

Detect presence and concentration of chemicals.

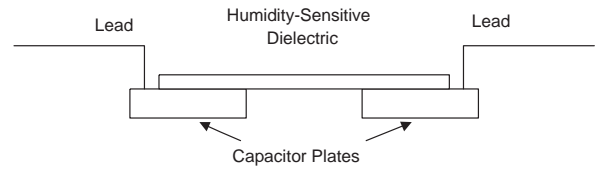
Two types will be discussed:

- *Humidity.*  
Measure humidity in air.
- *Oxygen.*  
Measure amount of oxygen in air.

Model functions will not be given for any transducer described in this set of lecture notes.

Two common types, capacitance and resistance.

Construction and Operation, Capacitance Type

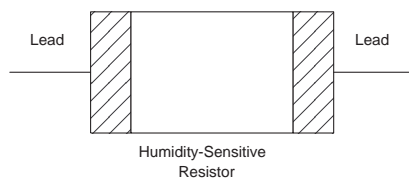


Transducer is a capacitor.

Capacitor's dielectric is exposed to environment.

The dielectric's permittivity changes with humidity ...  
... and so the capacitance changes with humidity.

Construction and Operation, Resistance Type



Transducer consists of leads placed on a special material.

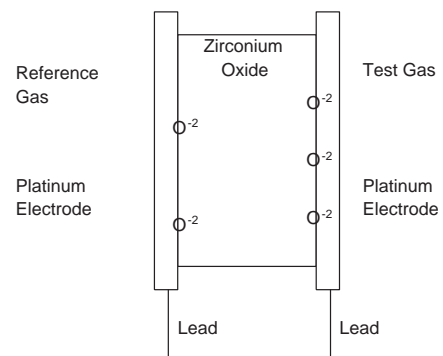
Water from the air adsorbs onto the surface.

This causes a change in resistance, which is measured.

Output of both types are highly temperature dependent.

Sensors usually sold with integrated conditioning circuits.

Construction and Operation



Consists of zirconium oxide,  $ZrO_2$ , between platinum electrodes.

One side exposed to reference gas ...  
... other side exposed to test gas.

Gases come in contact with both platinum and zirconium oxide.

On both sides  $O^{-2}$  adhere to zirconium oxide's surface.

Reference gas has a known concentration of oxygen.

Test side exposed to gas being measured.

Test gas oxygen concentration determined from electrode voltage.

In many biological and chemical sensors ...  
... a voltage between two liquids is measured.

As with thermocouple measurement ...  
... this is more difficult than it might seem.

#### Difficulty

A voltage will develop between a metal wire ...  
... and the liquid in which it is dipped.

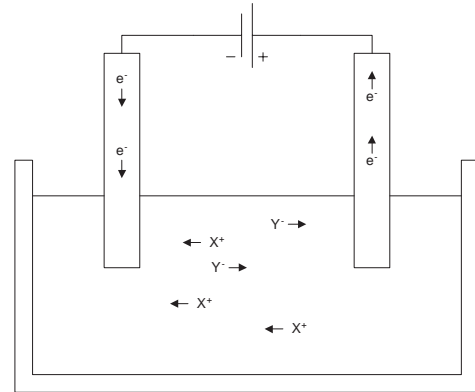
This voltage depends upon the liquid ...  
... which can be of unknown composition.

However, the voltage between ...  
... a *reference electrode* and the liquid is zero ...  
... avoiding the problem.

Reference electrodes will be used to:

- Measure potentials in a solution, for example a neuron firing.
- Measure the presence of dissolved chemicals.

Consider the following circuit:



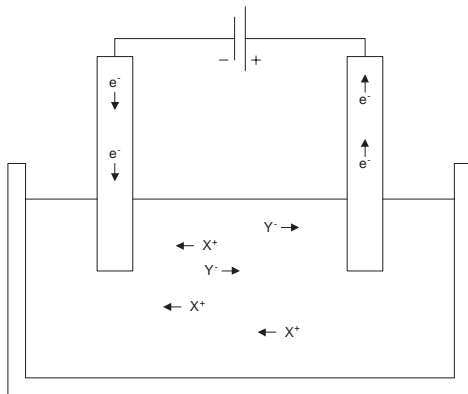
Current flow in metal is by the motion of electrons, as usual.

