Unit 3 - Electrical conductivity measurement

conductivity cell

AC electrodynamometer

pH measurements

pH meter

Automation in digital instruments

auto - zeroing

auto - ranging

automatic polarity indication

Digital storage oscilloscope.

Dec-18.

With the help of well labelled diagrams describe auto zeroing and auto ranging.

Explain in detail automatic polarity indication in electrical conductivity.

Draw the block diagram of storage oscilloscope and describe working of DSO.

Explain, what is pH ? what is automation & Explain the need of automation.

conductivity cell
ac electrodynometer
pH measurement
automation
} April- 2018.

pH measurement
DSO
automatic polarity indication
conductivity cell.
} April-2019

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Electrodynometer

Electrodynometer -

- The fundamental standards to which all the instruments should be callibrated are DC standards.
but moving-iron type instrument and some other ~~are~~ AC instruments are difficult to callibrated with these standards.
- In order to callibrate such instruments correctly, a transfer instrument is required that can measure AC quantities with no modification after being callibrated with a DC source.
- This requires the transfer type instrument to have same accuracy for ac and dc, which the electrodynometer have.
- The callibration of an ac instrument may be performed as follows:
  - The transfer instrument is first callibrated on dc. This callibration is then transferred to the ac instrument on alternating current, using operating conditions under which the latter operates properly.
- Electrodynamic meters (instruments) are capable of transfer instruments.
- Electrodynometer type of instruments are used ~~for~~ as ac voltmeters and ammeters both in the range of power frequencies

Operating principle of electrodynometer -

- The operating principle of electrodynometer is same as that of permanent magnet moving coil instrument.
- If ac current is to be measured, the current would flow through the coil with positive and negative half cycles, hence their driving torque would

be positive in one direction and negative in the other direction.

ie It would have torque in one direction during one ~~cycle~~ half of the cycle and an equal effect in the opposite direction during other half cycle.

- If the frequency were very small, the pointer would swing back and forth around the zero point.
- At higher frequencies, the inertia of the coil is so great that the pointer does not follow the rapid variations of driving torque and vibrates around the zero mark.
- If however, we want to reverse the direction of the flux each time the current through the movable coil reverses, a unidirectional torque would be produced for both positive and negative halves of the cycle.
- In electrodynometer instruments, the field can be made to reverse simultaneously with the current in the movable coil if the field coil is connected in series with the movable coil.

- ∴ To measure ac on a D'Arsonval movement, a rectifier has to be used to produce a unidirectional torque. This rectifier converts ac into dc and the rectified current deflects the coil.

another method is to use the heating effect of ac current to produce an indication of its magnitude.

~~Construction~~ -

Principle -

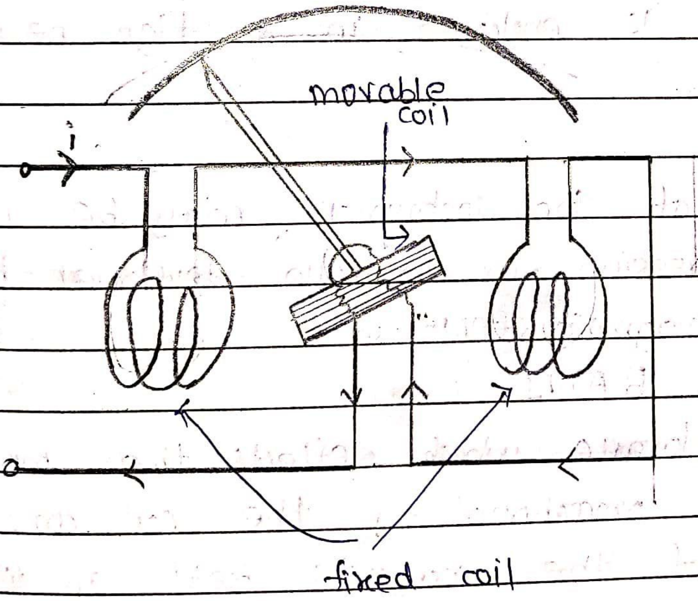
Electrodynometer type of instrument is used for measurement of AC and DC quantities.

Construction -

An electrodynamic type instrument consists of two fixed coils, a moving coil, control spring, damping device, and magnetic shielding arrangement.

(1) Fixed coils -

Fixed coils are used for production of magnetic field. This coil is divided into two sections so that a uniform magnetic field is achieved near the centre and allows passage of the instrument shaft.



(2) Moving coil -

Moving coil serves the purpose of actuating quantity into readable value on the scale.
It is generally wound on a non-magnetic metallic former. ~~Magn~~ metallic former can not be used as eddy

currents would be induced due to the change in flux (alternating field).

(3) Damping –
Air ~~dampine~~ friction damping is employed in electrodynamic type instrument. To provide air friction damping, a pair of aluminimum vane is attached to spindle at the bottom. These vanes move in a sector shaped chambers.

(4) Shielding –
The magnetic field in the electrodynometer is very weak and is of the order 0.005 to 0.006 wb/m^2.
∴ It is very important to protect the instrument from the effect of external magnetic field.
To provide magnetic shielding, normally electrodynometer type instrument is enclosed in a high permeability alloy.

