions. It does not need to be accurate for non-zero currents, but it should give reliable indication which way the current flows through it and when such current happens to vanish. Because that's how the Wheatstone bridge is is used: one carefully adjusts the variable resistor RV until the current through the ammeter becomes zero, at which point the four resistances in the circuit are related to each other as :

$$\frac{R_X}{R_2} = \frac{R_V}{R_1} \quad \Longrightarrow \quad R_X = \frac{R_2}{R_1} \times R_V . \qquad (1)$$

To derive this formula, note that *when the current through the ammeter happens to be zero,* the whole circuit acts as two independent voltage dividers, ABD and CD. Solving each divider for the voltage on its lower element, we have

$$V_{BD} = \frac{R_V}{R_1 + R_V} \times V_{AD} \text{ and } V_{CD} = \frac{R_X}{R_2 + R_X} \times V_{AD} . \qquad (2)$$

At the same time, zero current through the ammeter also implies zero voltage across the ammeter, thus

$$V_{BC} = 0 \quad \Longrightarrow \quad V_{BD} = V_{CD} \qquad (3)$$

Plugging in the voltages (2) into this equation gives us

$$\frac{R_V}{R_1 + R_V} \times V_{AD} = \frac{R_X}{R_2 + R_X} \times V_{AD} \qquad (4)$$

and hence

$$\frac{R_V}{R_1 + R_V} = \frac{R_X}{R_2 + R_X} \qquad (5)$$

regardless of the battery's voltage VAD. After a little algebra, this equation becomes

$$\frac{R_X}{R_2} = \frac{R_V}{R_1} \quad \Longrightarrow \quad R_X = \frac{R_2}{R_1} \times R_V . \qquad (1)$$

Modern sensitive ohmmeters often use similar Wheatstone bridges with an operational amplifier — an electronic circuit which greatly *amplifies small currents or small difference* in potential — instead of an analog ammeter.

5-Tanget Galvanometer

Theory of Tangent Galvanometer:

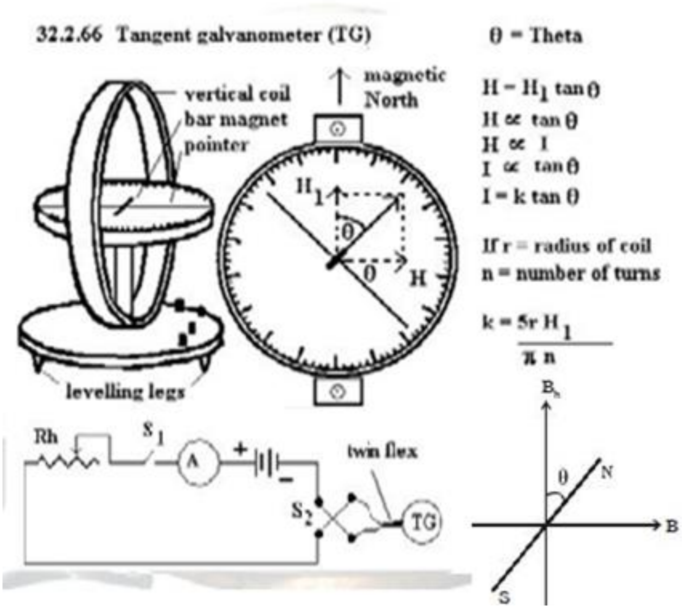
When the plane of the coil is placed parallel to the horizontal component of Earth's magnetic induction (Bh) and a current is passed through the coil, there will be two magnetic fields acting perpendicular to each other: (1) the magnetic induction (B) due to the current in the coil acting normal to the plane of the coil and (2) the horizontal component of Earth's magnetic induction (Bh) (Figure).

Due to these two crossed fields, the pivoted magnetic needle is deflected through an angle θ. According to tangent Law,

$$B = B_h \tan\theta \ \ldots (1)$$

If a current I passes through the coil of n turns and of radius a, the magnetic induction at the centre of the coil is

$$B = (\mu_0 NI / 2\alpha) \ \ldots (2)$$



Substituting equation (2) in equation (1)

$\mu_0 NI / 2\alpha = B_h \tan\theta$ so, $I = (2a B_h / \mu_0 N) \tan\theta$ Then $I = K \tan\theta$

where $K = 2a B_h / \mu_0 N$; is called the reduction factor of the tangent galvanometer. It is a constant at a place. Using this equation, current in the circuit can be determined.

Since the tangent galvanometer is most sensitive to a deflection of 45^0, the deflection has to be adjusted to be between 30^0 and 60^0

6- MULTIMETER

Multimeters are very useful test instruments. They are needed in every kind of robotic activity. Don't ever forget to carry this whenever you are going for a competition.

USE:

Multimeters can be used as an ammeter, a voltmeter, an ohmmeter; by operating a multi-position knob on the meter. They can measure DC as well as AC (but you shall rarely require measuring an AC quantity in robotics). There are also special functions in a multimeter like 'Detecting a Short Circuit', testing transistors and some have additional features for measuring capacitance & frequency.

They are available in two types in market:

1):Analog Multimeter

Analog multimeters may be more difficult to read than their digital counterparts, but the continuous movement of the needle allows a more precise monitoring of changes in current and resistance than a digital readout. An <u>analog multimeter generally consists of a screen with a pointer and multiple</u> scales, a range selector and two leads.

Connecting the two leads to the positive and negative terminals of an electrical circuit and setting the range selector to the right setting will give an accurate readout of the current in the circuit.

Analog meters take a little power from the circuit under test to operate their pointer (a hand like in a clock to indicate the reading).

They must have a high sensitivity of at least 20k /V or they may upset the circuit under test and give an incorrect reading.

