華僑中學

HWA CHONG INSTITUTION

C2 H2 PHYSICS

PLANNING QUESTION REVISION PACKAGE 2019 BOOK A

Planning Question

Common Apparatus

Past Year Questions

Produced by HCI Physics Unit
For Internal Circulation Only

Preparation Package for Planning Questions

Planning Questions (For GCE A-level 9749 H2 Physics P4) can broadly be classified into the following three types:

1) Investigating relationship between 2 or more quantities
2) Verifying a given relationship
3) Determining a physical quantity

Tips on Preparing for Planning Questions

- Study how the procedures for the normal practical tasks are written.
- Familiarize yourself with the different apparatus and experimental techniques through the normal practical practice tasks.
- A general guide about the procedures written for the planned experiment should be such that anyone carrying out the experiment ***should be able to follow the procedures written*** and ***carry out the experiment successfully***. Thus the procedures should be clear and ***follow a logical sequence***. The conclusions for the experiment ***should be reproducible (by anyone carrying out the experiment) and meet the objective stated in the planning question***.
- As the range of investigations that are possible for Physics planning questions is very wide (wide range of experimental techniques and apparatus), tackling the Planning Question in A-Levels will require *accumulated experience and knowledge from practical and theory lessons* **over the entire 1.5-years H2 Physics course.**

Main parts in answering a Planning Question consist of:

- *What **Diagram** to draw?*
- *How to measure & vary the **Variables**?*
- *What **Analysis** is needed?*
- *How to improve **Reliability*** and **Safety**?*

***Includes Controls**

(Variables, Analysis, Reliability and Safety:) **Describe clearly in your experimental procedures**

(All four:) **DVARs**

1. Aim of experiment (thinking process)

- Identify the aim of the experiment in the question - "Design an experiment......"
- State specficially the variables to be measured.
- Use the variables to **brainstorm** the general procedure and **conceptualise the setup.**
- Questions to ask can include:
  - What is the independent variable?
  - What is the dependent variable?
  - What are the controls?
  - For the *dependent variables and independent variables*:
    - Can they be measured *directly?* What is the best instrument /procedure to use?
    - Do we need to further determine other quantities? What is the best procedure / instrument?
    - How to use these variables to get variable of interest? e.g. equation.
    - How do we vary the independent variable?
    - What is the range of your variables?
  - For the *controls*:
    - What other variables if not controlled will affect the results of the experiment significantly?
    - How do we ensure these variables are controlled?
- **Do not spend time listing all the variables in your solution, no credit will be awarded unless the method of measurement is given.**

2. Experimental Setup (the start of your written solution)

- Schematic diagrams are recommended but you may draw 3D diagrams if they help you in the procedure writing.
- You can draw more than one diagram.
- **No apparatus list is required. Listing the apparatus is a waste of time.**
- Diagrams must (i) have all apparatus clearly labelled. (ii) have all physical quantities like distances and angles that you are measuring included and clearly labelled, (iii) Remember to include fine details like table-tops and lab bench, floor and wall etc to ensure your appraratus are not floating in the air.

3. Procedure

- A good procedure is one that is clear and detailed, , capable of being carried out by another person unfamiliar with the work.
- The following details are a must:
  - Comprehensive and logical flow of **steps taken** (use a numbered list).
  - How to measure the independent variable (apparatus used, how to operate if needed)?
  - How to measure the dependent variable (apparatus used, how to operate if needed)?
  - Formulae used for all calculations or derived quantities to be clearly stated.
  - Repeat the experiment for to obtain **10** different values of independent variable. What are the steps to repeat? What are the range to vary? How to vary the independent variable?
  - Graph to plot. If there is a relationship to verify, include the linearisation working here. State the graph to be plotted to verify the relationship. If there are constants to be determined, state how the constants will be related to the gradient and intercept of the graph plotted.

4. Experimental Precaution (increasing reliability)

- This section can be incorporated into the procedure or as a stand-alone.
- Identify the good experimental techniques and practices.
- Consider potential sources of error and include steps to reduce them.
- Explain the rationale for the steps taken.

5. Safety Precautions

- These are precautions that ensure the safety of the experimenter and to ensure that the laboratory equipment is well taken care of during the experiment. The rationale for the step taken must be included.
- If it is a relatively safe experiment and you find no safety issues, you should have a statement to justify why you think it is safe. e.g. "This is a generally safe experiment with no harzardous materials present."

Note: The question will state a series of requirements that the examiners will be marking for ("In your account, you should pay attention to......), you should check off each requirement to ensure that you have fulfilled them.

How to use this package:

This package consists of the following four sections:

1. ***Apparatus (App)***
   This section contains explanation of how common laboratory apparatus function. If you know how the apparatus work, you are more likely to make good choices of apparatus and procedures. You are strongly encouraged to read through this section carefully at least once before attempting any question on your own. You should pay particular attention to apparatus unfamiliar to you.

2. ***Question Bank (QB)***
   This section is basically a collection of 27 past year PQs for you to attempt. You are strongly encouraged to plan your revision such that you have time to attempt all the questions on your own before the promotional exam. When practicing on your own, do attempt the write-up within 30 minutes. This is to train your time management during the assessment.

3. ***Suggested Marking Scheme (MS)***
   This section contains suggested marking schemes for these past year PQs. ***These MS are merely our best guesses which may or may not resemble the actual marking schemes that Cambridge markers used.*** *Nevertheless, they are included here so that you can mark your own answers and have a better idea how to improve your scores. Each MS contains a list of examples of what may be deemed worthy of detail marks. These lists are by no means exhaustive. You will also notice that, run-of-the-mill kind of procedures like "repeating and take average", "use the set square", "keep the ambient temperature constant" can score points in some questions but not in others. So do not waste your time hounding your teachers, asking them whether a particular point is worthy of detail mark. Nobody is definitely sure.*

4. ***Suggested Solutions (SS)***
   We have also painstakingly came up with suggested solutions for each PQ, based on the MS we created. Do note that your approach may or may not resemble that of ours, but nevertheless, if your approach is able to satisfy the requirements of the particular PQ, then there is absolutely no problem coming up with a PQ solution that is unique to you.

Do take some time to attempt them on your own before checking against our suggested MS and solutions.

Have a fruitful time trying the problems!

Apparatus	***Page***

A. Mechanics

B. Thermal and Electrical

C. Waves and Superposition

D. EM and Nuclear

Mechanics

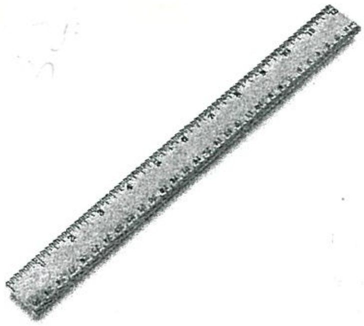
1m/s = 3.6km/h
1g/cm³ = 1000 kg/m³

Length

You are spoilt for choice when it comes to instruments for length measurements. Often the choice is made based on the resolution of the instrument in comparison to the length you are measuring. As a rule of thumb, you should choose an instrument which provides 1% precision or better, and no worse than 5%. Some instruments do come with unique features which may render them the "only" choice under certain circumstances. Read on to find out.

Ruler

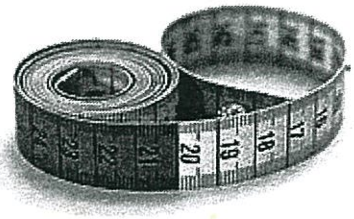
I am sure you know what a ruler is. These rigid sticks with calibrated scale, are used for measuring straight lengths, and other games like beating your friends. The common metre rule, half metre rule and 30-cm ruler all have a resolution of 1 mm. This translates to a precision of 1% or better for measurements of at least 10.0 cm.



Precisions:
- ruler: 0.1cm
- vernier caliper: 0.01cm
- micrometer screw gauge: 0.01mm

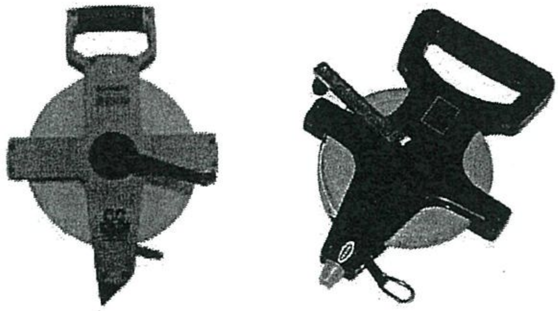
Measuring Tape

Measuring tapes come in different material and lengths. There is the type used by women to monitor their waistline. It has the same resolution as a metre rule. Made of flexible plastic, it has the advantage of measuring circumferences directly.



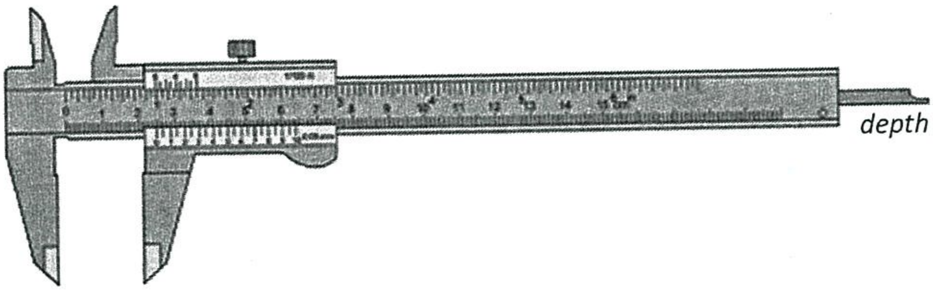
Then there is the type carried by contractors to measure ceiling height and so on. Made of metallic ribbon, it retracts into the container with a cool zip sound. It has the same resolution as a metre rule, but measures much longer lengths. Typical ranges on offer are 2 m, 3 m, 5 m and 8 m. precision: 0.1cm

Then there is the type used in sports to measure distances of javelin throws. These usually come in open reels and typical lengths of 30 m, 50 m and 100 m. Resolution is usually 1 cm.



Vernier Caliper

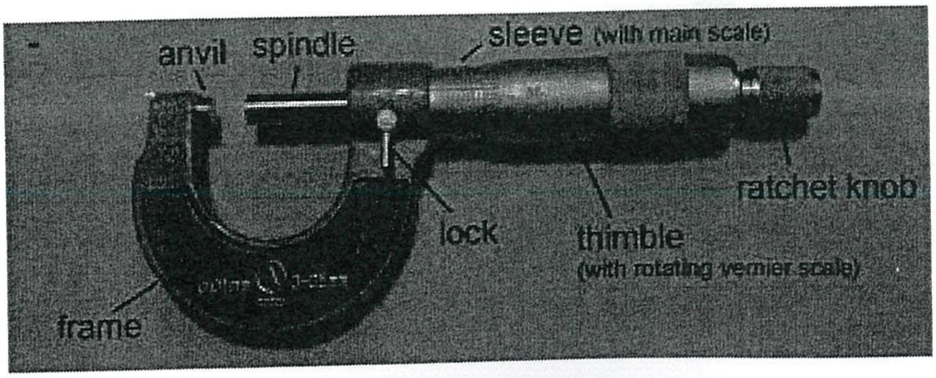
For lengths of a few centimeters, consider the Vernier Caliper. It typically has a resolution of 0.1 mm, or 0.01 cm. This translates to a precision of 1% or better for measurements of at least 1.00 cm. This foxy instrument comes with a pair of "jaws" for measuring outer diameter (e.g. of a coin or rod). It also has a pair of "ears" for measuring inner diameter (e.g. of a pipe). It even has a "tail" for measuring depth of a hole.



Featured in 03 CIE 2010 Nov P5 Q1 Hammering Nail

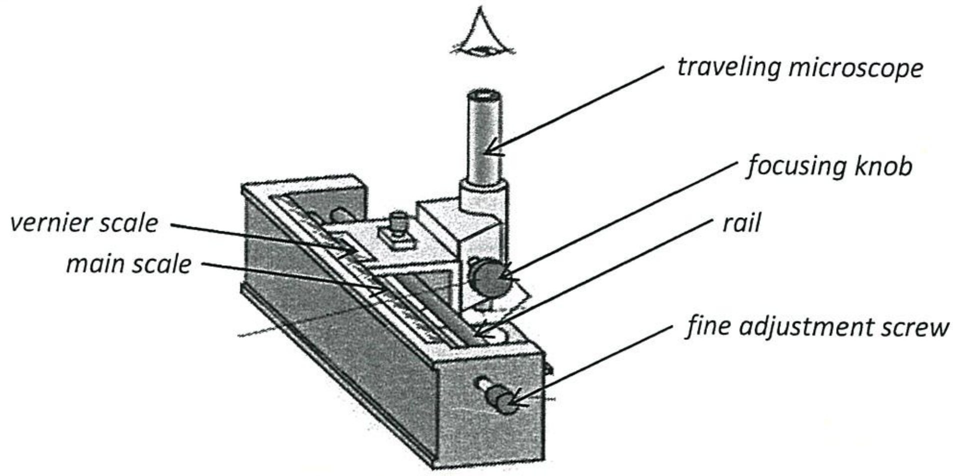
Micrometer

The micrometer, also known as the micrometer screw gauge, offers an incredible resolution of 0.01 mm. It is the instrument of choice for measuring lengths less than 1 cm, such as diameter of ball bearings and thickness of wires. Because the thimble is essentially a screwdriver, many people end up over tightening and literally screw up their measurements. They should remember to use the ratchet, which stops the spindle from advancing (and makes those delightful clicking sound) once sufficient resistance is encountered. This leads to greater accuracy and repeatability of measurements.