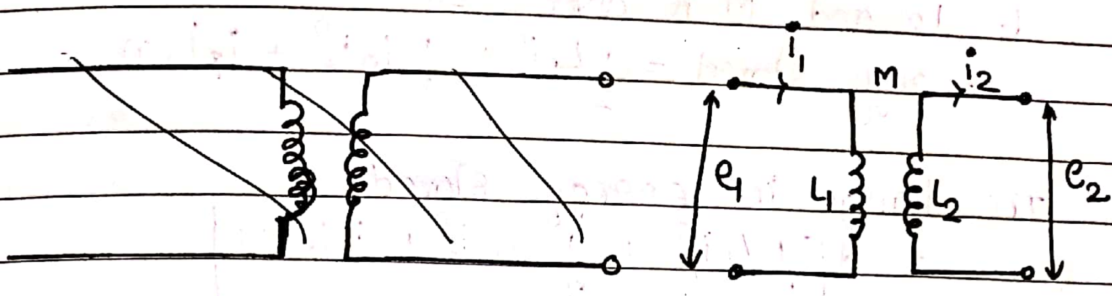
The operation of the instrument may be understood from the expression for torque developed by a coil suspended in magnetic field ie.

$$T = BANI$$

indicates the torque which deflects the movable coil is directly proportional to the coil constants (A & N)
B- strength of the magnetic field in which the coil moves
I- current flowing through the coil.

In an EDM, the flux density (B) depends upon the current through the fixed coil and ∴ proportional to the deflection current.

Torque equation of electrodynometer instruments -



i_1 - instantaneous value of current in the fixed coils

i_2 - instantaneous value of current in the moving coil.

L_1 - self inductance of fixed coils

L_2 - self inductance of moving coils.

M - mutual inductance between fixed and moving coils.

Flux linkages of coil 1

$$\phi_1 = L_1 i_1 + M i_2$$

Flux linkages of coil 2

$$\phi_2 = L_2 i_2 + M i_1$$

$$e_1 = \frac{d\phi_1}{dt} \quad \text{and} \quad e_2 = \frac{d\phi_2}{dt}$$

~~$e_2 = \frac{d}{dt}(L_1 i_1 + M i_2)$~~

$\therefore d\phi_1 = e_1 dt \qquad d\phi_2 = e_2 dt$

$\therefore$ electrical input energy $= e_1 i_1 dt + e_2 i_2 dt$

$= i_1 d\phi_1 + i_2 d\phi_2$

$= i_1 d(L_1 i_1 + M i_2) + i_2 d(L_2 i_2 + M i_1)$

$= i_1 L_1 di_1 + i_1^2 dL_1 + i_1 i_2 dM + i_1 M di_2 + i_2 L_2 di_2 + i_2^2 dL_2$
$+ i_1 i_2 dM + i_2 M di_1$ —(1)

The energy stored in the magnetic field due to L_1 L_2 and M is given by

energy stored $= \frac{1}{2} L_1 i_1^2 + \frac{1}{2} L_2 i_2^2 + i_1 i_2 M$

The change in energy stored

$$= d\left[\frac{1}{2} L_1 i_1^2 + \frac{1}{2} L_2 i_2^2 + i_1 i_2 M\right]$$

$$= i_1 L_1 di_1 + \frac{1}{2} dL_1 i_1^2 + \frac{1}{2} i_2^2 dL_2 + i_2 L_2 di_2 + i_1 i_2 dM$$

$$+ i_1 M di_2 + i_2 M di_1 \quad -②$$

From the principle of conservation of energy

energy input = energy stored + mechanical energy

∴ mechanical energy = energy input − energy stored

∴ subtracting eqn ② from ①

mechanical energy $= \frac{1}{2} i_1^2 dL_1 + \frac{1}{2} i_2^2 dL_2 + i_1 i_2 dM$.

The self inductance L_1 and L_2 are constant and hence dL_1 and $dL_2 = 0$.

∴ mechanical energy $= i_1 i_2 dM$.

if T_i be the instantaneous deflecting torque and $d\theta$ be the change in deflection then,

mechanical energy = mechanical workdone

$= T_i \, d\theta$

$$i_1 i_2 dM = T_i \, d\theta.$$

$$T_i = i_1 i_2 \frac{dM}{d\theta}$$

This is the expression for instantaneous deflection torque

Advantages of electrodynamic instruments -

- as these coils are air cored, these instruments are free from hysteresis and eddy current losses.
- low power consumption.
- free from hysteresis errors.
- These instruments can be used on both ac & dc.

Disadvantages -

- low sensitivity due to a low torque to weight ratio.
- expensive than other type of instruments
- They have a non-uniform scale

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Notes

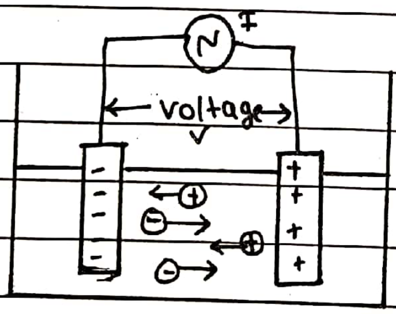
Conductivity Cell – Measurement of electrical conductivity

Conductivity –

- conductivity is the ability of the solution, a metal or a gas to pass an electric current.
- In solutions the current is carried out by cations and anions whereas in metals it is carried out by electrons.
- How well the solution conducts electricity depends upon
  ① concentration ② mobility of ions ③ valence of ions
  ④ Temperature.