2.) Digital Multimeter

* All digital meters contain a battery to power the display so they use virtually no power from the circuit under test.

* They have a digital display as shown.

There DC voltage ranges have a very high resistance (usually called input impedance) of 1M or more, usually 10 M , and they are very unlikely to affect the circuit under test.

Here we will have discussion on digital multimeter (as they are commonly used).

There are three sockets of wire, the black lead is always connected into the socket marked COM, short form for COMMON. The red lead is connected into the socket labeled V mA. The 10A socket is very rarely used.

Measuring resistance with a multimeter

To measure the resistance of a component it must not be connected in a circuit. If you try to measure resistance of components in a circuit you will obtain false readings (even if the supply is disconnected) and you may damage the multimeter.
The techniques used for each type of meter are very different so they are treated separately:

Measuring resistance with a DIGITAL multimeter

1. Set the meter to a resistance range greater than you expect the resistance to be. Notice that the meter display shows "off the scale" (usually blank except for a 1 on the left). Don't worry, this is not a fault, it is correct - the resistance of air is very high!

2. Touch the meter probes together and check that the meter reads zero. If it doesn't read zero, turn the switch to 'Set Zero' if your meter has this and try again.

3. Put the probes across the component. Avoid touching more than one contact at a time or your resistance will upset the reading!

If the meter reads 1, this means that the resistance is more than the maximum which can be measured on this range and you may need to switch to a new position, 2000 k or so, to take a reading.

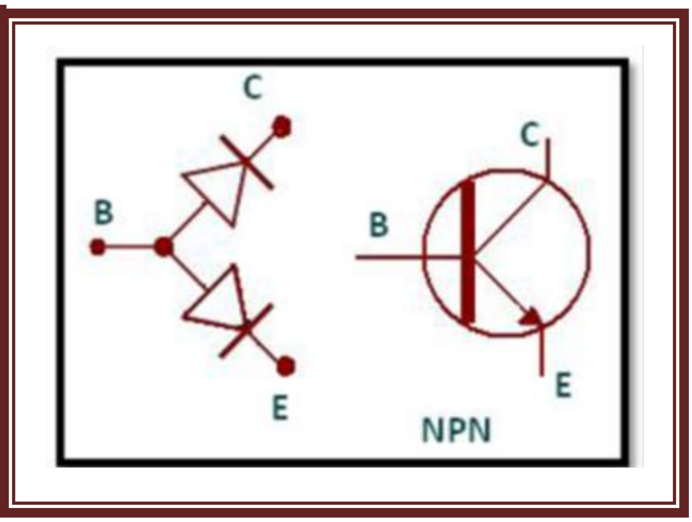
Note: It is recommended purchasing a multimeter with a 'continuity' feature built in. This mode allows us to 'tone' out circuits. In this mode, if you touch the two probes together (or there is a short circuit), you should hear a tone indicating that there is a direct connection between one probe and the other (obviously - you have them touching!). This feature is used countless times during trouble shooting.

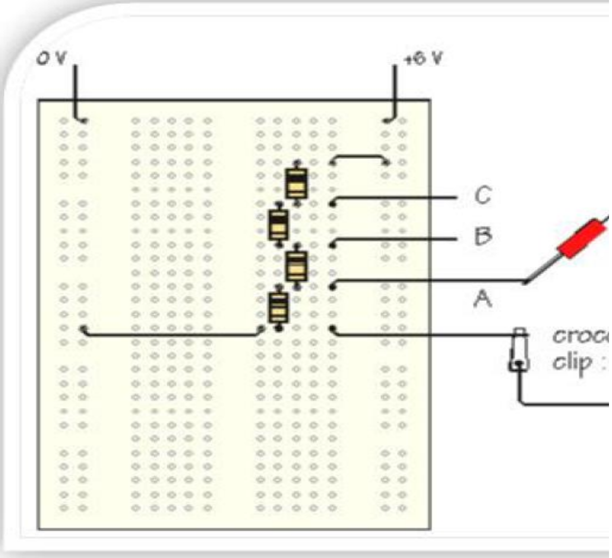
Measuring Voltage with Voltmeter

1. Select a voltage range with a maximum greater than you expect the reading to be. If the reading goes off the scale immediately disconnect and select a higher range.

2. Connect the red (positive +) lead to the point you where you need to measure the voltage

3. The black lead can be left permanently connected to 0V while you use the red lead as a probe to measure voltages at various points. (The black lead can be fitted by using a crocodile clip.)





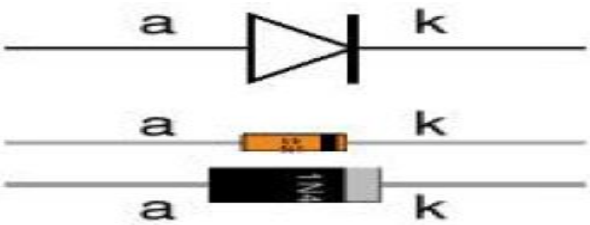
you can measure the current by choosing a suitable range. If it displays a ‘1’ at left, choose a higher current range.

Testing a diode with a DIGITAL multimeter

* Digital multimeters have a special setting for testing a diode, usually labeled with the diode symbol.

* Connect the red (+) lead to the anode and the black (-) to the cathode. The diode should conduct and the meter will display a value (usually the voltage across the diode in mV, 1000mV

* Reverse the connections. The diode should NOT conduct this way so the meter will display "off the scale" (usually blank except for a 1 on the left).



Testing a transistor with a multimeter

Set a digital multimeter to diode test and an analogue multimeter to a low resistance range such as × 10 ohm as described above for testing a diode.

Test each pair of leads both ways (six tests in total):
- The base-emitter (BE) junction should behave like a diode and conduct one way only.
- The base-collector (BC) junction should behave like a diode and conduct one way only.
- The collector-emitter (CE) should not conduct either way.