Current flow in the solution is by the *motion of ions*.

Point of interest is the interface between the metal and the solution.

A chemical reaction is occurring in which an electron is transferred to or from the metal, from or to the solution.

The reaction has a certain energy, which is responsible for the voltage between the electrode and solution.



The reaction might:

- Result in accretion of material on the electrode.
- Result in the eroding of material from the electrode.
- Leave the electrodes unchanged.

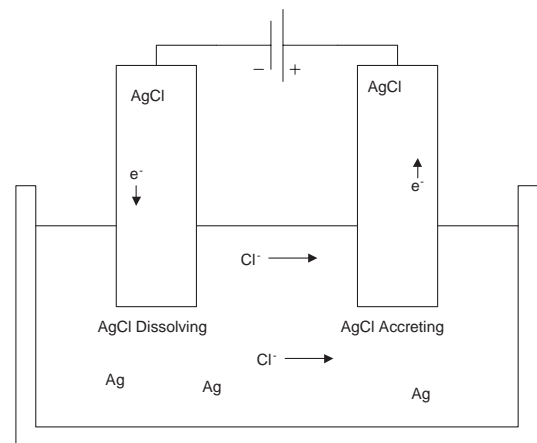
The first two cases occur in a battery and in electro-plating ...  
... the third case occurs in the electrolysis of water.

#### Reversible Electrodes

These should not be confused with reference electrodes.

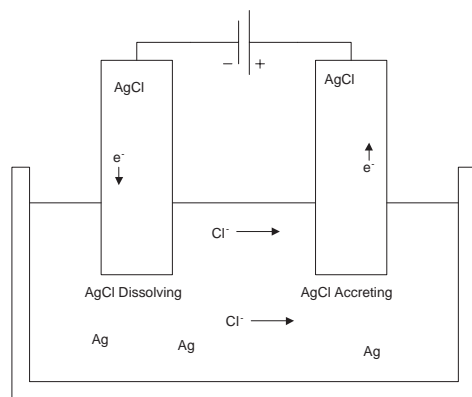
An electrode is *reversible* if the chemical reaction can occur either way, depending upon the direction of current flow.

The Ag|AgCl Reversible Electrode



Reaction:  $\text{Ag} + \text{Cl}^- \rightleftharpoons \text{AgCl} + e^-$ .

Current flows in solution by motion of chlorine ions,  $\text{Cl}^-$ .



In forward direction current flows from electrode to solution (electrons flow from solution to electrode).

Chlorine ion gives electron to electrode, then combines with a neutral silver atom to form AgCl, which deposits on surface of electrode.

In reverse direction current flows from solution to electrode (electrons flow from electrode to solution).

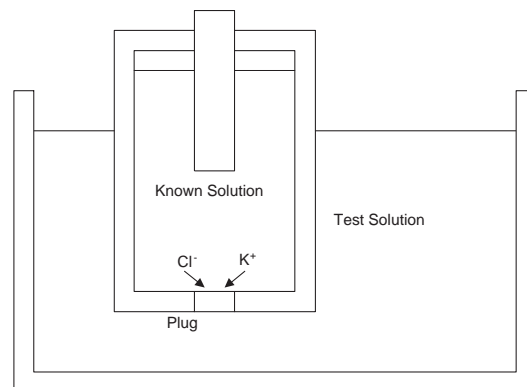
AgCl on electrode splits into silver and chlorine, an electron from electrode ionizes the chlorine.

The reaction energy depends upon the concentration of the reactants.

In measurement problems, these may be unknown.

In a reference electrode current can flow with a zero potential drop.

Construction:



A reversible electrode is placed in a small container with a solution of known concentration.