How is conductivity measured –

- conductivity can be measured by applying an alternating electrical current (I) to two electrodes immersed in a solution and measuring the resulting voltage (V).
- During the process, the cations migrate to the negative electrode, the anions to the positive electrode and the solution acts as a electrical conductor.



What is a conductive solution –

- Conductivity is typically measured in aqueous solutions of electrolytes
- electrolytes are substances containing ions ie solutions of ionic salts or of compounds that ionise the solution.

The ions formed in solution are responsible for carrying the electric current.

- Electrolytes include acids bases and salts and can be either strong or weak.
- Most conductive solutions measured are aqueous solutions, as water has capability of stabilising the ions formed by a process called solvation.

Strong electrolytes - substances that are fully ionised in soln. ∴ the concn of ions in the solution is proportional to the concentration of electrolyte added.
solutions of strong electrolytes conducts electricity because the positive and negative ions can migrate largely independently under the influence of an electric field.

Weak electrolytes - substances that are not fully ionised in solution.
- a solution of weak electrolyte conducts electricity but usually not as well as strong electrolyte because there are lesser ions to carry the charge from one electrode to the other.

conductance - (G)
The reciprocal of electrical resistance of a solution between two electrodes

$$G = \frac{1}{R}$$

The conductivity meter measures the conductance and displays the reading converted into conductivity.

Cell constant -
The ratio of distance betn the electrodes to the area (a) of the electrodes

$$k = \frac{d}{a}$$

K - cell constant (cm^{-1})
a = effective area of electrodes (cm^2).
d = distance between the electrodes (cm).

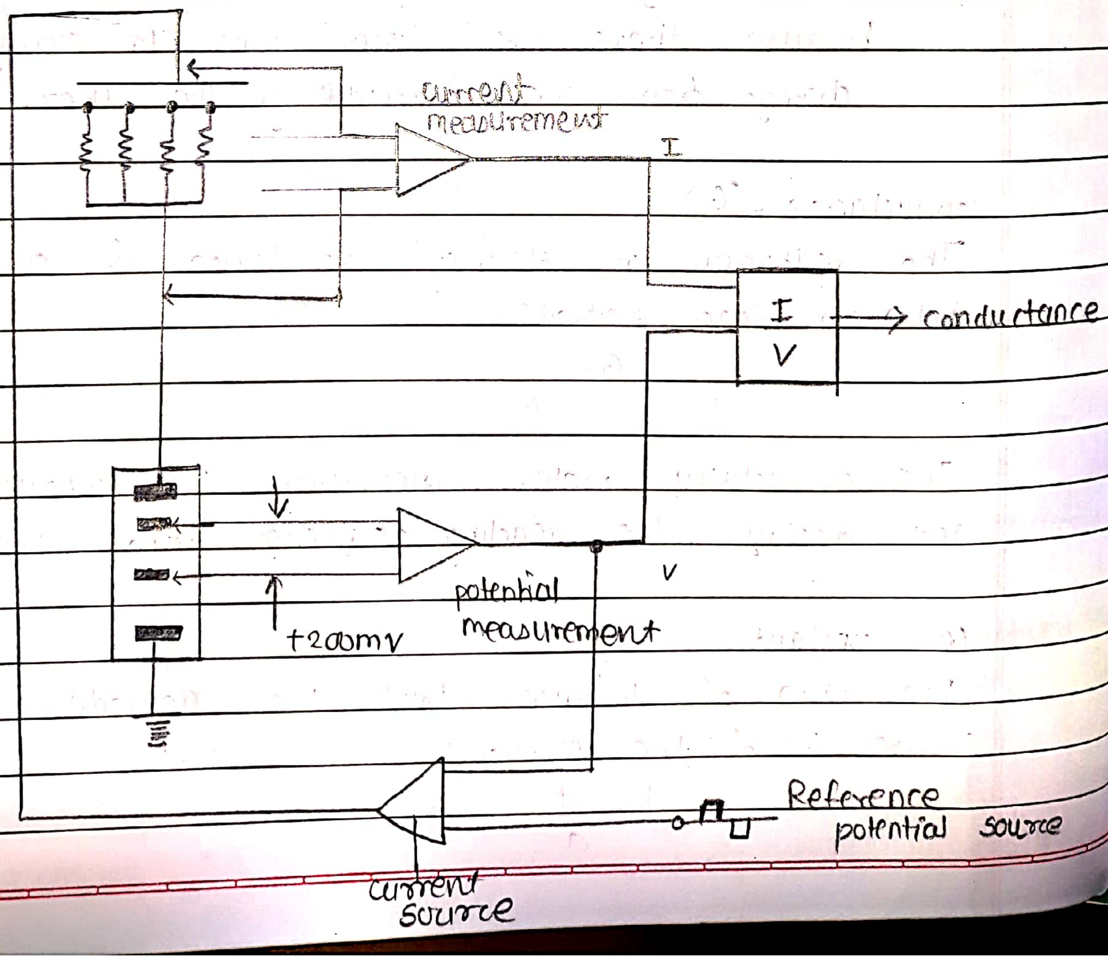
The conductivity meter :-

- ~~The~~ A typical conductivity meter applies an alternating current (I) at an optimal frequency to two active electrodes and measures the potential (V).
- Both current and potential are used to calulate the conductance