NOTE: Conducting in one way simply means it will behave as a short circuit and
The diagram shows how the junctions behave in an NPN transistor. The diodes are reversed in a PNP transistor but the same test procedure can be used.
Some multimeters have a 'transistor test' function; please refer to the instructions supplied with the meter for details.

Advantages and Disadvantages of Digital and Analog Multimeters

First: Digital multimeters.

Advantages :

1. They are more accurate than analog multimeters.
2. They reduce reading and interpolation errors.
3. The 'auto-polarity' function can prevent problems from connecting the meter to a test circuit with the wrong polarity.
4. Parallax errors are eliminated. If the pointer of an analog multimeter is viewed from a different angle, you will see a different value. This is parallax error. A digital multimeter's numerical display solves this problem
5. Digital multimeter displays have no moving parts. This makes them free from wear and shock failures.
6. The reading speed is increased as it is easier to read.
7. Unlike analog multimeters, zero adjustment is not required.
8. Digital output is suitable for further processing or recording and can be useful in a rapidly increasing range of computer controlled applications.
9. With the advent of Integrated circuits, the size, cost and power requirements of digital multimeters has been drastically reduced.
10. Accuracy is increased due to digital readout. You can make mistake in reading the scale in analog multimeter, but digital multimeters have a LCD display to show accurate reading.
11. DMMs can be used in testing continuity, capacitors, diodes and transistors. More advanced digital multimeters can also measure frequency.
12. The 'auto-ranging' feature of a digital multimeter helps in selecting different measurement ranges, which can prevent damage to the meter if the wrong range is selected.
13. Portable size makes it easy to carry anywhere.
14. They cause less meter loading effects on the circuits being tested.
15. Some advanced digital multimeters have microprocessors and can store the readings for further processing.
16. They have very high input impedance.

Disadvantages

The LCD display depends on a battery or external power source. When the battery is low, the display will be dim, making it difficult to read.

1. In case of fluctuations or transients, it can record an error.
2. Warming of the meter during its use can change its properties leading to errors in measured value.
3. The A/D converter has a limitation on word length which can cause quantization noise giving rise to error in measured value.
4. There is a voltage limitation. If it is increased beyond the limit, the meter will be damaged.
5. The digital nature makes it unsuitable for adjusting tuning circuits or peaking tunable responses.
6. They are expensive due to high manufacturing cost.

In spite of above mentioned disadvantages, the digital multimeters are gaining popularity and are most widely used.

Second : Analog multimeters.

Analog multimeters are the ones with the swinging needle. It measure volts, amps and ohms. Analog multimeters are usually cheaper, quicker to respond and don't need batteries as long as you are not measuring ohms. Analog multimeters also have some serious disadvantages.

Advantages :

- **Cheaper than digital meters**

When we discuss the benefits of analog multimeters, we must start with the price. An analog multimeter is cheaper than a digital multimeter, and is perhaps the main reason why people still use analog multimeters.

If you are looking for a digital multimeter, a digital multimeter should be your ideal choice. But that does not mean that a budget multimeter must be analog. An analog multimeter is not as fancy as a digital one, and you have to spend less if you purchase the former.

- **Responds quickly**

The responsiveness of an analog multimeter is pretty quick. Analog multimeters have been around for quite a long time, and during this time the device has undergone a lot of changes and upgradations. When we discuss the advantages and disadvantages of analog multimeters, may be there are more disadvantages. But response time is never an issue.

Although you have to read the parameters manually, you do not need to wait for the results to appear. There are many users who are more comfortable with analog multimeters.

- **No batteries required**

Another good thing about an analog multimeter is that it does not require any battery, except when you need to measure resistance. Perhaps there is no digital multimeter that works without batteries. But that is not the case with an analog multimeter. This is one of the most obvious advantages of this device.

- **Advanced features**

Analog multimeters respond to the electrical phenomena that they are measuring. They do not have the analytical power of digital electronics that is available in digital multimeters. Therefore, they will never have the features that top-of-the-line digital multimeters offer. These features include frequency measurements and waveform analysis. Choosing an analog multimeter means you are choosing not to have these features.

Disadvantages

• Less accuracy

Accuracy is the most serious disadvantage of analog multimeters. There are three causes of error.

First, the mechanics of the device makes it inaccurate--the instructions that come with an analog multimeter suggest you set the scale so the needle registers on the right-hand side of the scale where the inaccuracy is only 1 or 2 percent. The inaccuracy increases as you move left across the scale.

Second, making mistakes when counting the marked graduations is easy, especially if your observation angle is off. You also must interpolate the last digit when the needle falls between two graduations.

Third, scales can introduce insidious inaccuracies. Being on the wrong scale--for example AC instead of DC--is the most obvious of these. In addition, for most measurements you must do a bit of mental arithmetic, and that is often a mistake waiting to happen. If the meter reads 4.7 and the scale is set to "times 10,000," this is pretty easy to do in your head, but this is also pretty easy to get wrong. A lax moment can lead to a big error.

• Robustness

The needle in an analog multimeter is activated by a magnetic field that causes it to rotate. You can damage this delicate by dropping the multimeter or simply using it for years. Making scaling mistakes or bad guesses can also "peg the meter," which is when the needle swings rapidly until it slams into the post at the end of the scale. Repeated pegging can damage the mechanism and make the multimeter inaccurate. The best way to avoid pegging the meter is to get into the habit of always starting on the highest scale and backing down until you get a good reading.

• Lack of advanced features

When it comes to responding to the electrical phenomena, analog multimeters work pretty well. However, unlike digital multimeters, analog multimeters lack analytical power. That means analog multimeters do not have advanced features.