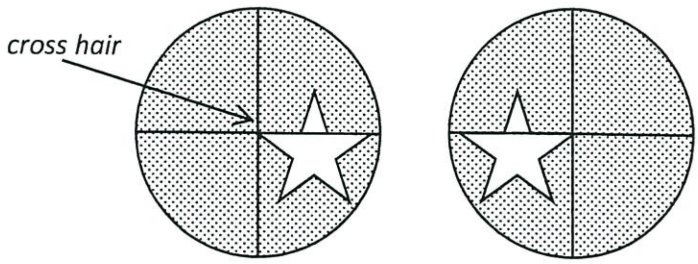
Traveling Microscope

The traveling microscope is essentially a microscope which can be moved along a rail (or two) and whose position can be read off to a precision of 0.01 mm thanks to the attached vernier scale.



Its operation principle is a mouthful to explain. Say you want to measure the width of the star on the $1 coin. The first thing you have to do is of course to place a $1 coin under the microscope. You look through the eye piece and adjust the focusing knob to bring the coin into focus. You also notice see a cross hair which has been affixed inside the microscope to help you pinpoint the location of the microscope. Your job now is to bring the cross hair to align with the left edge of the star. This is achieved by sliding the microscope along the rail for coarse positioning, and by turning the fine adjustment screw for fine positioning. Now take the reading for the initial position P1 of the microscope using both the main and vernier scale. Next move the microscope to align the cross hair with the right edge of the star. Take the reading for the final position P2. The width of the star can now be calculated by the displacement P2 – P1.

$1 coin



View through the eye piece

As you can see, its operation is rather cumbersome so we use the traveling microscope only for short lengths that cannot be measured by the micrometer, like holes, indents, writings and biological specimens.

Featured in
"10 CIE 1999 Nov P4 Q3 Hardness of Lead vs Setting Time"
"12 CIE 2009 Nov P5 Q2 Expansion of Hot Wire"

Time

Stopwatch

The standard timekeeper in physics labs today is the crystal oscillator digital stopwatch which offers an incredible resolution of 0.01 sec. Strangely enough, every stopwatch seems to adopt the timeless 2-button design:

1. *Pressing the right button (often labeled as START·STOP button) starts the timer running.*
2. *Pressing the right button again stops it, leaving the elapsed time displayed.*
3. *Pressing the left button resets the stopwatch to zero.*

The left button is often labeled as the LAP/SPLIT button because it allows lap times to be recorded conveniently. Here is how it works. Say you want to time your friend's 2.4 km run.

1. *Press the right button at the start of his run. This starts the timer running.*
2. *Press the left button when he completes his first lap. This freezes the display but the timer continues running in the background. This allows you to jot down his lap time.*
3. *Press the left button again. This unfreezes the display.*
4. *Repeat steps 2 and 3 at every lap.*
5. *Press the right button at the end of his run. This stops the timer.*

Now you can report to your friend not only his total race time, but also all his lap times.

Velocity

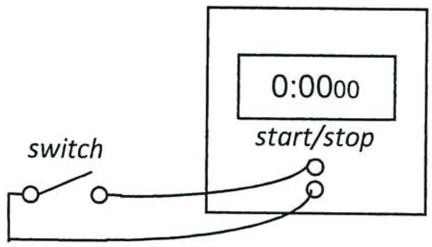
The obvious way to measure the speed of a moving object is to use a stopwatch to time how long it takes for the object to move a certain distance. For motion that is over in the blink of an eye, using a manually operated stopwatch is error prone because of human reaction time.

Electronic Timer

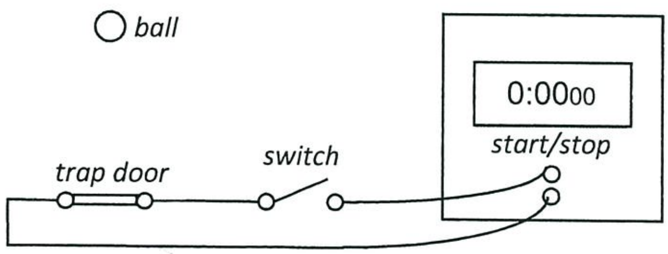
Electronic timers refer to stopwatches which have terminals (usually at the back panel) that allow for connection to external triggers such as electrical switches or photogates, thus bypassing the limitation of human reaction. It is common for electronic timers to have resolution of 1 μs or even better.

Depending on their design, different timers operate with different trigger signals.

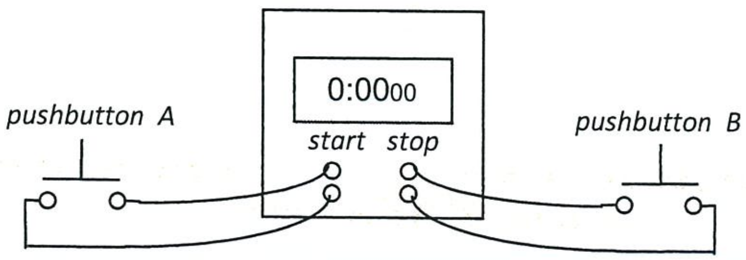
Some timers are "level-triggered": the timer runs when the terminals are shorted, stops when the terminals are open. In other words, if the terminals are connected by a switch (see diagram below), the timer would be measuring the duration for which the switch is closed.



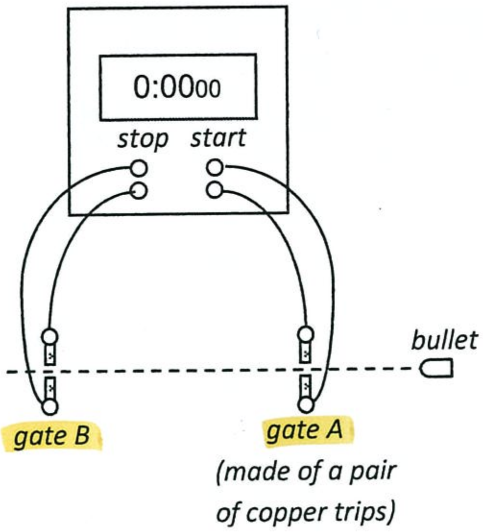
The diagram below illustrates how the fall of a ball can be timed using a "level-triggered" timer: The ball is dropped at the same instant as the switch is closed (which starts the timer). At the end of the fall the ball impacts and opens the trap door (thus stopping the timer).



Some timers are "pulse-triggered": the timer runs/stops each time the terminals are shorted. Many "pulse-triggered" timers come with two pairs of terminals, one pair awaits the signal to start the timer, and another awaits the signal to stop the timer. In other words, if the terminals are connected by pushbuttons (see diagram below), the timer would be measuring the duration between the pressing of pushbutton A and B.



The diagram below illustrates how a bullet's path can be timed using a "pulse-triggered" timer: The bullet is shot through two "gates". Each gate is made up of 2 pieces of thin copper strips positioned so that there is a small gap *between them. Each time the metallic bullet passes through a gate, it brushes the copper foils and closes the circuit momentarily. The timer is thus started when the bullet passes gate A and stopped when it passes gate B.*

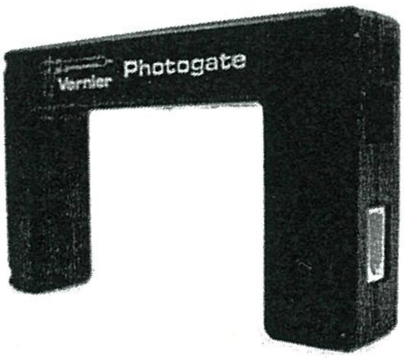


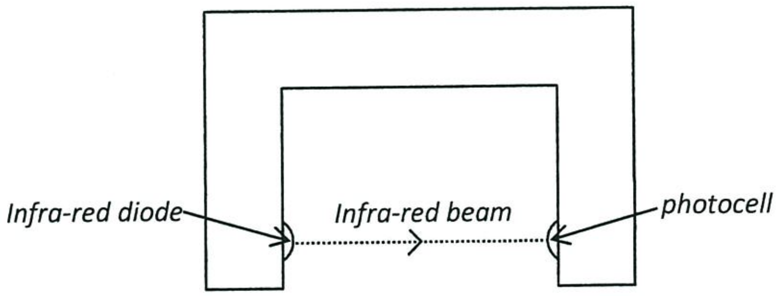
Some timers can be configured to operate "the other way round", meaning the timer runs when the terminals are open (instead of shorted). This allows even more flexibility in your experimental set up.

Featured in "02 UCLES 2003 Nov P5 Q2 Efficiency of a Bow"

Photogates

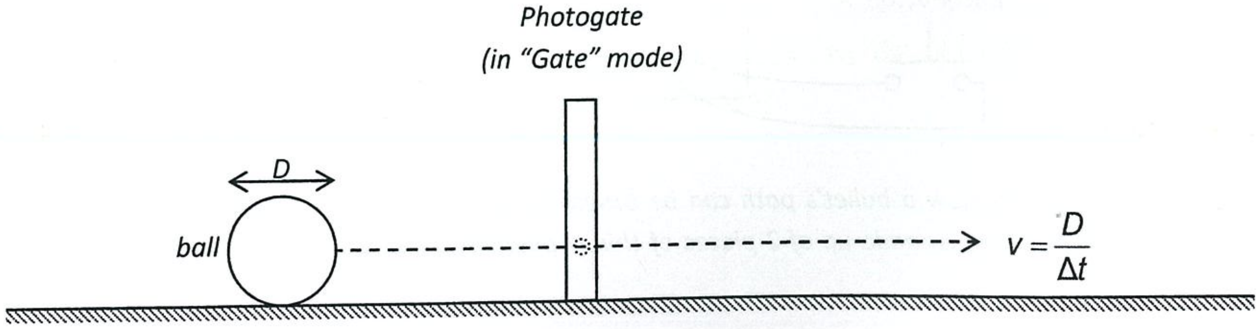
The photogate consists of an infra-red diode (which emits the infra-red beam) and a photocell (which detects the infra-red beam). When an opaque object comes in-between them, the infrared beam is interrupted. This provides the trigger signal to operate an electronic timer.



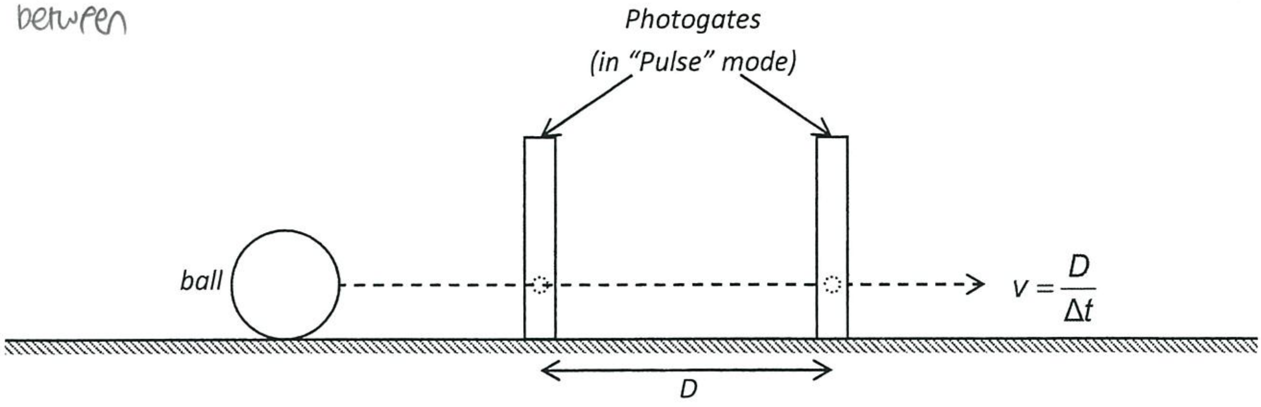


A photogate can be operated in either the "Gate" mode or "Pulse" mode.

When in the "Gate" mode, the photogate measures the duration for which the beam is broken. For example, if you know the diameter of a ball rolling through a photogate, you can determine the speed of the ball by dividing the diameter by the time the photogate is blocked by the ball. This requires only one gate, but the gate has to be positioned carefully so the light beam intersects exactly the middle of the ball.



When operated in the "Pulse" mode, timing starts or stops each time the beam is broken. For example, if you know the distance the two photogates, you can determine the speed of the ball by dividing the distance by the time elapsed between the first and second time the photogates are blocked by the ball.