$V = IR \quad R = \frac{V}{I} \quad \therefore \text{conductance} = \frac{I}{V}$

- conductivity meter uses conductance and cell constant to display conductivity.

conductivity = cell constant x conductance



conductivity cells.

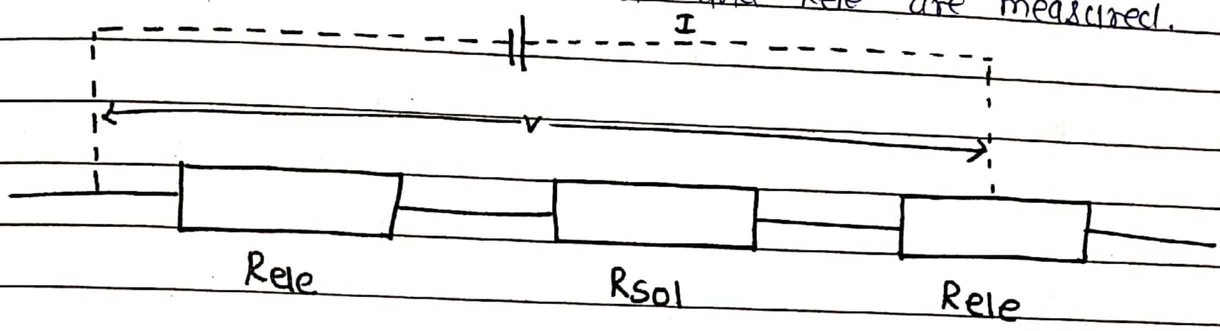
2 pole cell -

an alternating current is applied between the two poles and resulting voltage is measured.

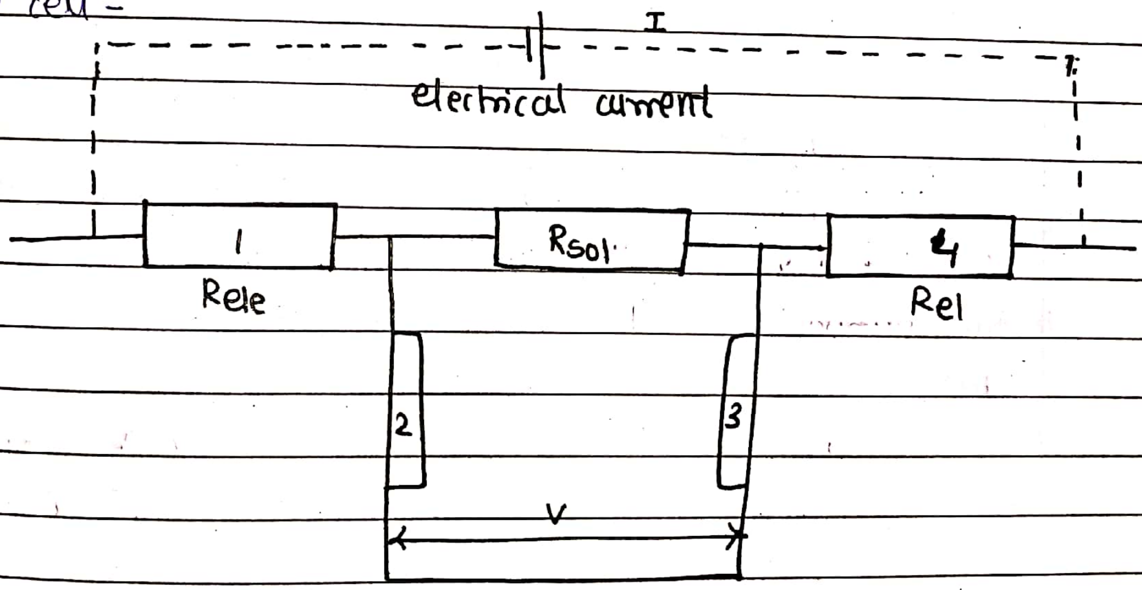
The main aim is to measure the solution resistance only. however, the resistance caused by polarisation of electrodes and the field effect interfers with the measurement and both Rsol and Rele are measured.

(Rsol)

(Rele)



4 pole cell -



a current is applied to the ~~other~~ outer rings (1 & 4) in such a way that a constant potential difference is maintained between the inner rings (2 & 3).

As this voltage measurement takes place with a negligible current, these two electrodes are not polarised ($R_2 = R_3 = 0$).

The conductivity will be directly proportional to the applied current.

- what influences the measurement :-

The accuracy of conductivity measurements can be influenced by following factors.