If you want to do waveform analysis or frequency measurements, you will have to use a digital multimeter. If you choose an analog multimeter, you should not expect these advanced features. And that is perfectly understandable, because analog multimeters were invented way before digital ones.

7--Cathode Ray Oscilloscope (CRO)

Definition: The cathode ray oscilloscope (CRO) is a type of electrical instrument which is used for showing the measurement and analysis of waveforms and others electronic and electrical phenomenon. It is a very fast X-Y plotter shows the input signal versus another signal or versus time. The CROs are used to analyse the waveforms, transient, phenomena, and other time-varying quantities from a very low-frequency range to the radio frequencies.

The CRO is mainly operated on voltages. Thus, the other physical quantity like current, strain, acceleration, pressure, are converted into the voltage with the help of the transducer and thus represent on a CRO. It is also used for knowing the waveforms, transient phenomenon, and other time-varying quantity from a very low-frequency range to the radio

Construction of Cathode Ray Oscilloscope

The main parts of the cathode ray oscilloscope are as follows.

1. Cathode Ray Tube 2.Electronic Gun Assembly 3.Deflecting Plate

4.Fluorescent Screen For CRT 5. Glass Envelop

1. Cathode Ray Tube

The cathode ray tube is the vacuum tube which converts the electrical signal into the visual signal. The cathode ray tube mainly consists the electron gun and the electrostatic deflection plates (vertical and horizontal).The electron gun produces a focused beam of the electron which is accelerated to high frequency.

The vertical deflection plate moves the beams up and down and the horizontal beam moved the electrons beams left to right. These movements are independent to each other and hence the beam may be positioned anywhere on the screen.

2. Electronic Gun Assembly

The electron gun emits the electrons and forms them into a beam. The electron gun mainly consists a heater, cathode, a grid, a pre-accelerating anode, a focusing anode and an accelerating anode. For gaining the high emission of electrons at the moderate temperature, the layers of barium and strontium is deposited on the end of the cathode.

After the emission of an electron from the cathode grid, it passes through the control grid. The control grid is usually a nickel cylinder with a centrally located co-axial with the CRT axis. It controls the intensity of the emitted electron from the cathode.

The electron while passing through the control grid is accelerated by a high positive potential which is applied to the pre-accelerating or accelerating nodes.

The electron beam is focused on focusing electrodes and then passes through the vertical and horizontal deflection plates and then goes on to the fluorescent lamp. The pre-accelerating and accelerating anode are connected to 1500v, and the focusing electrode is connected to 500 v. There are two methods of focusing on the electron beam. These methods are

- Electrostatic focusing
- Electromagnetic focusing.

The CRO uses an electrostatic focusing tube.

3. Deflecting Plate

Vertical Plates : The electron beam deflects along the X-axis due to a periodic electrostatic force applied at a constant rate. More clearly to say, the glowing spot moves along the X-axis on the phosphor screen. It moves at a constant speed with constant intervals.

Horizontal Plates : In addition to that, we apply the electrostatic force on the electron beam along the Y-axis. This force is proportional to the amplitude of the signal. Hence, the electron beam deflects up and down along the Y-axis

4. Fluorescent Screen for CRT

The front of the CRT is called the face plate. It is flat for screen sized up to about 100mm×100mm. The screen of the CRT is slightly curved for larger displays. The face plate is formed by pressing the molten glass into a mould and then annealing it.

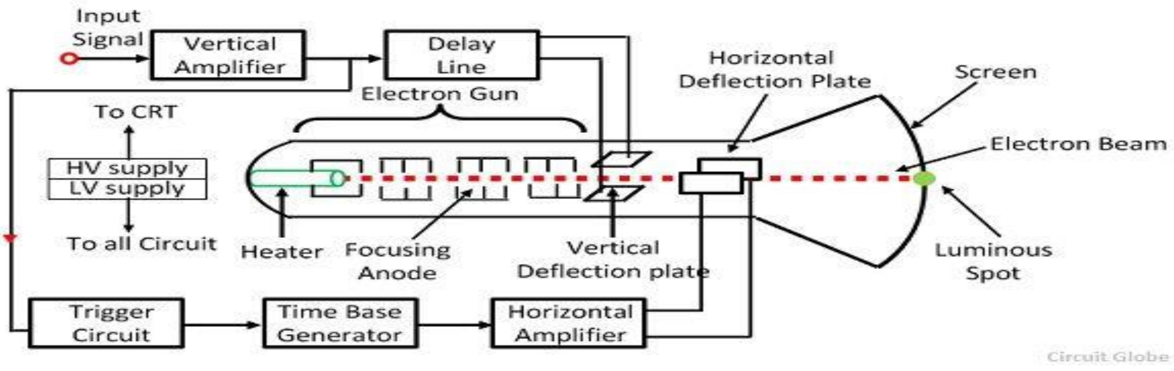
The inside surface of the faceplate is coated with phosphor crystal. The phosphor converts electrical energy into light energy. When an electronics beam strike phosphor crystal, it raises their energy level and hence light is emitted during phosphorous crystallisation. This phenomenon is called fluorescence.

5. Glass Envelope

It is a highly evacuated conical shape structure. The inner surface of the CRT between the neck and the screen is coated with the aquadag. The aquadag is a conducting material and act as a high-voltage electrode. The coating surface is electrically connected to the accelerating anode and hence help the electron to be the focus.

Working of Cathode Ray Oscilloscope

When the electron is injected through the electron gun, it passes through the control grid. The control grid controls the intensity of electron in the vacuum tube. If the control grid has high negative potential, then it allows only a few electrons to pass through it. Thus, the dim spot is produced on the lightning screen. If the negative potential on the control grid is low, then the bright spot is produced. Hence the intensity of light depends on the negative potential of the control grid.