Featured in "07 CIE 1997 Nov P4 Q3 Pellet Penetration vs speed"

Video Camera on Tripod

It is increasingly convenient to analyse a motion by filming it using a video camera and replaying it frame-by-frame.

The time precision provided by video is dependent on the frame-rate. Frame-rate is quoted in fps, or frame per second. Typical frame rate of 30 fps provides a good precision of about 33 ms. High speed cameras have even higher frame rates of 210 fps, 420 fps and even 1000 fps. For example, the time interval between say frame number 132 and 165 of a video captured at 210 fps would be (165-132) $\div$ 210, or 157 $\pm$5 ms.

It is common practice to arrange a stationary ruler or some other measuring scale to be filmed together with the moving object. The length precision therefore depends on the resolution of the ruler/scale implanted in the video.

The first advantage of video photography is that it bypasses the limitation of human reaction time during manual operation of stopwatches. This makes it an attractive tool for studying motion that is too quick for the human reflex. The second advantage is that since the entire motion is filmed continuously, we are able to construct the s-t graph of the motion. The v-t and a-t graphs can be derived accordingly!

It is important for you to be aware that much care must be taken in the set up to ensure reliable analysis can be obtained from video photography.

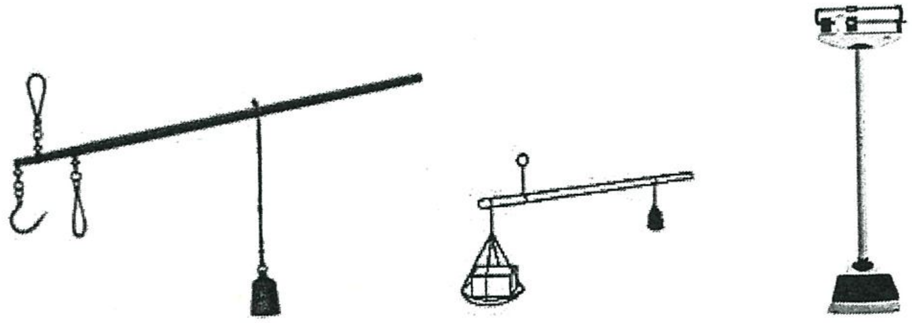
1. *The camera must be stationary throughout the filming. Use a tripod.*
2. *The ruler or scale to be "implanted" into the video should be positioned close to the motion to minimize parallax error.*
3. *The motion should be restricted to a plane parallel to the camera front.*

Featured in "06 CIE 1998 Nov P4 Q4 Terminal Velocity of Parachute vs Diameter"

Mass, Weight and Force

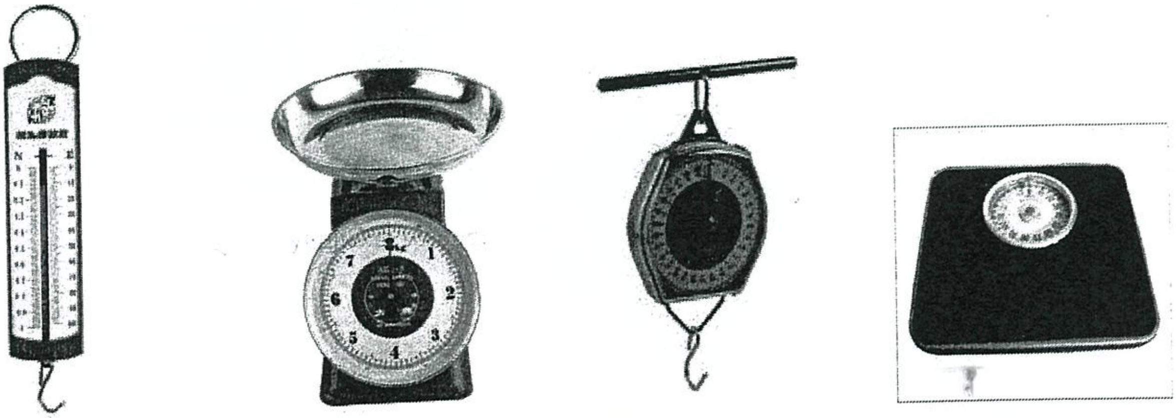
Traditional Weighing Balances

Weighing balances refer to instruments that measure mass of an object based on the Principle of Moments. A balance utilizes a horizontal lever, and balances the moment due to the unknown weight to the moment due to a standard reference weight. Balances are going out of fashion among the butchers, but they are still used at Chinese medicine stores to "weigh" herbs, and at clinics to "weigh" patients.



Traditional Weighing Scales (Spring Scales)

Weighing scales (also called spring scales) refer to instruments that measure weight of an object based on Hooke's Law. A scale utilizes a spring which compresses or stretches under load condition, a needle which moves as a result, and a scale which is calibrated so that the needle shows the correct "mass". You should recognise them as the ones used by fishmongers to weigh your fish, butchers to weigh your meat, and women to weigh themselves.



Make no mistake, a scale actually measures weight, or more specifically how hard the Earth pulls on the object, but is calibrated to show mass. Since the value of g differs slightly with location, a scale must be recalibrated when used in a new location.

To purists, weighing scales are completely different from weighing balances (one measures weight, the other measures mass) and the two terms should never be confused. However, most people (including even scientists and equipment suppliers) do not care and it has become acceptable to use the two names interchangeably.

Electronic Balance

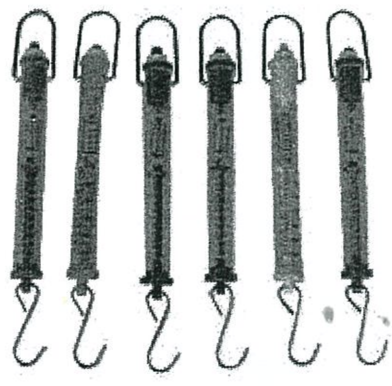
To measure mass in the lab, we almost always use the electronic balance. Chances are you will never get to use a traditional weighing balance or scale in the lab, simply because the electronic balance is much more precise and convenient.

An electronic balance actually measures weight, but is calibrated to display mass. Electronic balances utilize strain gauges, whose resistances vary as they are compressed or stretched. This allows us to convert a pressure signal into an electrical voltage which can be calibrated to show the correct "mass". It should be clear to you that an electronic balance needs to be recalibrated when used in a new location where the value of g is significantly different.

There is usually a tare function which resets the display to zero: from then only the additional mass is displayed. This function is used to subtract out the mass of the weighing pan/container so that only the mass of the content is displayed. E.g. the balance is first tared with an empty beaker on the pan. Subsequently, the balance displays only the mass of the liquid in the beaker.

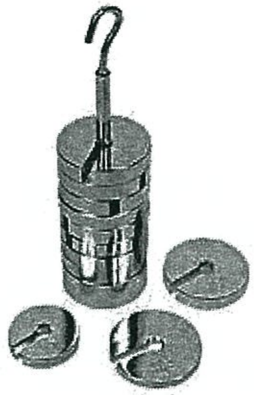
There is a complete range of electronic balances, offering maximum weighing capacities from tens of grams (used by jewelers) to tens of kilograms (used by NTUC aunties). The ones found in Physics labs usually weigh up to 1 kg with precision of 0.01 g.

Spring Balance (Newtonmeter)



Spring balances refer to the spring scales which are found in Physics labs. However, you should not use it to measure mass of any object because the electronic balance is far more precise and convenient. When we do use it, it is often to measure a force. For example, you can use it to pull a block along an incline, and measure the pulling force at the same time. For that purpose, most spring balances come with a dual scale, one in grams and the other in newtons. They come in a range of maximum force capacities from 1 N to 30 N

Slotted Mass and Hanger



Slotted masses are so called because they come with slots which allow them to be hung on a weight hanger. This allows you to quickly create any desired amount of mass. Standard masses are 500, 200, 100, 50, 20, 10, 5, 2, and 1 gram, and their values are always engraved on the masses. The hanger of course has a mass too and its value is engraved on it too.

Volume

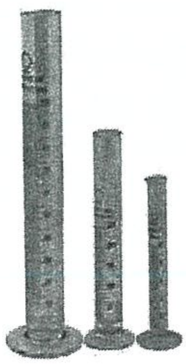
Beaker

A beaker is intended as a container for stirring, mixing and heating liquids. They are ***NOT*** *intended for obtaining a precise measurement of volume. Even though they are graduated (i.e. marked on the side with lines), the markings are too coarse and can only serve as an estimation.*

Beakers are available in a wide range of sizes, from several mL to several litres. 50 mL, 100 mL, 250 mL, 500 mL, 1000 mL are the more common sizes.

Measuring Cylinder point reading

A measuring cylinder is used to accurately measure the volume of a liquid.



Measuring cylinders are available in a wide range of sizes, from several mL to several litres. Resolution vary according to sizes from 0.05 mL to 1 mL.

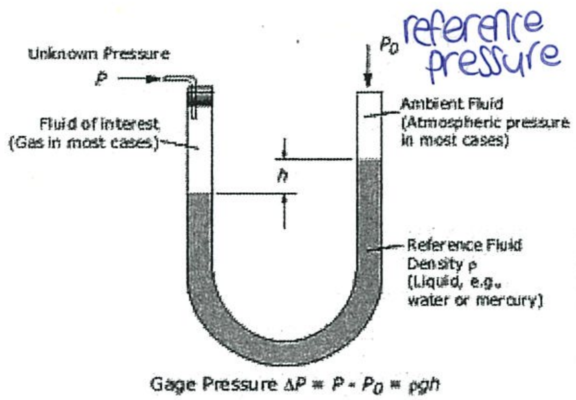
Thermal and Electrical

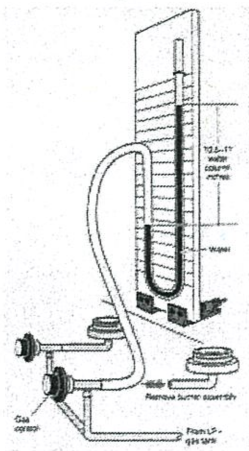
Pressure

*According to NBA rules, the basketball is to be inflated to between 7.5 psi to 8.5 psi (52 kPa to 59 kPa). Wait a minute, isn't that even lower than atmospheric pressure of about 100 kPa? Well, you have to know the difference between absolute pressure and gauge pressure. The **absolute pressure** is measured relative to absolute zero pressure (i.e. the pressure of a perfect vacuum). All calculations involving the gas laws require pressures (and temperature) to be in absolute units. On the other hand, a **gauge pressure** is measured relative to atmospheric pressure (or more accurately ambient air pressure). Most everyday pressure measurements (e.g. tire pressure and blood pressures) are gauge pressures (because the instruments we use to measurement them measure gauge pressure by design). So a basketball inflated to a (gauge) pressure of 55 kPa has an absolute pressure 55 kPa above atmospheric pressure, or 155 kPa.*

Manometer

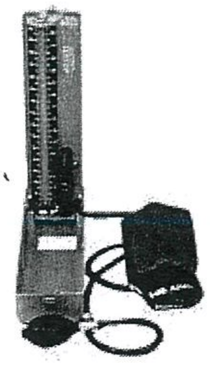
A manometer can refer to any pressuring measuring instrument designed to measure pressure near atmospheric. However, one usually has in mind a liquid column instrument when one uses the term manometer. The archetypical manometer is a U-tube half-full of mercury. One end of U-tube is exposed to the pressure to be measured, while the other end is exposed to a reference pressure. The height difference in the mercury levels (in mm Hg) measures the pressure difference between the two ends. p = hdg





To function as a barometer, the reference end can be connected to a vacuum, in which case it measures absolute pressure.

Usually, however, the reference end is left open to the atmosphere, so the manometer measures the gauge pressure. If the height difference is too small, a liquid of lower density such as water or even alcohol can be used in place of mercury. The main limitation of manometers is actually that the height difference is too large. So it is usually only used to measure pressure near the atmospheric. You may have seen one specific type of manometer before at hospitals or clinics. Doctors use them to measure their patients' blood pressure. It is called a sphygmomanometer.

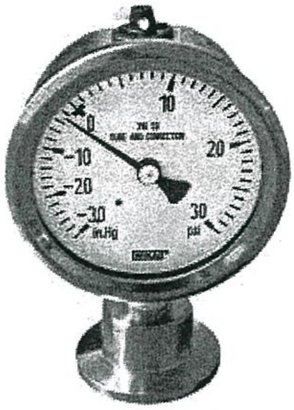


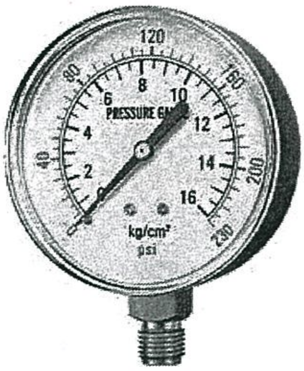
<u>Bourdon gauge</u>

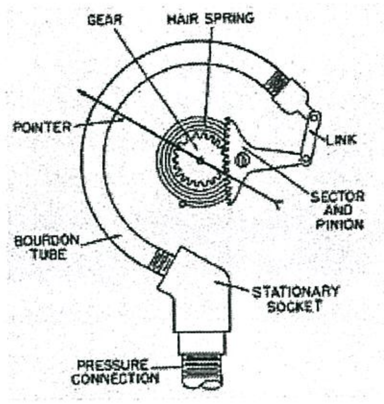
You may have seen Bourdon gauge on top of gas cylinders before. Or at the air pump station at petrol kiosks.