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pH measurement, pH meter.

- To measure the acidity or alkanity the pH of the solution is determined.
- The pH value is defined by ~~Soreson~~ Sorenson equation as negative logarithm of the H+ concentration in a given solution.

$$pH = -\log[H^+]$$

- The need ~~of~~ for ~~quantitive~~ quantitative measurement of acidity ~~or~~ alkanity ie the pH value, has led to the development of special hydrogen ion detectors and associated circuitry.
- The most common industrial method of pH determination is by glass electrode.
- The degree of acidity or alkanity of aqueous solution is determined by the relative concentrations of hydrogen and hydroxyl ions in the solution.
- When the hydrogen ions predominate, the solution is acidic. where the hydroxyl ions are in the majority, the solution is alkaline.
- Since the product of hydrogen ion and hydroxyl ion concn in any such solution has a constant value, measurement of hydrogen ion concentration indicates not only the acidity of a solution but its effective ~~alkani~~ alkalinity as well.
- pH value of a solution is defined as the negative logarithm of the hydrogen ion concn or

$$pH = -\log_{10}[H^+]$$

This scale ranges from 0 to 14.

- The hydrogen ion concn can be measured on a pH scale which varies from 0 to 14.

- In a neutral solution, the concn of both hydrogen and hydroxyl ions are equal ie both are 10^{-7}.
∴ for a neutral soln.

$$pH = -\log [10^{-7}] = 7$$

Thus for a neutral soln like pure water has a pH value of 7.

** pH measurement :-

- The most common industrial method for pH measurement is by a glass electrode and a salt bridge connecting the calomel cell electrode to the sample solution whose pH is to be measured.

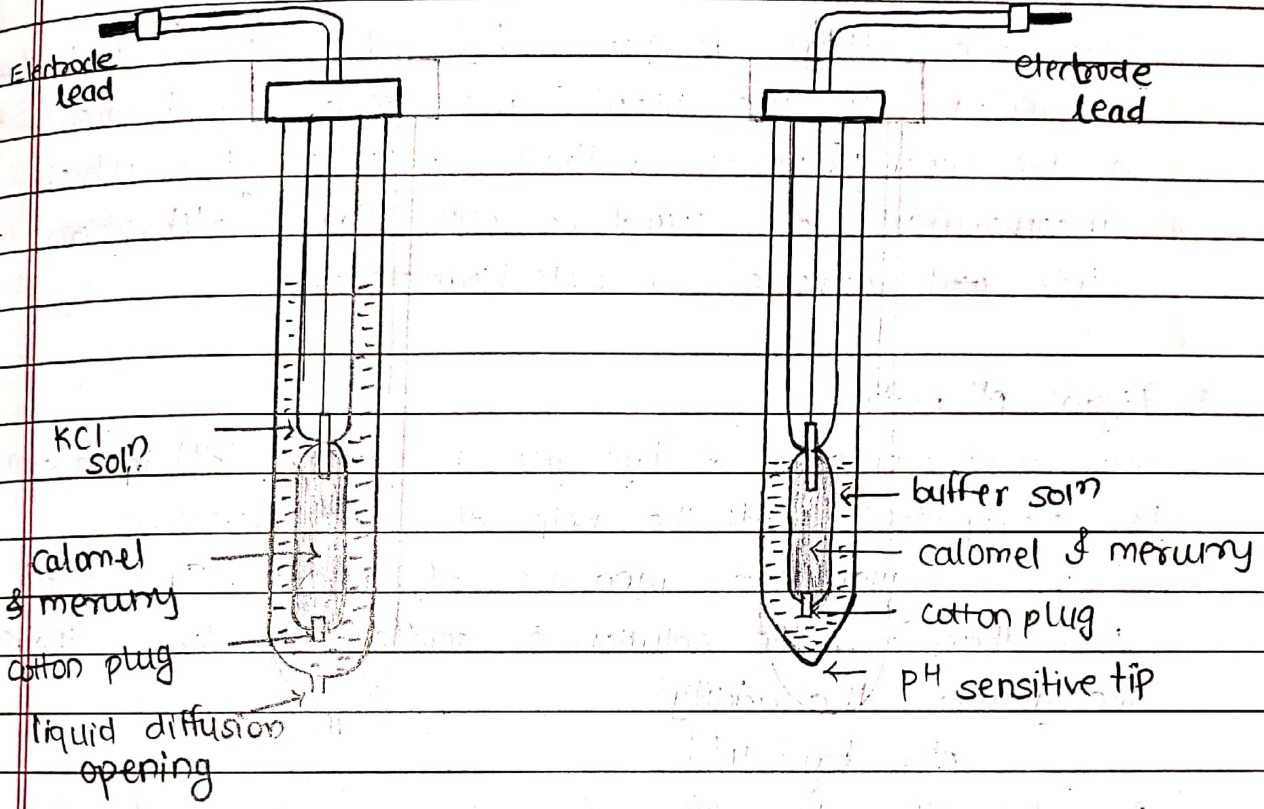
- In the pH cell, two electrodes are used
  1. reference electrode
  2. measuring electrode.
- Reference electrode is at a constant potential regardless of the pH value of the solution under test.
- The potential of the other electrodes, called the measuring electrode, is determined by the pH value of the solution.