After moving the control grid the electron beam passing through the focusing and accelerating anodes. The accelerating anodes are at a high positive potential and hence they converge the beam at a point on the screen.

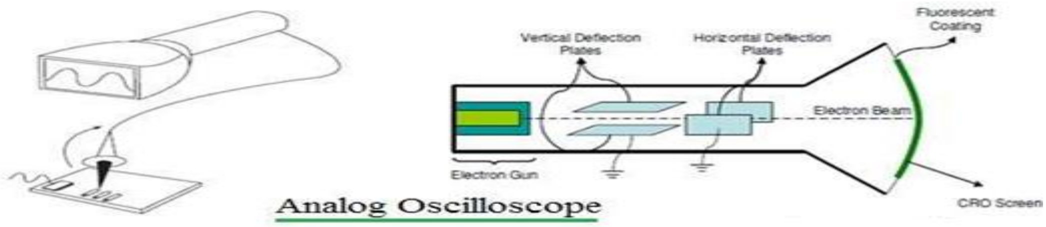
After moving from the accelerating anode, the beam comes under the effect of the deflecting plates. When the deflecting plate is at zero potential, the beam produces a spot at the centre.If the voltage is applied to the vertical deflecting plate, the electron beam focuses at the upward and when the voltage is applied horizontally the spot of light will be deflected horizontally.

Related Terms:

1. **Electron Gun** 2. **Electrostatic Deflection in CRT** 3.**Cathode Ray Tube (CRT)**

4. **Sampling Oscilloscope** 5-**Dual Trace Oscilloscope**

Benefits or advantages of Oscilloscope (Analog Type)



➡It is cheaper compare to digital counterpart.
➡It delivers reasonable performance which are accurate for many lab exercises.
➡It does not require ADC, µP (Microprocessor) and acquisition memory for measurement purpose.

Drawbacks or disadvantages of Oscilloscope (Analog Type)

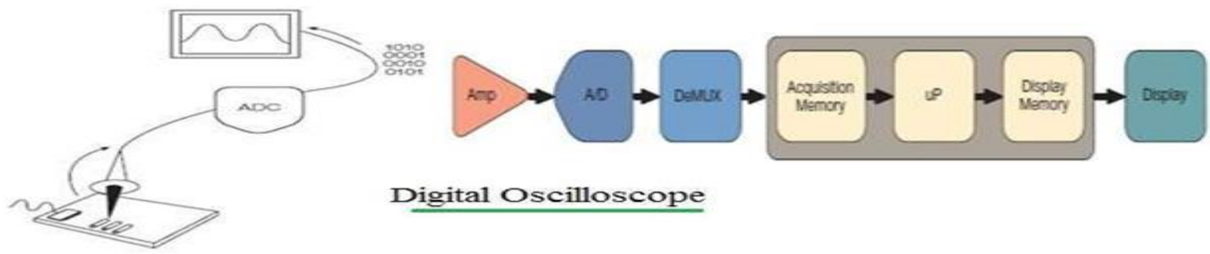
➡As there is no storage memory available, it can only analyze signal in real time.

➡It can not analyze high frequency sharp rise time transients.

➡It does not offer all the capabilities as supported by digital oscilloscope type.

➡It requires some amount of training to use it.

Benefits or advantages of Oscilloscope (Digital Type)



➡It can analyze signal in real time as well as can analyze large samples of acquired data with the help of storage memory.

➡It can analyze high frequency transients due to advanced DSP algorithms available

.**Drawbacks or disadvantages of Oscilloscope (Digital Type)**

➡It requires ADC, µP and acquisition memory for measurement purpose.

➡It is costly and cost depends on features supported in different available models viz. digital storage oscilloscope, digital phosphor oscilloscope and digital sampling oscilloscope.

Application of Cathode Ray Oscilloscope

There are uncountable applications of Cathode Ray Oscilloscopes. It is next to impossible to provide a complete list of such applications here.

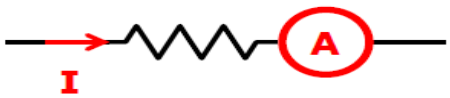
1. The CRO traces the actual waveform of an electrical signal.
2. Also, it determines the amplitude of the waveform.
3. It can compare the phases and frequencies of electrical signals.
4. Cathode Ray Oscilloscopes can also measure capacitance and inductance values.
5. One very common application of cathode ray oscilloscope is on the television.
6. A CRO can display the B-H curve for the hysteresis loop.
7. Also, CROs have wide application in the medical field. For displaying heartbeat rates, nervous reactions, etc. Medical practitioners use CROs for purposes.
8. We can also use this device to check the defective components in an electrical circuit.

8-Summary

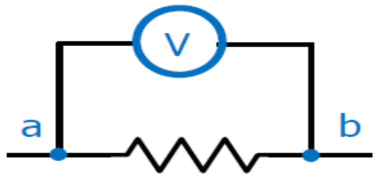
Measuring current, voltage, and resistance

Ammeter:
- measures current (A)
- connected **in series**

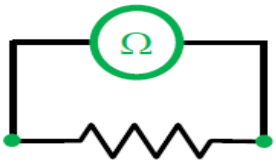
(current must go through instrument)



Voltmeter:
- measures potential difference (V)
- connected **in parallel**



Ohmmeter:
- measures resistance of an isolated resistor (not in a working circuit)



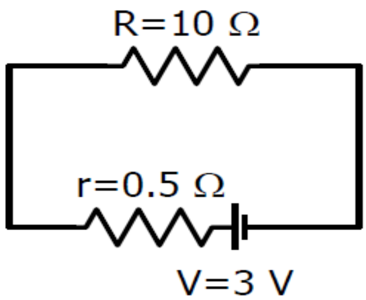
Example: an ammeter of resistance 10 mΩ is used to measure the current through a 10 Ω resistor in series with a 3 V battery that has an internal resistance of 0.5 Ω. What is the relative (percent) error caused by the ammeter?