A Bourdon gauge works on the same principle as that of the snakelike, paper party whistle which straightens when you blow into it. Inside each Bourdon gauge is a thin-walled metallic tube which uncoils slightly when the pressure in the gas inside it increases. This movement is magnified by a lever mechanism to move a pointer move across a scale. The scale may be calibrated in any of the many units of pressure such as psi, kPa, Bar, mmHg, psi, etc.

Bourdon tubes measure gauge pressure. When the pressure is less than atmospheric, the Bourdon tube can uncoil in the opposite direction, so it can be used as a vacuum gauge to measure vacuum pressure as well. Bourdon gauges are a lot more popular than manometers because they are more robust, more convenient and can measure much higher pressures. But they have to be calibrated before they can be used.





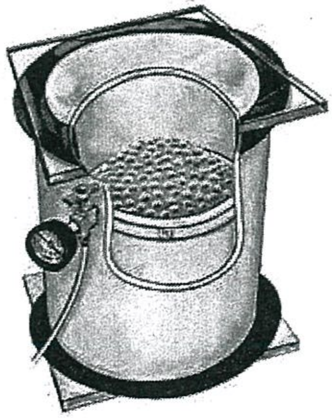


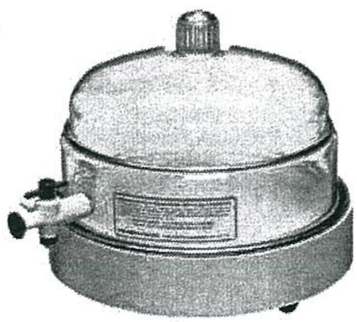
<u>Barometer</u>

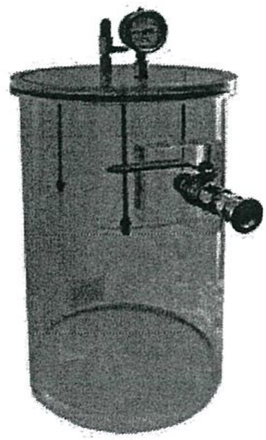
A barometer refers to an instrument designed to measure atmospheric pressure and only atmospheric pressure. If someone proposes using a barometer to measure anything else, like the pressure of a basketball, we know that person has never seen a barometer before.

<u>Vacuum Chamber</u>

Some experiments have to be carried out in low pressure (< 1 atm) environment. For that, you need a vacuum chamber.



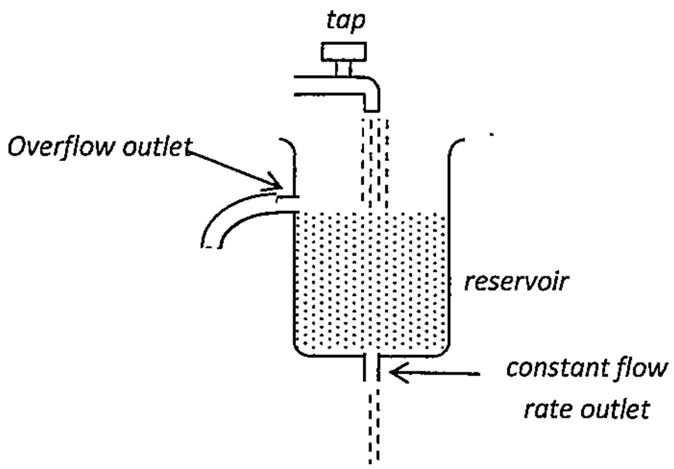




*A **vacuum chamber** is a rigid enclosure made of metal or glass. Metallic ones are usually fitted with a glass window so that you can view the inside. It has at least one opening connected to a pressure gauge and a vacuum pump. The **vacuum pump** removes gas molecules from the chamber to leave behind a partial vacuum. This is obviously not a true vacuum, but nevertheless it is commonly referred to as a vacuum. Additional openings can be made to feedthrough* *power cables, instrumentation wires and so on. All these openings have to be air tight of course.* ***Vacuum grease*** *is commonly used to seal these openings. It is actually a rubbery lubricant. Because of its low volatility it does not evaporate in low pressure environments.*

Constant Head

Some experiments require a continuous flow of water at a constant rate. This can be achieved with a simple contraption. All that is required is (in the words of the plumbing profession) a "constant head", that is, a fixed water level above a hole.



The figure above shows the design of a constant head. A running tap continuously supplies water to a reservoir. The reservoir has two outlets. The first outlet, near the top, drains excess water so the water level is fixed. The second outlet, at the bottom, is where water flows out at a constant flow rate. The flow rate can be varied by adjusting the vertical position of the overflow outlet.

Featured in "19 UCLES 2002 Nov P5 Q1 Umbrella Diffraction Grating"

Temperature

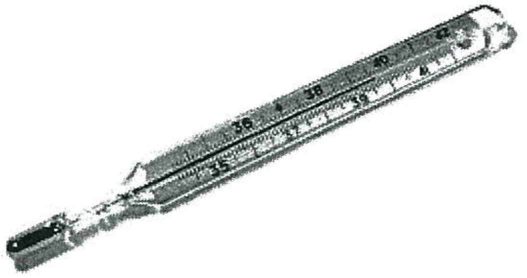
Mercury-in-glass

You should be most familiar with the mercury-in-glass thermometer. You may not realize that the mercury-in-glass thermometer has two severe limitations:

1. In principle mercury allows temperature range from-39 °C. to 357 °C. In practice, it is hard to find one that measures below -20°C or above 200 °C.

2. The size of the thermometer bulb does not allow it to measure temperature of a small local region. In fact, if you cannot immerse the bulb in it, you cannot measure it.

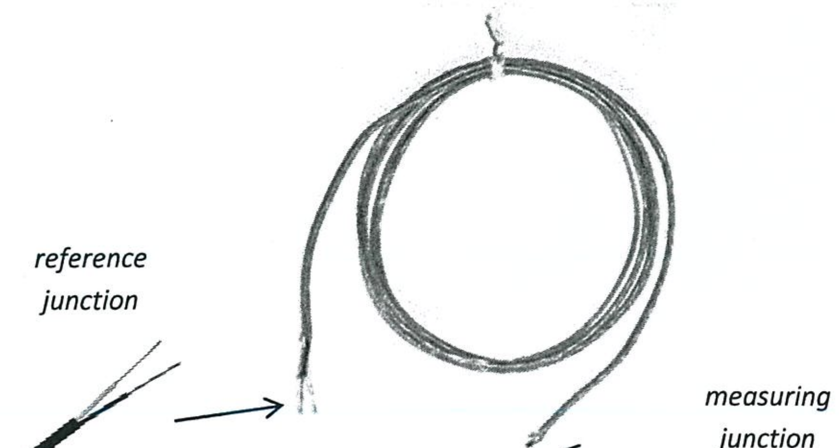
Come to think of it, I bet you have used the mercury-in-glass to measure only these three things: (1) temperature of liquid (usually water) between -10 °C and 110 °C (2) room temperature and (3) your body temperature



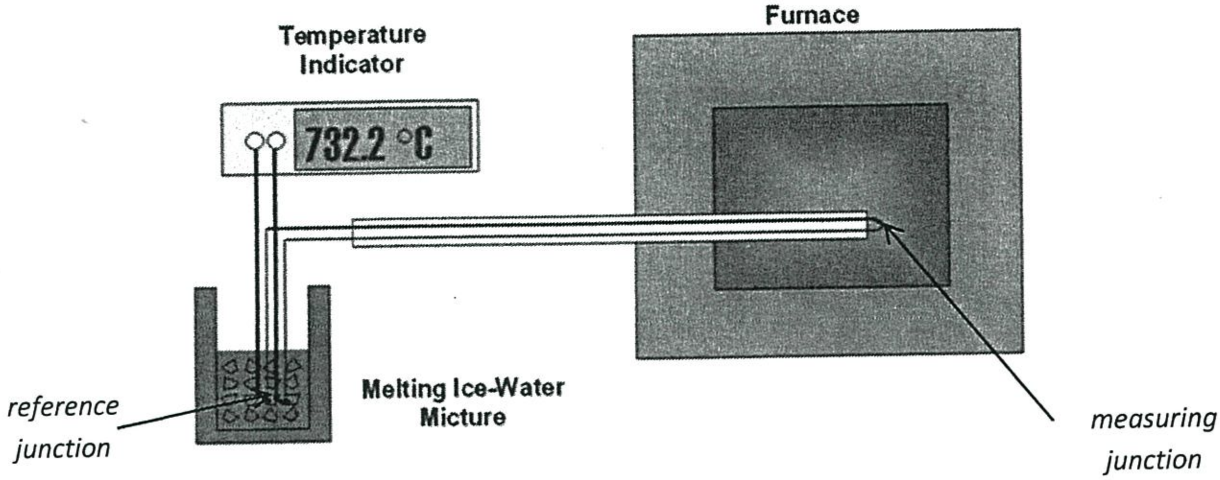
Thermocouple

How does a thermocouple work? The theory is quite complicated to be honest. If you are bent on finding out the whole truth, this webpage http://www.msm.cam.ac.uk/utc/thermocouple/pages/ThermocouplesOperatingPrinciples.html *is a good starting point. However, to learn how to use a thermocouple to measure temperature is much simpler, and you only have to read on.*

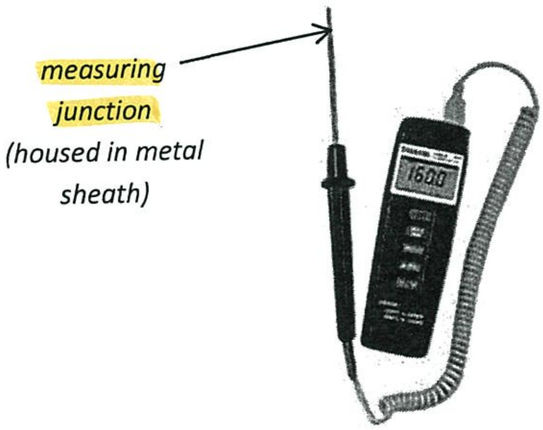
Well, a thermocouple is nothing more than a pair of wires made of dissimilar metal. The most common combination is the Type K thermocouple, which consists of a chromel (nickel-chromium) wire and a alumel (nickel-aluminium) wire. It is inexpensive and allows you to measure temperature between -200 °C to +1300 °C.



At one end of the thermocouple, the wires are twisted and welded together. This is the measuring junction. It should be in thermal contact with the temperature you are trying to measure. The other end of the thermocouple is the reference junction. It should be dipped in an ice bath to keep it at 0 °C. You can now use a millivoltmeter to measure emf between the two wires. The magnitude of this emf is directly proportional to the temperature difference between the two junctions. To tell the temperature at the measuring junction, you must refer to the standard table for Type K thermocouple, which tabulates the expected emf for each temperature. Obviously, if you just left your reference junction hanging at room temperature, the emf generated would be smaller. However, if you know the actual reference junction temperature, it is not too difficult to compensate for the "wrong" reference junction temperature in your computation to derive the correct temperature.



Today, you can get an all-in-one thermocouple thermometer. You probably cannot see the measuring junction because it is housed in a metal sheath. Neither can you see the reference junction because it is hidden inside the instrument. In fact, you do not even need to provide the reference ice bath because the instrument can sense the reference temperature (usually by using a thermistor) and electronically compensate for the "wrong" reference junction temperature. All you have to do is to read the digital display. It is that convenient!



The resolution of the thermocouple is usually a couple of degree Celsius, which is poorer than what the mercury-in-glass offers. However, it has the following important advantages:

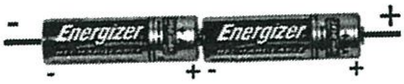
1. *It has a wide temperature range from -200 °C to +1300 °C. This makes it the instrument of choice for measuring anything outside the 0 °C to 100 °C range. This includes applications such as ovens, gas turbines, engines, etc.*
2. *The sensing element is as small as you can get. This means quick response time so it can measure rapidly changing temperature. This also means it can measure temperature of a small local region.*

3. *It is robust and versatile. The measuring junction can be immersed in liquid, pressed against a solid surface, screwed into a cavity, wrapped around a rod, so it achieves good thermal contact easily.*

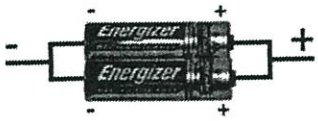
Power Supply

DC Cells

The alkaline batteries that you are so familiar with are convenient for demonstrations. However, they have severe limitations for use in science experiments. (1) They come in fixed voltages of about 1.5 V. (2) They can supply a current of typically no more than 100 mA before the terminal voltage falls drastically. Sure, you can connect a few of them in series to increase the terminal voltage. You can also connect a few of them in parallel to increase the current capability. You can even connect a few in parallel and in series to increase both. But surely you see it can be quite cumbersome.