Thus the potential difference between two electrodes depends upon the pH value of the solution.

- Reference electrode is made ~~up~~ of glass and consists of an inner assembly containing a solution of calomel (mercury chloride) and mercury. This assembly is surrounded by a larger glass tube and the space between the two contains KCl (potassium chloride) soln.

A tiny opening in the bottom of electrode permits the potassium chloride to diffuse very

slowly into the solution under test.
In this way, electrical contact is made between this soln and calomel solution of electrode.



- The measuring electrode (also known as glass electrode) is somewhat similar to the reference electrode. However, the mercury - calomel element is surrounded by a buffer solution of a constant pH. The bottom of the outer tube has ~~to~~ no opening. Instead, it tapers down to a tip made of thin glass of special composition.

At this tip a potential difference is developed betn the buffer solution and the solution under test because of the difference in the pH value of two solutions.

Since the pH value of the buffer solution is constant, the net potential of this electrode is a function of pH value of the solution being tested.

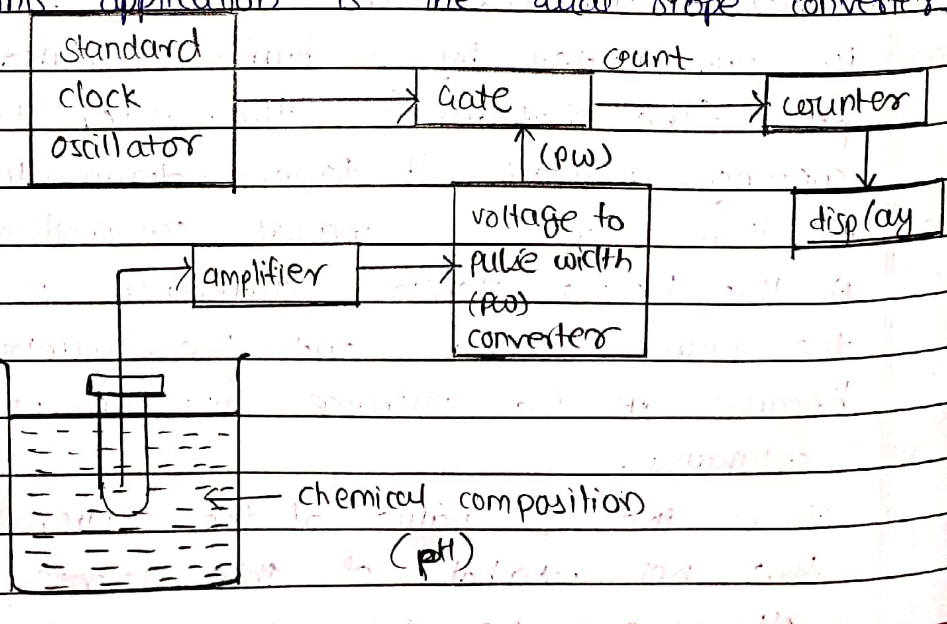
The algebraic sum of the potentials of the two half cells is proportional to the concentration of hydrogen ions in the solution and this becomes the measure of the pH value.
Thus, the voltage produced by the two electrodes is applied at the input measuring instrument such as the null balance millivolt potentiometer which incorporates a standard cell for calibration of slide ~~wid~~ wire of a potentiometer.

- Digital pH meter –

The measurement of hydrogen ion activity (pH) in a solⁿ can be accomplished with the help of a pH meter.
pH is a quantitative measure of acidity. If the pH is less than 7, the solution is acidic (the lower the pH, the greater the acidity).

$$pH = -\log [H^+]$$

A digital pH meter differs from an ordinary pH meter, in this the meter is replaced by an analog to digital converter (ADC) and a digital display. A frequently used ADC for this application is the dual slope converter.



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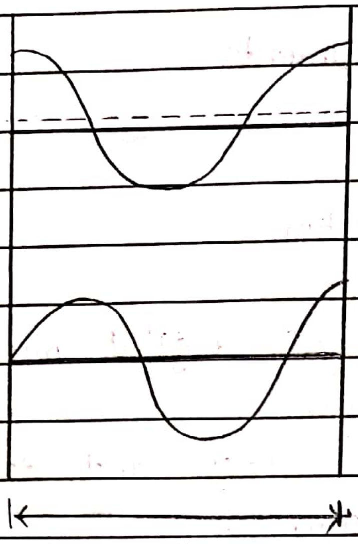
Automation in digital instruments

auto zeroing
auto ranging
auto polarity indication

- One of the advantages of digital multimeters is in their ease of operation.
- The reading is easy to take and does not lend itself to errors of interpretations.
- moreover, the number of ranges is limited because the ranges more in steps of 10 (instead of $\sqrt{10}$ steps used for analog instruments).
- Nearly all instruments today have automatic polarity display and automatic decimal point positioning, while many have automatic ranging and zeroing too.