Actual current **without** ammeter:

$$I = \frac{V}{R + r}$$

$$I = \frac{3}{10 + 0.5} A$$

$$I = 0.2857 \text{ A} = 285.7 \text{ mA}$$



You might see the symbol ε used instead of V.

Current with ammeter:

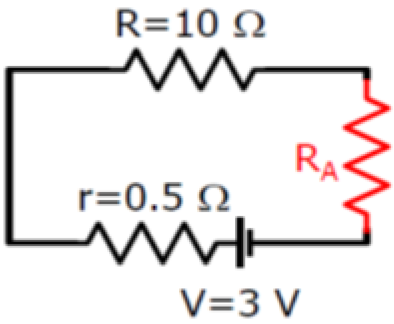
$$I = \frac{V}{R + r + R_A}$$

$$I = \frac{3}{10 + 0.5 + 0.01} A$$

$$I = 0.2854\ A = 285.4\ mA$$

$$\%\ Error = \frac{0.2857 - 0.2854}{0.2857} \times 100$$

$$\%\ Error = 0.1\ \%$$

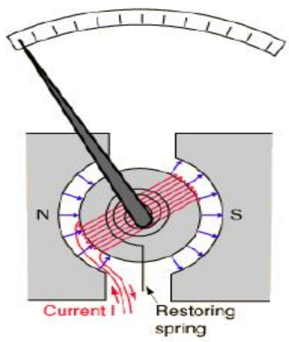


Designing an ammeter

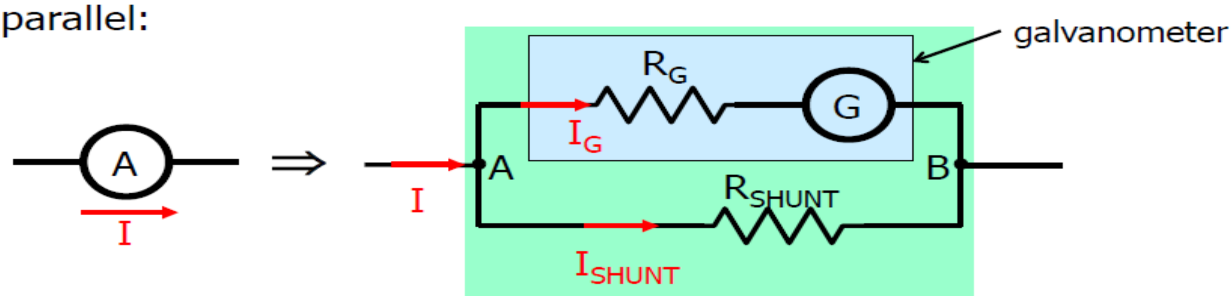
Galvanometer:

- current flows through a coil in a magnetic field
- coil experiences a torque, connected needle deflects

(see later chapters of this class)



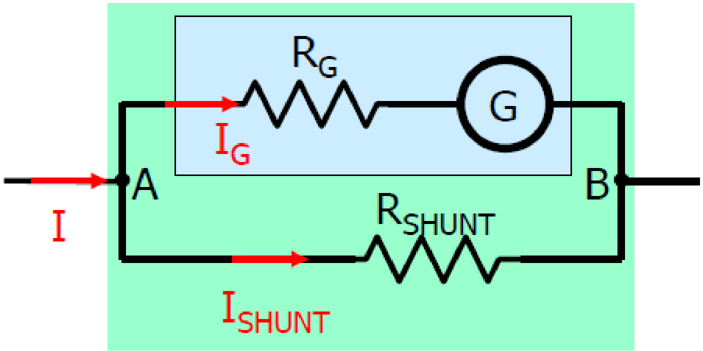
Ammeter uses a galvanometer and a shunt, connected in parallel:



Everything inside the green box is the ammeter.

- Current I gets split into I_{shunt} and I_G

> Homework hint:
> If your galvanometer reads 1A full scale but you want the ammeter to read 5A full scale, then R_{SHUNT} must result in I_G=1A when I=5A. What are I_{SHUNT} and V_{SHUNT}?

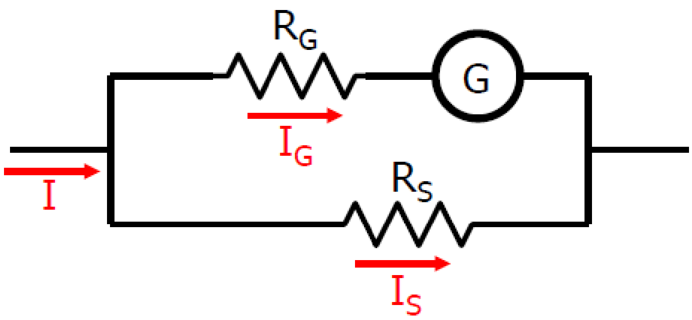


Shunt also reduces resistance of the ammeter:

$$\frac{1}{R_A} = \frac{1}{R_G} + \frac{1}{R_{SHUNT}}$$

$$R_A = \frac{R_G\, R_{SHUNT}}{R_G + R_{SHUNT}}$$

Example: what shunt resistance is required for an ammeter to have a resistance of 10 mΩ, if the galvanometer resistance is 60 Ω?



$$\frac{1}{R_A} = \frac{1}{R_G} + \frac{1}{R_S}$$

$$\frac{1}{R_S} = \frac{1}{R_A} - \frac{1}{R_G}$$

$$R_S = \frac{R_G\, R_A}{R_G - R_A} = \frac{(60)\,(.01)}{60 - .01} = 0.010\ \Omega$$