Double the terminal voltage



Double the current capability

Double the terminal voltage and current capability

Variable DC Power Supply

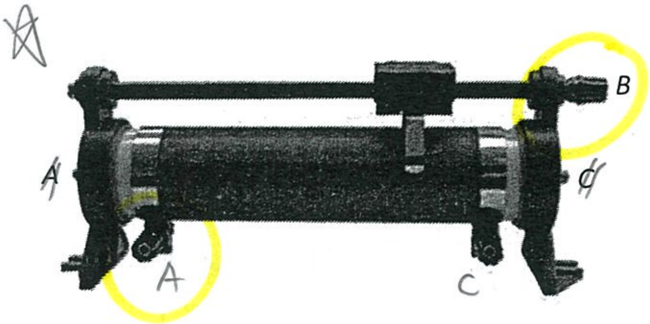
All serious electronics laboratories are stocked with voltage regulators, or just simply called the DC power supply. They take in the AC power supply, and convert it to a DC output of adjustable voltage. For example, for the model below, just turn the voltage knob and you can adjust the output voltage from 0 V to 30 V in steps of 0.1 V. They usually have negligible output impedance (think of it as the internal resistance) and can supply current of easily up to 5 A. Now you can focus on your experiment instead of your battery pack.

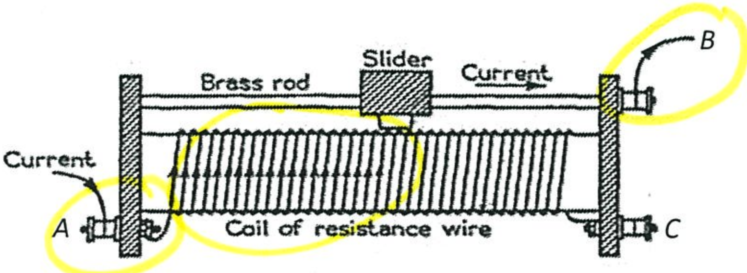
Variable Resistance

It is usually more than sufficient for you to be able to draw the symbol for a variable resistor, and label it as a variable resistor. If you are interested however you can read on to find out the difference between a rheostat and a pot.

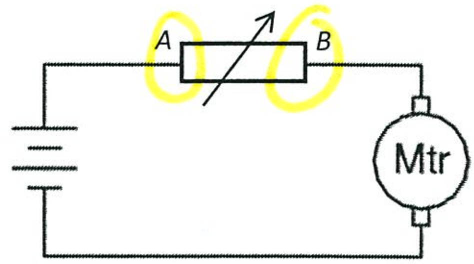
Rheostat

When we say rheostats what we have in mind are those wire-wound type that have a long length of conductive wire coiled into a tight spiral. The position of the slider controls the resistance. They are usually connected in series with the device whose current we are trying to control.





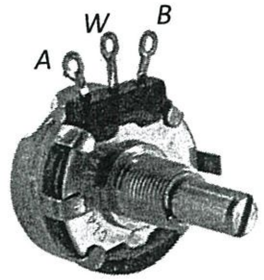
Wire-wound rheostat

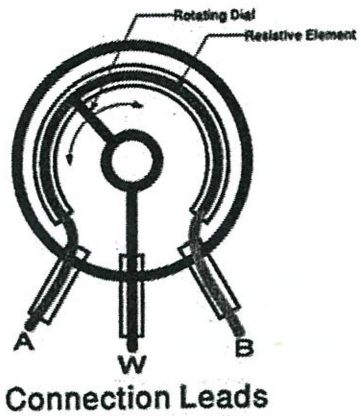


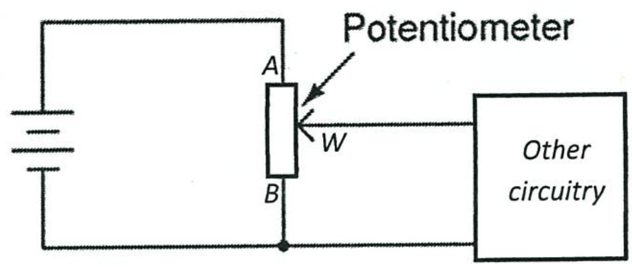
Potentiometer

If you pluck out the volume knob of a Hi-Fi system, or the brightness knob of a lamp, you should be able to see a potentiometer (or "pot" for electronic engineers). As shown above, a potentiometer consists of a resistive element (e.g. carbon) whose ends are accessible through terminals A and B. The third terminal W contacts the "wiper" which can be rotated to contact at any position along the length of the resistive element. Can you see that these three terminals A, W and B can form the potential divider circuit, and the dividing ratio can be adjusted continuously by rotating the dial?

In theory, a potentiometer can be wired as a rheostat by using only the wiper terminal and one other terminal. There is also nothing to stop us from wiring a rheostat as a potentiometer by using all three terminals. We do both quite often during simple demonstrations. In practice, however, potentiometers are designed to have low power rating of 1 W or less, since they are meant to work only with controlling signals which involve only very small current. Rheostats on the other hand are made with power ratings of up to several thousand watts in order to handle large currents in say DC motors, generators, etc.



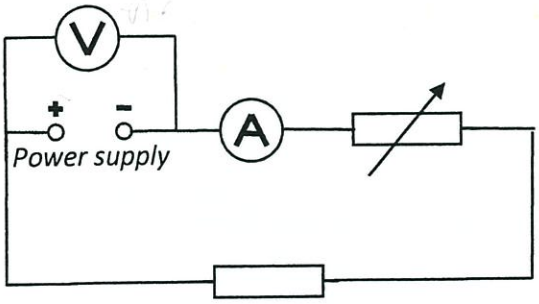




Voltmeter and Ammeter

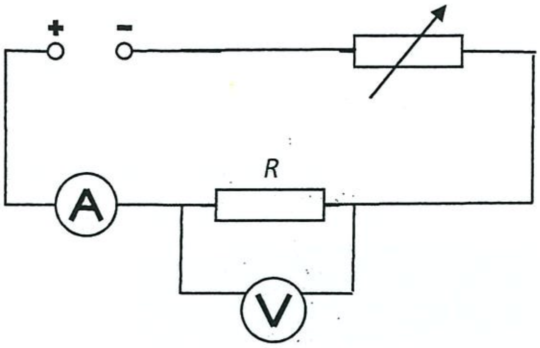
To measure voltages or potential differences, we use the voltmeter. To measure current, we use the ammeter. To measure power or resistances, we need to use a voltmeter AND an ammeter.

Power supplied



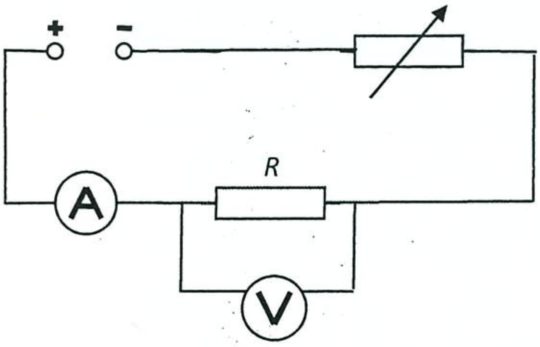
The diagram above show how a voltmeter and an ammeter are used to measure the electrical power supplied by the power supply: a voltmeter measures the terminal potential difference of the power supply, and an ammeter measures the current output by the power supply. The power drawn from the power supply is calculated by P = V I.

Power dissipated



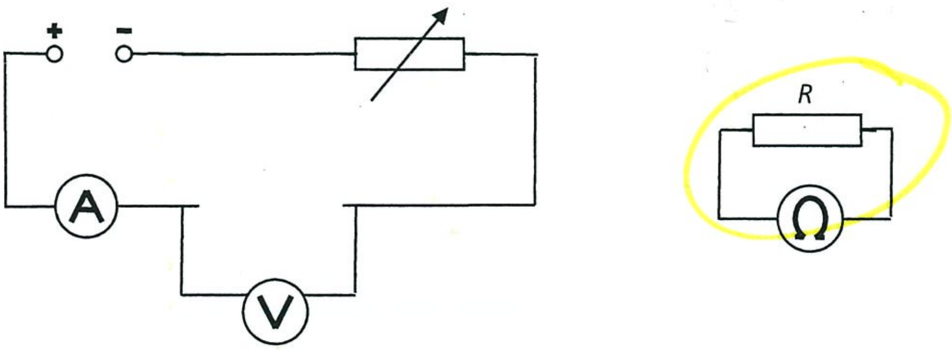
The diagram above show how a voltmeter and an ammeter are used to measure the electrical power dissipated in the resistor R: a voltmeter measures the potential difference across the resistor, and an ammeter measures the current passing through the resistor. The power dissipated in the resistor is calculated by P = V I.

Resistance



The diagram above show how a voltmeter and an ammeter are used to measure the resistance of the resistor R: a voltmeter measures the potential difference across the resistor, and an ammeter measures the current passing through the resistor. The resistance of the resistor is calculated by R = V / I.

You should have noticed it is the exact same circuit allows us to calculate the power dissipation in the resistor. You may also wonder why not use an ohmmeter to measure the resistance of the resistor R directly. Well you can. Just note two things: 1) if you use an ohmmeter, you must remove the resistor from the circuit to make the measurement. (see diagram below)



2) If the resistor varies significantly when in operation, and you are trying to determine the resistance of the resistor when in operation, then only the voltmeter plus ammeter method should be used. For example, if you are trying to measure the resistance of a filament lamp when it is lighted, measuring its "cold" resistance using an ohmmeter is meaningless.

Featured in "14 CIE 2008 Jun P5 Q1 Resistivity of Glass"

Digital Multimeter Ⓥ Ⓐ Ⓞ

The digital multimeter (often called the DMM) is the Swiss knife of electronics engineers because it is a voltmeter, ammeter, ohmmeter, and many more instruments all combined into one.

A DMM found in school labs probably look similar to the one shown above. A voltmeter or ammeter comes with two terminals. But you should notice this DMM has four sockets, called ports, near the bottom. Which two do we use? Well, it depends on which function of the DMM you are using.

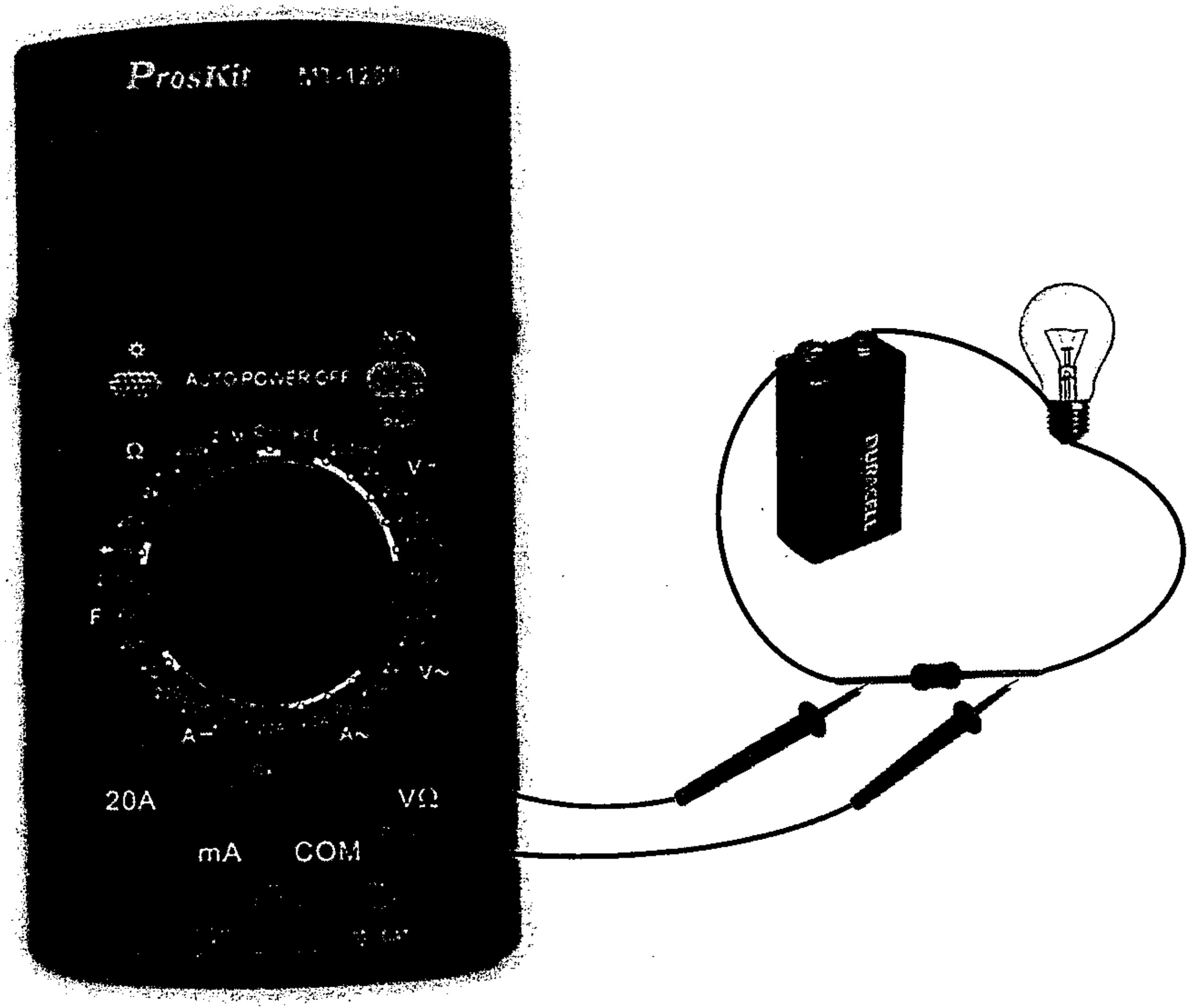
Your first probe is always connected to the COM port (usually in black), no matter what. That's why it is called the common port.