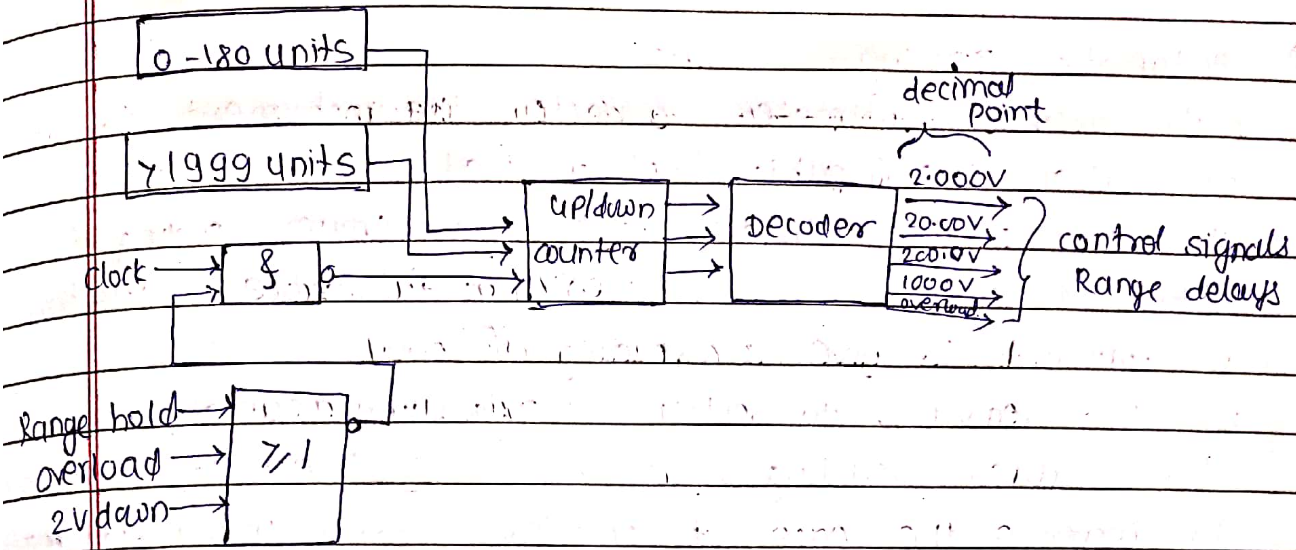
(1) Automatic polarity indication -

- The information contained by ADC is responsible for polarity indication.
- For integrating ADCs, only the polarity of integrated signal is of importance.
- The polarity should be measured at the end of the integration period.
- The integration period is measured by counting the pulses.
- The last count or some of the last counts can be used to start the polarity measurement.
- The output of the ~~po~~ integrator is then used to set the polarity flip-flop, the output ~~of~~ which is stored in the momory until the next measurement is done.



② Auto - ranging -

- It is easy to take readings on digital instruments as these readings have only one interpretation.
- The purpose of automatic ranging is ~~to~~ of getting a reading with a optimum resolution under all the circumstances.
- Ex. 155 mV should be displayed as 155.0 and not as 0.155.
- consider 3½ digit display ie one with the maximum reading of 1999. This means that any higher value must be reduced by a factor of 10 before it can be displayed (eg. 201 mV as 0201).
on the other hand, any value below 0200 can be displayed with one decade more resolution (eg. 195 mV as 195.0).
If the display is less than 0200, the instrument should be automatically switched to a range which is more sensitive while if display is higher than 1999 then the next less sensitive range must be automatically selected.