(actually 0.010002 Ω)

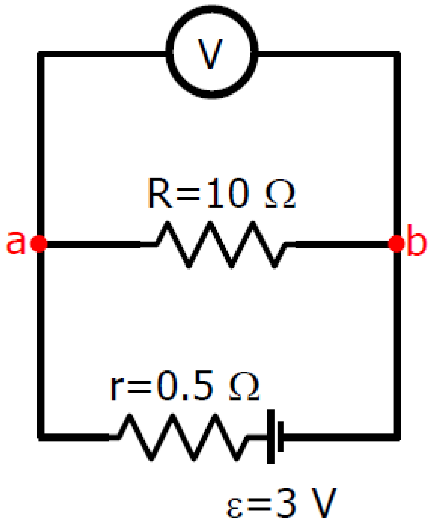
To achieve such a small resistance, the shunt is probably a large-diameter wire or solid piece of metal.

Effect of voltmeter on circuit

Measuring voltage (potential difference) V_{ab} in a simple circuit:

- connect voltmeter in parallel

Are we measuring the correct voltage?
(the voltage in the circuit without voltmeter)



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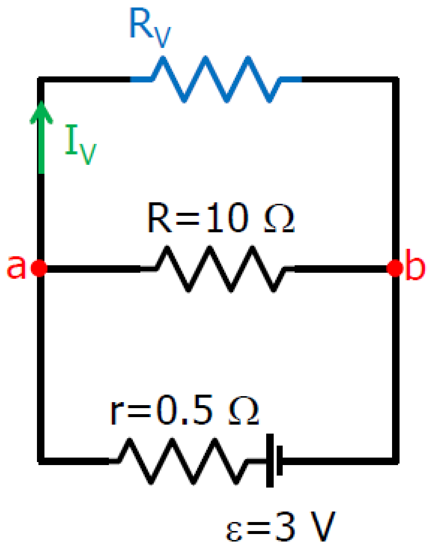
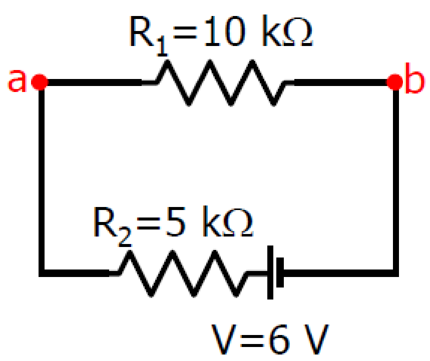


- voltmeter has **some resistance R_V**
- **current** I_V flows through voltmeter
- extra current changes voltage drop across r and thus V_{ab}

To minimize error, voltmeter resistance r must be very large.
(ideal voltmeter would have infinite resistance)

Example: a galvanometer of resistance 60 Ω is used to measure the voltage drop across a 10 kΩ resistor in series with an ideal 6 V battery and a 5 kΩ resistor. What is the relative error caused by the nonzero resistance of the galvanometer?

Actual voltage drop without instrument:



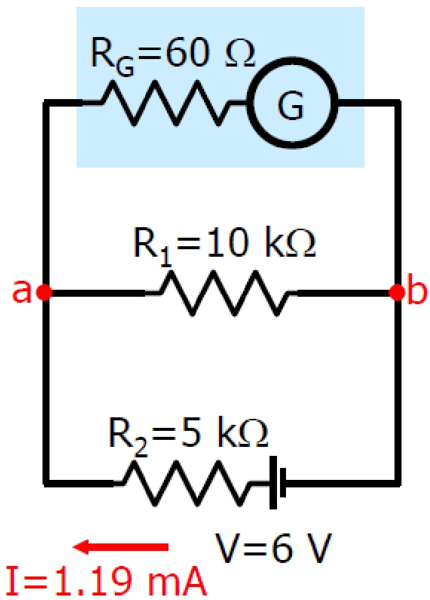
$$R_{eq} = R_1 + R_2 = 15\times10^3\ \Omega$$

$$I = \frac{V}{R_{eq}} = \frac{6\ V}{15\times10^3\ \Omega} = 0.4\times10^{-3}\ A$$

$$V_{ab} = IR = \left(0.4\times10^{-3}\right)\left(10\times10^3\ \Omega\right) = 4\ V$$

The measurement is made with the galvanometer.

60 Ω and 10 kΩ resistors in parallel are equivalent to 59.6 Ω resistor.



Total equivalent resistance: 5059.6 Ω

Total current: $I=1.186\text{x}10^{-3}$ A

V_{ab} = 6V – IR_2 = 0.07 V.

The relative error is:

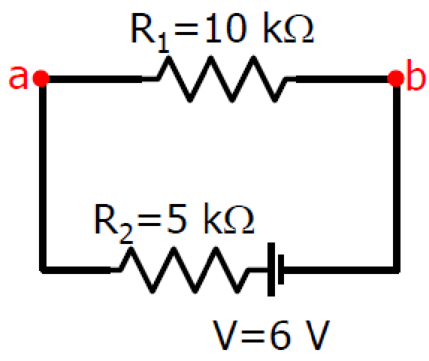
$$\%\ \text{Error} = \frac{4-.07}{4}\times100 = 98\%$$

Would you pay for this voltmeter?
We need a better instrument!

Example: a voltmeter of resistance 100 kΩ is used to measure the voltage drop across a 10 kΩ resistor in series with an ideal 6 V battery and a 5 kΩ resistor. What is the percent error caused by the nonzero resistance of the voltmeter?