If you are going to use the DMM as a voltmeter or ohmmeter, you must connect the 2nd probe to the VΩ port.

If you are going to use the DMM as a milliammeter, you must connect the 2nd probe to the mA port. If you are measuring a large current (> 200 mA), you must connect the 2nd probe to the 20 A port. The difference between the mA and 20 A ports is the mA port is fitted with a 200 mA fuse. If by mistake you pass a large current, say 1.0 A into the mA port, the fuse will melt to protect the DMM, and you will have to trouble the lab technician to replace the fuse for you. The 20 A port has no such show stopper because it has no fuse. The problem is if by mistake you pass a very large current that is beyond the specification into the 20 A port, say 50 A, you may see smoke rising from your DMM. It is very unlikely you will ever need to use the 20 A port in school. We never put you in a situation where your clumsiness or incompetence can lead to injuries.

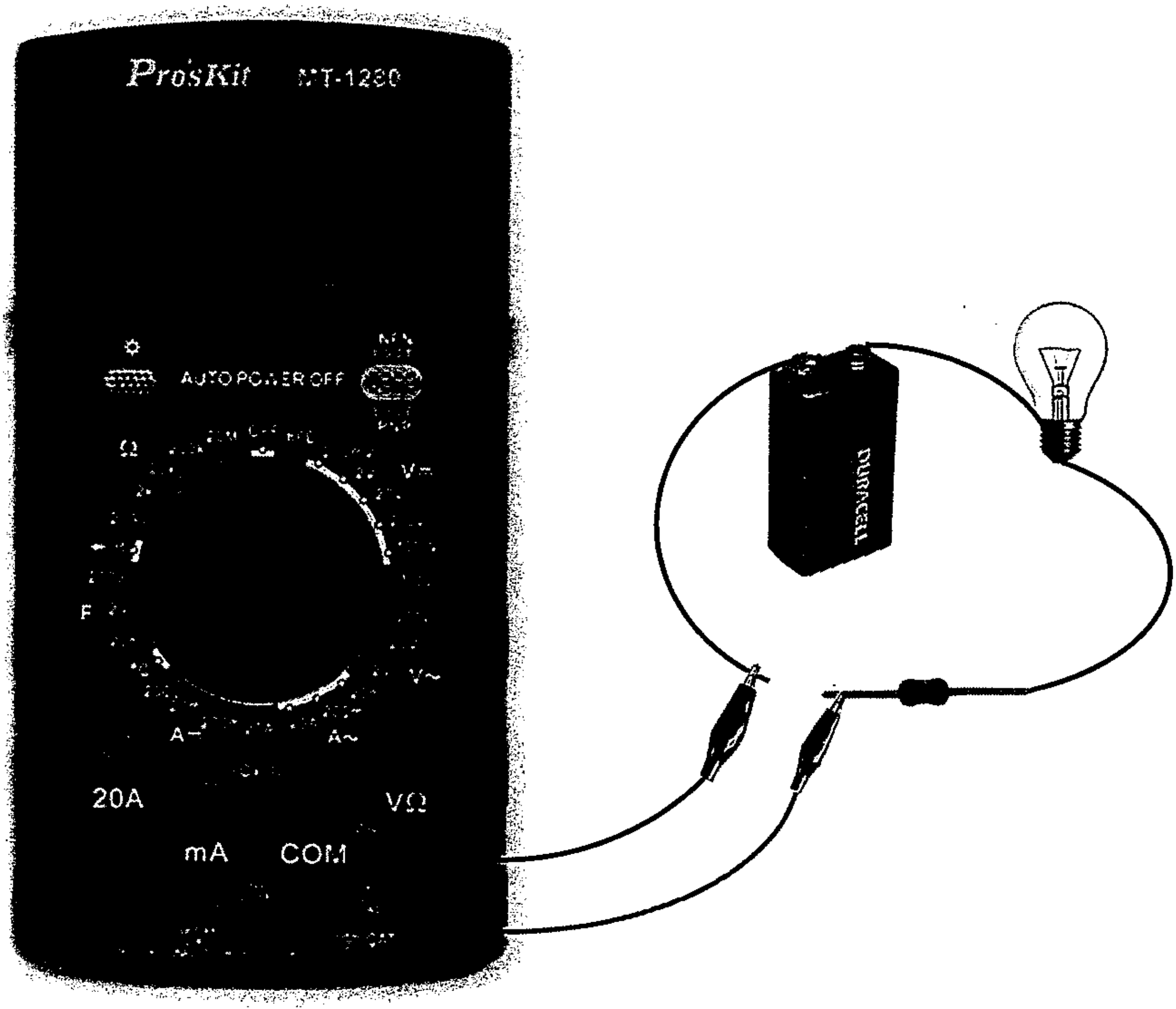
Let's now move on to the rotary dial. It is through this dial that you select the function of the DMM. It is also through this dial that you select the range (and thus resolution) of the measurement you are making. It is only logical for the settings for different ranges to be arranged in groups according to functions. For this particular model, beginning from the 12 o'clock position and moving clockwise, you see the range settings for DC voltage measurements (V⎓), AC voltage measurements (V~), AC current measurements (A~), DC current measurements (A⎓) and resistance measurements (Ω).

DMM as a voltmeter



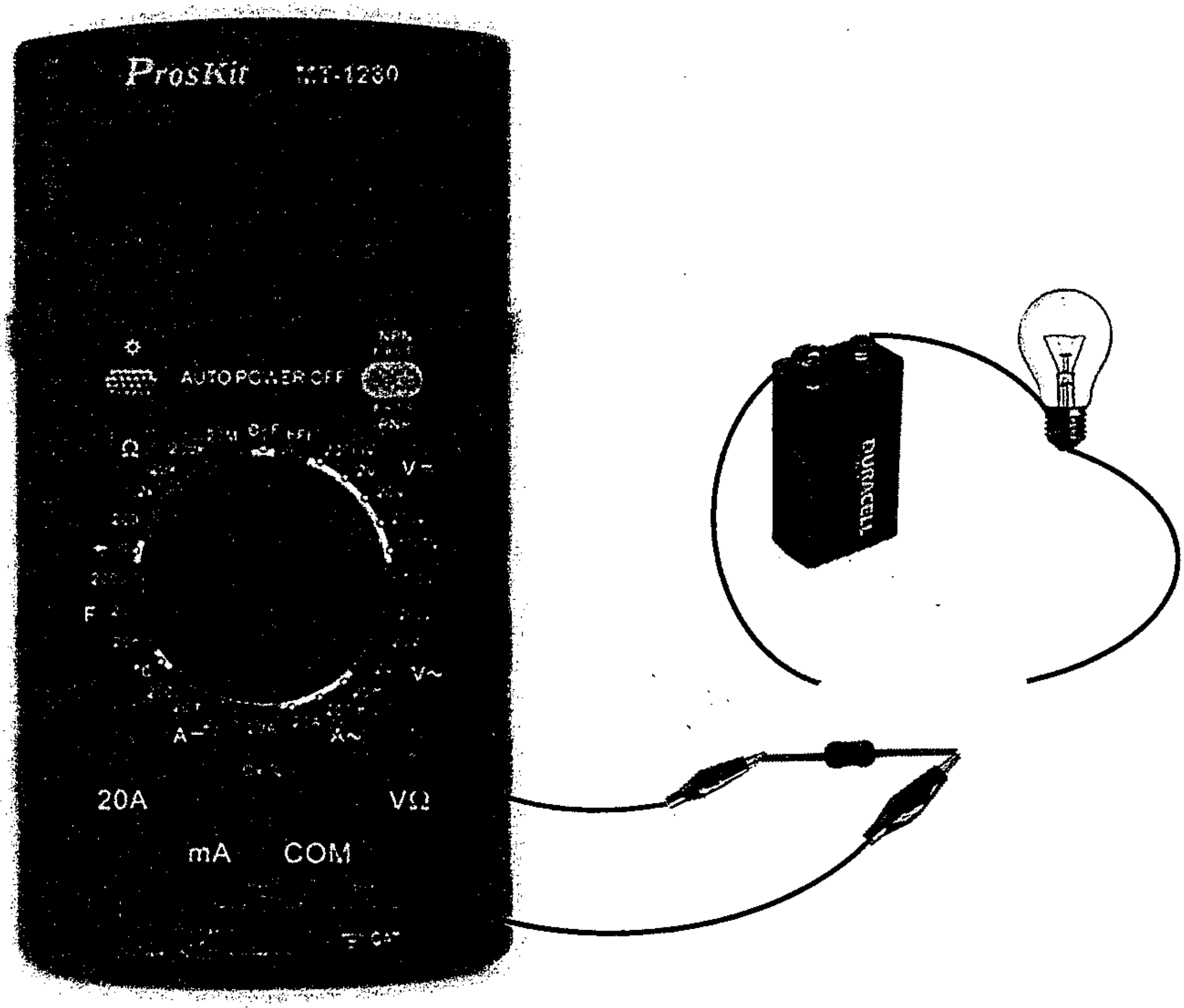
The diagram above shows the DMM being used to measure the potential difference across the resistor, which turned out to be 2.07 V. Firstly, notice that the DMM is connected in parallel to the voltage between measured, just like how a voltmeter would be connected. Next, notice that the two probes are connected to the COM port and the VΩ port. Finally, notice the rotary switch is set to "V⎓" at range setting "20 V". The "2 V" range is not usable since the measured voltage of 2.07 V exceeds the 2 V range. The "200 V" is usable but it would have given us a less precise reading of 2.1 V. In practice we just adjust the range setting until the highest precision reading shows up.

DMM as an ammeter



The diagram above shows the DMM being used to measure the current through the resistor, which turned out to be 22.7 mA. Firstly, notice that the DMM is connected in series with the current being measured, exactly how an ammeter should be connected. This means the circuit has to be "split apart" so that the DMM can be "inserted" into the path. Next, notice that the two probes are connected to the COM port and the mA port. Finally, notice the rotary switch is set to "A⎓" at range setting "200 m". The "20 m" range is not usable since the measured current of 22.7 mA exceeds the 20 mA range. The "20 A" is usable but it would have given us a reading low precision reading of 0.023 V. In practice we just adjust the range setting until the highest precision reading shows up.