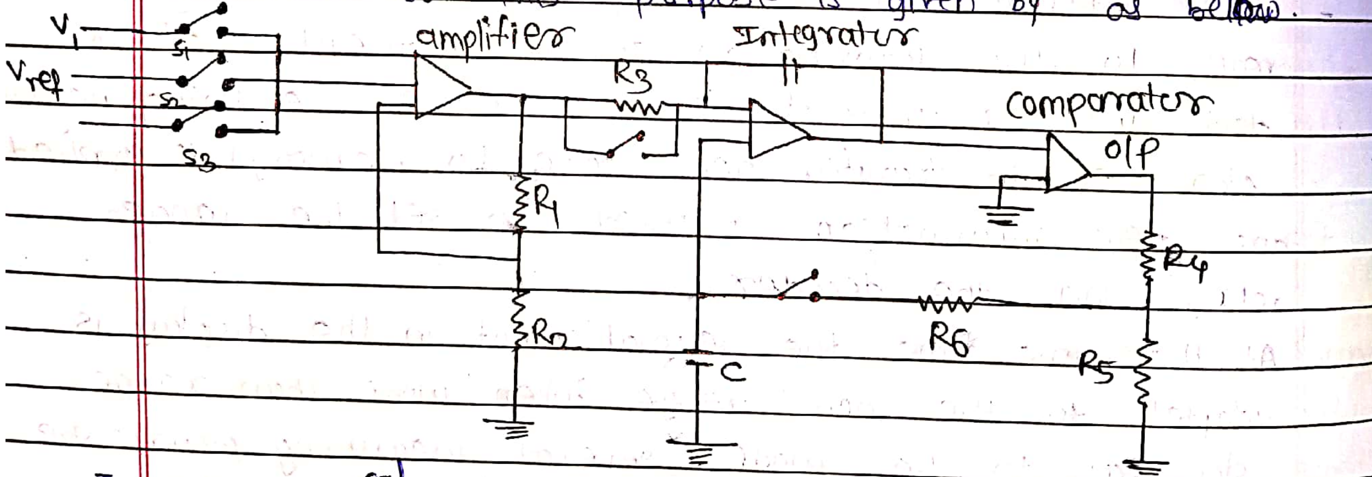


- The information contained in the counter of ADC yields a control pulse for down ranging when the count is less than 180 and one for up ranging when the count exceeds 1999 units.
- The up/down counter of the automatic ranging circuit reacts to this information at the moment that a clock pulse (a pulse at the end of the measuring period, also used to transfer new date to memory) is applied and new information is used to set the range relays via the decoder.

At the same time the decimal point in the display is adapted to the new range, when more than range step has to be made, several measuring periods are needed to reach the final result.

③ Automatic zeroing-

- Each user of voltmeter expects the instrument to indicate zero when the input is short-circuited.
- In a digital voltmeter with a maximum reading of 1999, a zero error of 0.05% of full scale deflection is sufficient to give a reading of 0001.
  For this reason, to obtain maximum accuracy with low valued readings, a zero adjustment is necessary.
- To increase the ease of operation, many instruments contain an automatic zeroing circuit.
- In a system used in several multimeters, the zero error is measured just before the real measurements and stored as an analog signal.
- A simplified circuit diagram of a circuit that can be used for this purpose is given by as below.



- Before the real measurements is made, switches S_3 S_4 S_5 are closed for 50ms, thus grounding the input, giving the integrator a short RC time and connecting the output of comparator to capacitor c. This capacitor is charged by the offset voltages to the amplifier and the integrator and comparator. When S_3 S_4 S_5 are opened again to start real measurements the total offset voltage of the circuit (equal to zero error) is stored in this capacitor and real input voltage is measured correctly.

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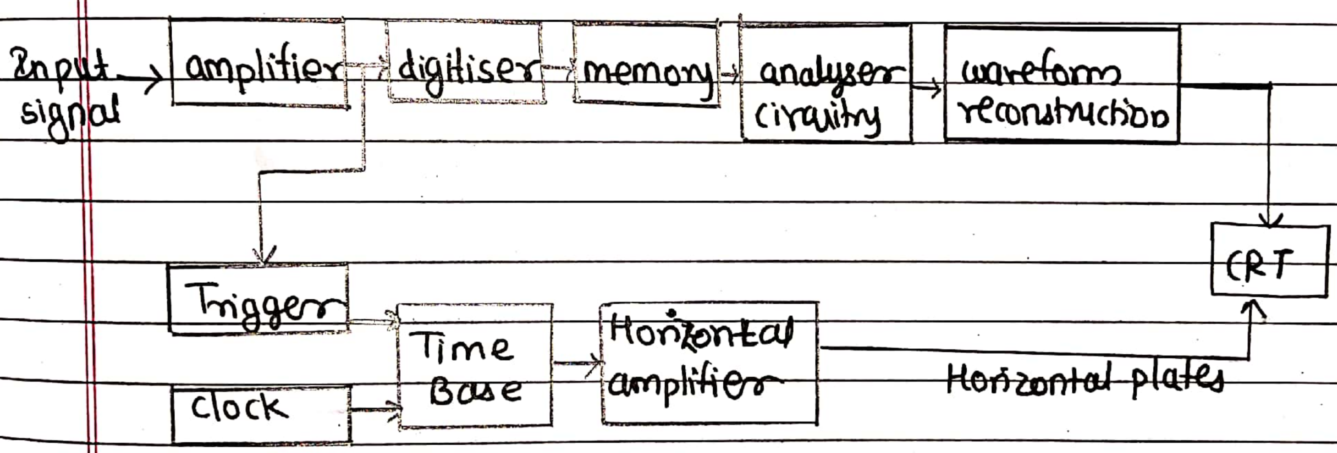
Digital storage Oscilloscope - (DSO)

- A digital storage oscilloscope is an oscilloscope which stores and analyses the signal digitally rather than using analog techniques.
- It captures the non-repetitive signals and displays it consciously until the device gets reset.
- In DSO, the signals are received, stored and then displayed.
- The maximum frequency measured by the digital oscilloscope depends upon the two things-
  (1) sampling rate of the scope
  (2) nature of the converter. (converter : digital or analog)



Block diagram of a basic digital storage oscilloscope

Working of DSO

- From the above block diagram, we can see that the an input signal is fed into the preamplifier unit. This unit amplifies the input so as to raise the level of the amplitude of the signal.
- This signal is then fed to the analog to digital converter (ADC) and the trigger detector. The input signal is digitised and stored in the memory in the digital form

- In this state it is capable of being analysed to produce a variety of different information.
- To view the display on CRT the data from memory is reconstructed in analog form by using (DAC)
- any further changes in the applied input, retriggers the oscilloscope which causes the memory to reset. That means the memory is overwritten with the new upcoming data unless the system is in HOLD mode.