We already calculated the actual voltage drop (2 slides back).

$$V_{ab} = IR = \left(0.4\times10^{-3}\right)\left(10\times10^{3}\ \Omega\right) = 4\ \text{V}$$



The measurement is now made with the "better" voltmeter.

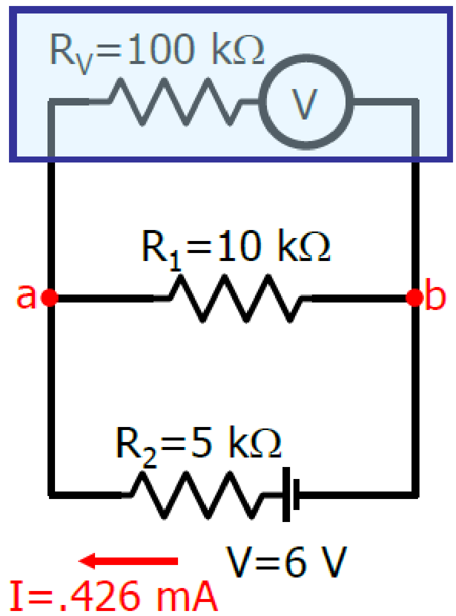
100 kΩ and 10 kΩ resistors in parallel are equivalent to an 9090 Ω resistor.
Total equivalent resistance: 14090 Ω

Total current: $I=4.26\text{x}10^{-4}$ A

The voltage drop from a to b:
$6-(4.26\text{x}10^{-4})(5000)=3.87$ V.

The percent error is.

$$\%\ \text{Error} = \frac{4-3.87}{4}\times 100 = 3.25\%$$



Not great, but much better.

The measurement is now made with the "better" voltmeter.

100 kΩ and 10 kΩ resistors in parallel are equivalent to an 9090 Ω resistor.
Total equivalent resistance: 14090 Ω

Total current: $I=4.26\times10^{-4}$ A

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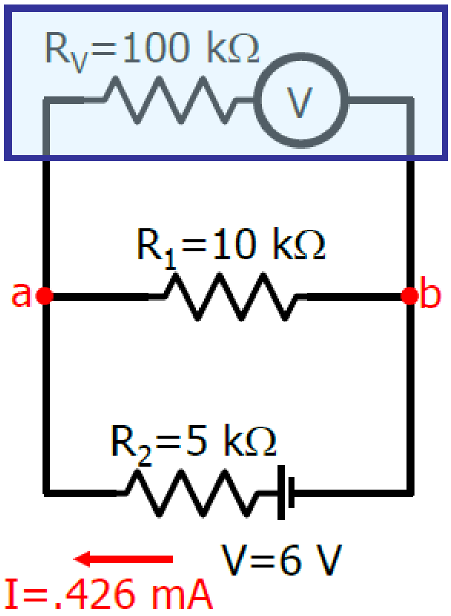
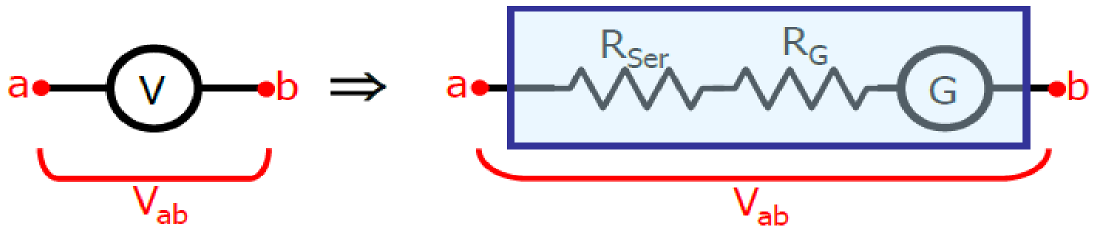


Not great, but much better.

Designing a voltmeter

- voltmeter must have a very large resistance
- voltmeter can be made from galvanometer in series with a large resistance



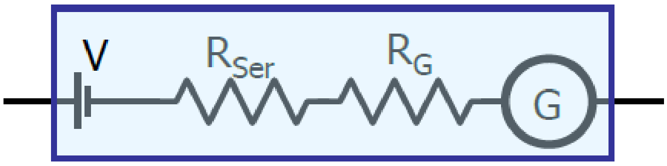
Everything inside the blue box is the voltmeter.

Homework hints: "the galvanometer reads 1A full scale" would mean a current of I_G=1A would produce a full-scale deflection of the galvanometer needle.

If you want the voltmeter shown to read 10V full scale, then the selected R_{Ser} must result in I_G=1A when V_{ab}=10V.

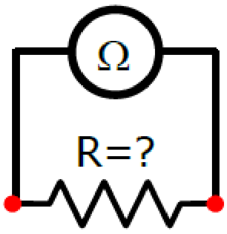
Measuring Instruments: Ohmmeter

- Ohmmeter measures resistance of isolated resistor
- Ohmmeter can be made from a galvanometer, a series resistance, and a battery (active device).



Everything inside the blue box is the ohmmeter.

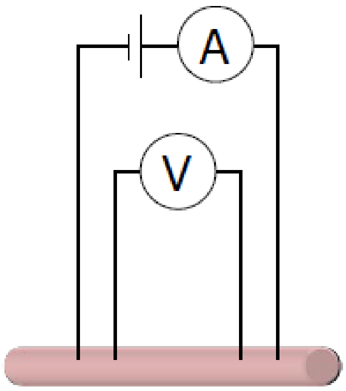
- Terminals of ohmmeter are connected to unknown resistor
- battery causes current to flow and galvanometer to deflect
- $V=I\ (R_{ser} + R_G + R)$ solve for unknown R



Alternatively:

- separately measure current and voltage for resistor
- Apply Ohm's law

Four-point probe:



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