DMM as an ohmmeter



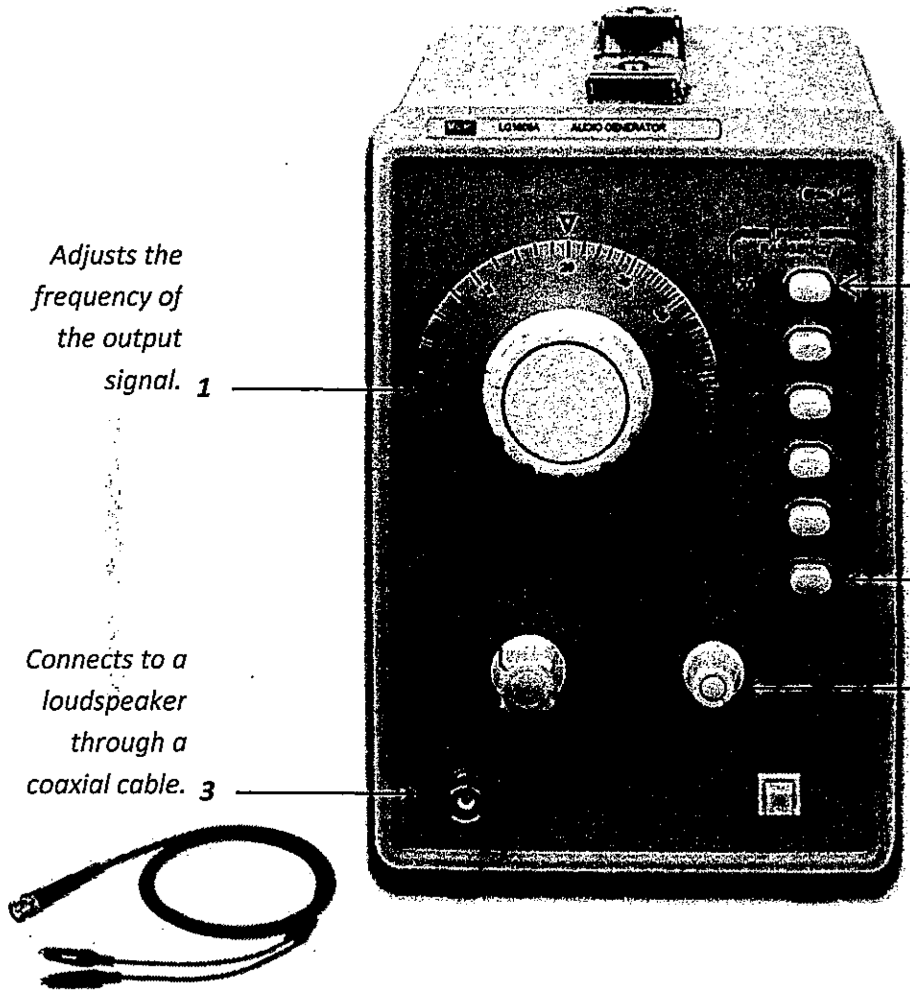
*The diagram above shows the DMM being used to measure the potential difference across the resistor, which turned out to be 0.220 kΩ. Firstly, notice that the resistor **must be removed from the circuit**. Next, notice that the two probes are connected to the COM port and the VΩ port. Finally, notice the rotary switch is set to "Ω" at range setting "2k". The "200" range is not usable since the measured voltage of 0.220 kΩ exceeds the 200 Ω range. The "20 k" is usable but it would have given us a reading of a less precise reading of 0.22 kΩ. In practice we just adjust the range setting until the highest precision reading shows up.*

Featured in "13 CIE 2008 Nov P5 Q1 Resistance of LDR"

Waves and Superposition

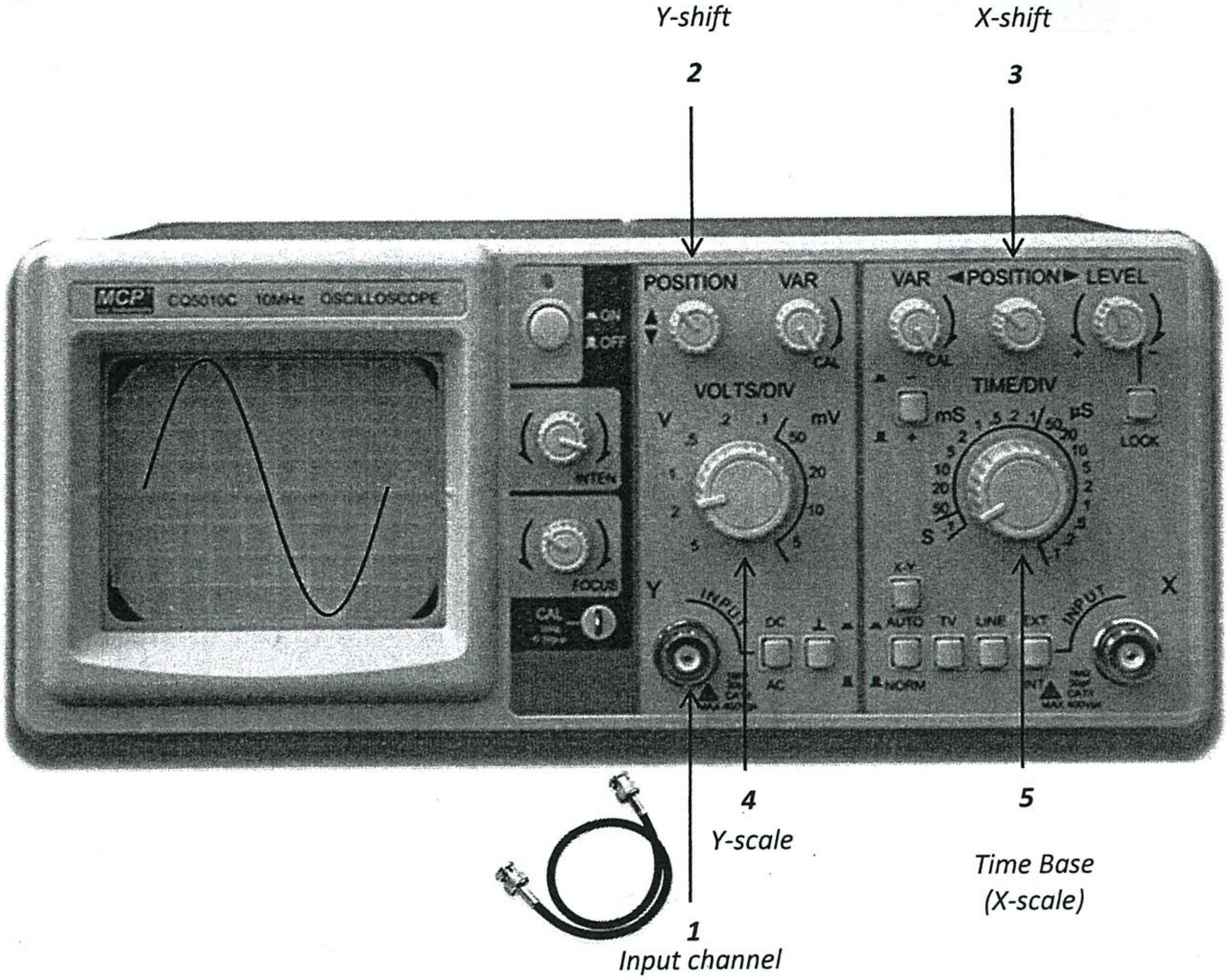
Signal Generator

You use a signal generator to produce a periodic electrical signal (sinusoidal wave, square wave, etc) of your chosen frequency and amplitude. It is widely used by electronic engineers to generate clock and data signals to test, analyse and trouble shoot electronic circuits. Unfortunately, electronics has disappeared from the A-level syllabus ages ago. Still, you are likely to encounter an audio signal generator. It is the one you connect to a loudspeaker so that you can produce a sound of your chosen pitch and loudness.



Oscilloscope

A digital multimeter may be able to provide you with the rms value of an ac signal. But to see the actual waveform, you need an oscilloscope. Basically, you can feed any constantly varying ***voltage*** *signal to an oscilloscope, and it will plot the entire voltage-time graph on the display screen in real time continuously. This allows you to view the waveform, measure peak-to-peak voltages, and most importantly, measure time-domain parameters such as period, pulse width and so on.*

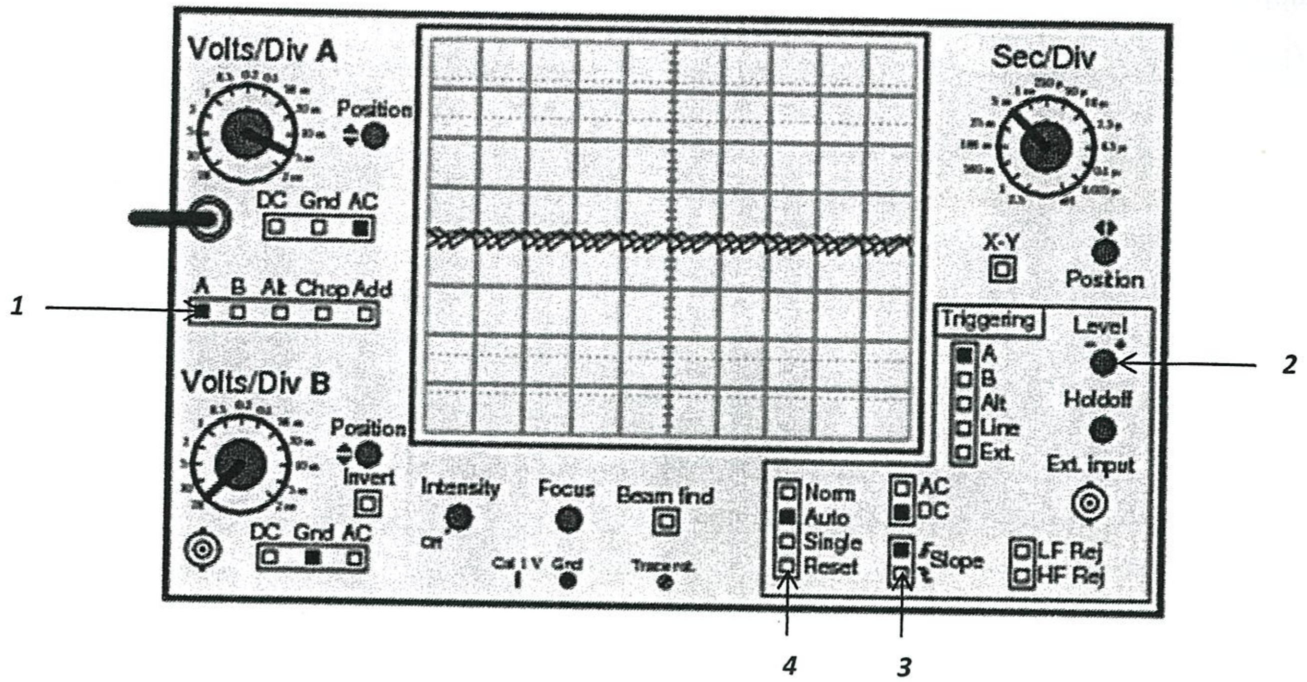


Obviously, to view a voltage signal you must first feed it into the input channel. Of all those buttons and knobs, you usually use only four: The X-shift, the Y-shift, X-scale and Time base (also called Y-scale, both names used interchangeably) to shift and scale the waveform on the display accordingly. The aim is to maximize the region of interest or align the point of interest against the grid so that accurate measurements can be made.

Measurements read off the grid scale on the screen must be multiplied by the scaling factors, as indicated by the current setting on the X-scale and Y-scale knobs, to obtain the correct values. For example, in the figure above, the sinusoidal waveform occupies 7.5 divisions horizontally and 8.0 divisions vertically. Since the Time base is set to 0.1 s/div, the period is calculated to be 7.5 x 0.1 = 0.75 sec. Since the Y-scale is set to 2 V/div, the peak-to-peak voltage is calculated to be 8.0 x 2 = 16.0 V.

Let's look at a higher-end scope as shown on following page. The first thing you should notice is there are two sets of Y-shift and Y-scale knobs on the left. This scope comes with two input channels A and B so you can study two voltage signals at one time. The row of A|B|Alt|Chop|Add buttons let you select which channel and mode to display ([1] in figure).

A	*Display Channel A only.*
B	*Display Channel B only.*
Alt	*Display both Channel A and B.*
Chop	*Same as Alt but with a slight difference that you don't have to know.*
Add	*Channel A and B are algebraically added together, and the sum displayed.*



On the right are buttons that pertain to how the display is triggered. Argh... looks like I have to explain what triggering is about. Alright, the scope updates the display each time in one sweep. This sweep is triggered to begin only when certain condition is met. Let's say for example the trigger level ([2] in figure) is set to 0.1 V, and trigger slope ([3] in figure) set to rising. This means the sweep begins only when the input signal crosses 0.1 V on the rise. After completing the sweep, the scope does not begin until this same condition is met again. So the signal is always displayed starting from the same point in the cycle. This mechanism stabilizes the display of a periodic signal, giving you a clean trace. Without this mechanism, the sweep starts from a different point in the cycle each time, and all these different snap shots overlap to form a useless jumble on the display.

Now, what if you are trying to capture a non-repetitive signal, like a pulse? Some oscilloscopes provide a single sweep function. You first set the trigger mode ([4] in figure) to single sweep. There may be an additional button to "arm" the trigger. The scope is now ready to capture the pulse. You can now close a circuit or something to activate the pulse. When the trigger condition is met, the sweep is triggered once and only once. In some oscilloscopes, the display remains on the screen for 2 to 3 seconds. This is all the time you have for making any measurement. In the newer digital oscilloscopes, the display can be saved and retrieved for viewing any time you please.

Now, what if you are trying to measure an AC current in a resistor? Do not connect the oscilloscope in series with the resistor like an ammeter! An oscilloscope can only measure a voltage signal. Think of it as a sophisticated voltmeter. What you should do is to connect the oscilloscope in parallel with the resistor to measure the potential difference across the resistor. As far as the shape of wave forms are concerned, the current and potential difference wave forms look exactly the same. The exact value of current can always be calculated by dividing the potential difference with the resistance value of the resistor.

Featured in
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16 CIE 2007 Nov P5 Q1 Attenuation of Sound by glass
17 CIE 2004 Nov P5 Q2 Ringing Bell in Bell Jar
18 CIE 1998 Nov P4 Q3 Frequency Response of a Microphone

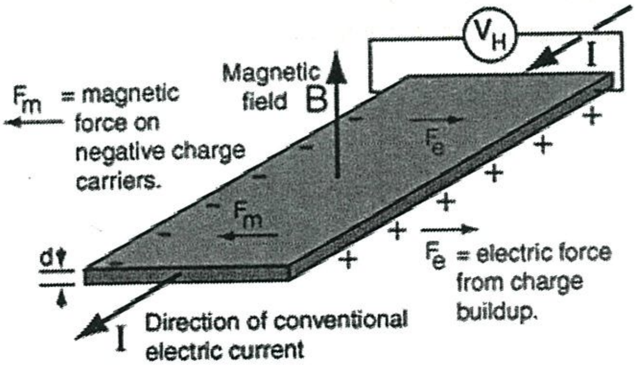
EM and Nuclear

Hall Probe

To measure magnetic field strength, you need a hall probe with a gaussmeter. The hall probe generates an output voltage proportional to magnetic field strength. The gaussmeter measures the output voltage and display the reading in gauss or tesla.

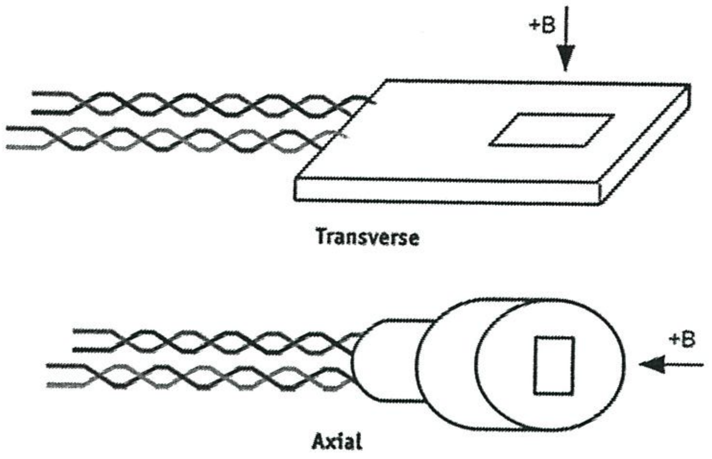
A hall probe works on the principle of Hall effect: A voltage develops across a sheet of current-carrying conductor when it is placed in a magnetic field. How is that so? Well those electrons "drifting" in the conductor (thus making up a current) experience the Lorentz force which "pushes" electrons to accumulate on one side of the conductor. (You can use Fleming's left hand rule to figure out which side.) This leads to an internal electric field, so those poor electrons are now subjected to two opposing forces: the magnetic Bqv and the electric qE. These two forces will eventually balance each other exactly, meaning that the resultant voltage potential across the width of the conductor (called the Hall voltage) is directly proportional to the magnetic field strength and current. So that's how it works.

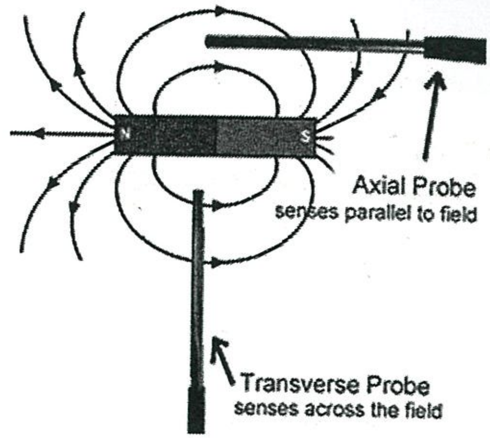
$$F_m = F_e$$
$$Bqv = qE$$
$$E = Bv$$
$$\frac{V_H}{d} = Bv$$
$$V_H \propto BI$$



Do you now realize that the hall probe is trying to measure a vector quantity? Or rather, the probe only measures the component of magnetic field that is directed perpendicularly into its cross section. So before you stick the probe in, you must first check out the orientation of the conductor sheet in the probe. The two most popular orientations are called transverse and axial.

***Transverse** probes, most often rectangular in shape, measure fields normal to their stem width. They are especially convenient for work in magnet gap. **Axial** probes, usually round, measure fields normal to their end. They are especially convenient for measuring fields inside solenoids.*





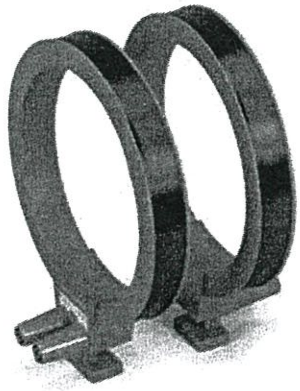
If you are measuring a weak magnetic field, you must account for the magnetic field caused by the Earth and other electromagnetic objects. This means you must first measure the background magnetic field strength (without the magnetic field of interest), and subtract this amount from the combined magnetic field strength later. Some probes come with a null function for this purpose. It works exactly like the tare function in electronic balances.

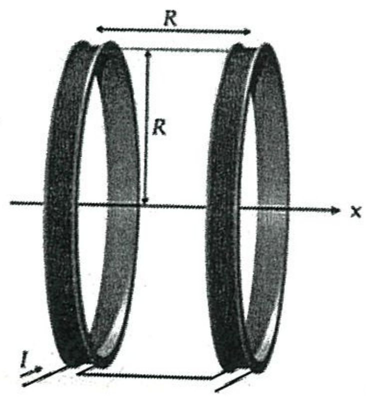
(to account for m-field caused by Earth and other electromagnetic objects

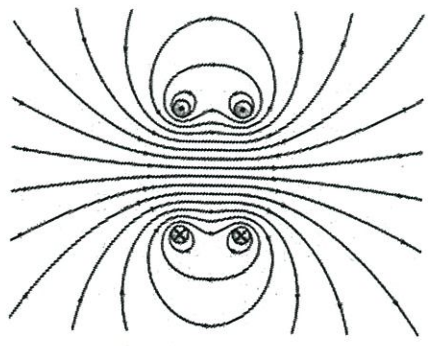
Helmholtz Coil

Many experiments require a region of uniform magnetic field, preferably of adjustable field strength. Where can you find such a magnetic field? Between the poles of two bar magnets, and adjust the gap to vary the field strength? Nope. We have a more glamorous method. We use the Helmholtz coil.

A Helmholtz pair consists of two identical circular magnetic coils carrying electric current flowing in the same direction. Here comes the important bit: the coils should be separated by a distance equal to the radius of the coil. At this spacing, the magnetic field in the region between the coils is nearly uniform. No more than 7% difference in fact. And the field strength can be varied easily by adjusting the magnitude of current in the coils. So it is really quite neat.



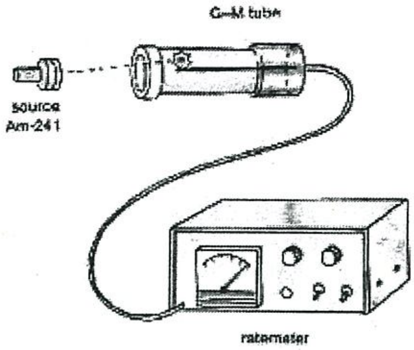




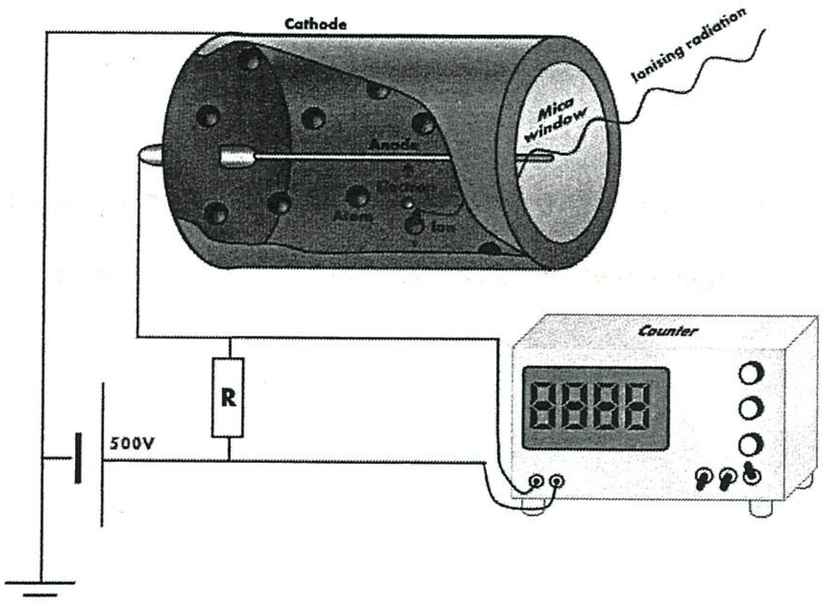
Featured in "28 CIE 2004 Jun P5 Q2 Deflection of Beta Radiation by Magnetic Field"

GM Tube

To detect ionizing radiation, you need a Geiger–Müller tube with a ratemeter (also called a Geiger counter) or scaler. The GM Tube is the sensing element. The ratemeter contains the electronics to do the counting and display the reading in count per minute (cpm) or other units.



A Geiger–Müller tube is filled with a low-pressure (~0.1 atm) inert gas (such as helium, neon or argon) and a halogen gas. At one end, it has a ***very thin*** *mica-window through which radiation can enter. The walls of the tube form the cathode. The anode is a wire passing up the center of the tube. A potential difference of* ***several hundred volts*** *is maintained between the cathode and anode. Despite this high p.d., because the inert gas is an electrical insulator, no current flows between the cathode and anode. Not yet.*



Things become interesting when an ionizing radiation makes its way through the mica-window into the tube, and ionizes the inert gas molecules, creating positively charged ions, and electrons. These charged particles are immediately accelerated by the strong electric field created by the tube's electrodes. In fact, they gain so much kinetic energy they can ionize more gas molecules, which get accelerated and ionize more gas molecules, which get accelerated and ionize more gas molecules, which ... I think you get the idea: an avalanche of charged particles! This results in a short, intense pulse of current which passes (or cascades) from the negative electrode to the positive electrode. These pulses are measured or counted by the ratemeter. The ratemeter usually also includes a loudspeaker which gives a "click" for each pulse. This gives rise to the cute clicking sound you hear.

A few things worth noting:

- *A pulse is a pulse, whether caused by an alpha particle, beta particle or a gamma photon. A simple trick employed to distinguish between beta and gamma radiation is to insert a suitable absorber (e.g. a thin aluminium sheet)*

only gamma radiation able to pass through

B and γ radiation able to pass through

between the radiation source and the GM tube. If the count rate drops drastically, it is a beta source. Likewise, a piece of paper can be inserted to remove alpha radiation from the count rate.

- *A pulse is a pulse, whether caused by high or low energy radiation. So the count rate is not a measure of the energy of radiation. In fact, the more energetic the gamma radiation, the more likely it will pass right through the tube. So a high energy gamma source can produce a lower count rate than a low energy one.*
- *The count rate is not the same as activity. In fact, each beta particle that enters the tube usually generates one pulse, whereas only a fraction of gamma radiation does. So a low activity beta source can produce more clicks per minute than a high activity gamma source.*
- *Even in the absence of any radiation source, GM counters may produce a background pulse rate of about 70 clicks per minute, due to cosmic ray background. This background count rate must be subtracted from the measured count rate to obtain count rate due to the radioactive source alone.*
- *Since radioactivity is a random event. One should always average repeated measurements for accuracy.*
- *You may come across the term Geiger counter. A Geiger counter is just another name for the ratemeter.*
- *You may come across the term scaler. A scaler is the same as a ratemeter except that it reports accumulative count instead of count rate.*

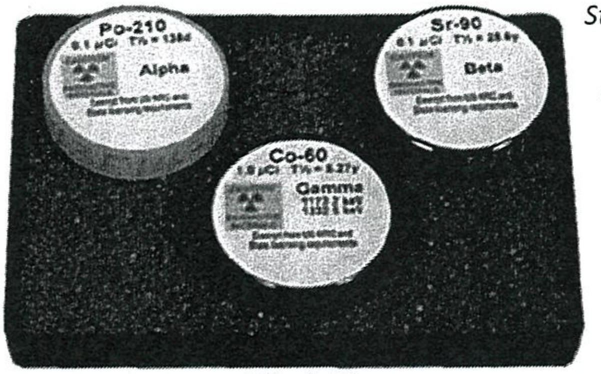
Radioactive Sources

Sample radioactive sources are used for testing geiger counters and for performing experiments involving radioactivity. The samples are commonly deposited in the well of a 1-inch diameter plastic disk. The well is sealed with epoxy so they can be handled without the concern that the radioactive material is dispersed onto hands or clothing. Each disk is clearly labeled with the radioactive nuclide, amount of activity (usually in uCi), calibration date and serial number.

When choosing radioactive sources, the first consideration is the radiation type. Does your experiment require alpha, beta or gamma radiation? The next consideration is the half-life. Usually you want a source with long half-life (1 year or more) so that it provides a constant activity throughout your experiment as you investigate other variables.

All radioactive samples should be kept in lead containers when not in use. Unsealed sources should be handled with tongs.

Polonium-210
0.1 uCi
138 days
Alpha
5304.5 keV



Strontium-90
0.1 uCi
28.5 years
Beta
546 keV

Cobalt-60
1 uCi
5.27 years
Gamma
1173.2 keV
1332.5 keV