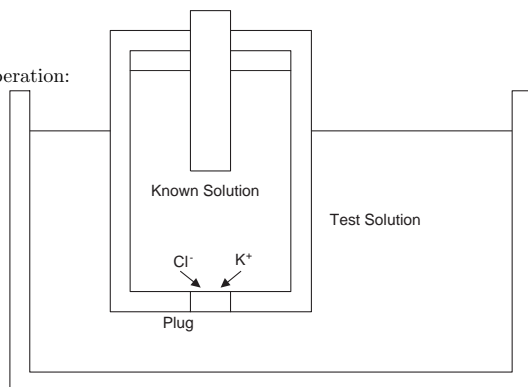
The container and its contents are the reference electrode.

The reference electrode is placed in test solution.

The container is sealed except for a tiny plug.

The plug is usually filled with gel, fibers, or a tightly packed powder.

Operation:



A small amount of ions can flow through the plug.

Flow is small enough so that concentration of solution in reference electrode does not change by a significant amount.

Plug is large enough so that current-carrying ions will not be impeded.

Solution in reference electrode is chosen so that there will be no potential across the plug.

For example, consider KCl, which is frequently used.

Both potassium, K<sup>+</sup>, and chlorine ions, Cl<sup>-</sup>, will flow through plug.

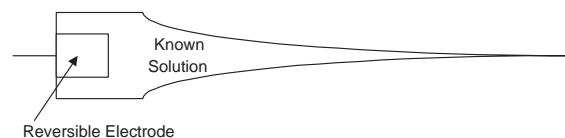
Materials were chosen because their flow rate is such that their potentials cancel.

Therefore, *reference electrode potential does not depend upon test solution.*

Used for measurement of biological potential.

A type of reference electrode.

Construction:



Reference electrode container in shape of tapered tube.

Fat end holds the reversible electrode and lead.

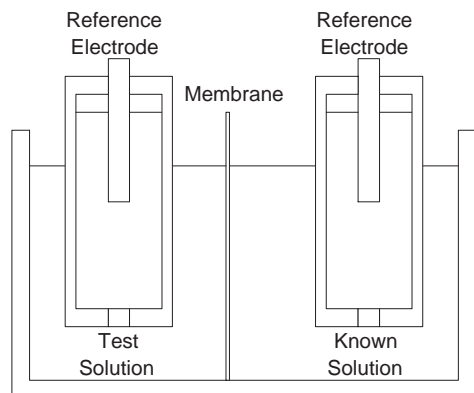
Thin end has the hole. Hole is open, there is no gel or other plug.

Hole diameter about 1 μm.

Thin end can be inserted into an individual cell.

Sensor measures concentration of ions dissolved in water.

Construction:



Consists of a container divided into two halves by a membrane.

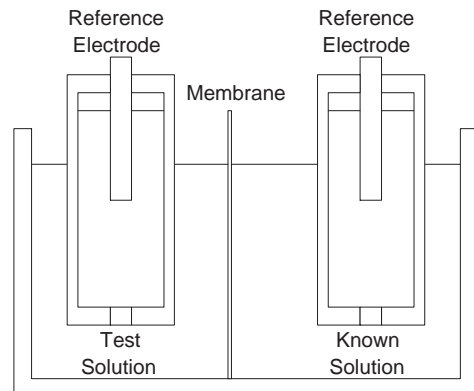
In one half is a solution of known composition.

In the other half is the test solution.

Membrane will allow ion being measured to cross, but will not allow others to cross.

A reference electrode is placed in each half, the voltage across the electrodes are measured.

Operation



Test ions cross membrane, causing a potential to develop across the membrane.

The potential will eventually stop the flow of ions.

The strength of the potential is proportional to ion concentration.

The potential is measured by the reference electrodes.

The pH of a solution is the negative log of hydrogen ion,  $H^+$ , concentration.

Construction:

Reference electrode and membrane are combined to form probe.

Probe is used with a second, conventional, reference electrode.

Membrane, which must be permeable only to protons, is glass.

Operation:

Hydrogen ions (protons) cross membrane until potential impedes their flow.

Potential is measured at reference electrode leads.

Because of reference-electrode properties, the voltage across leads is same as voltage across membrane.

Because of glass membrane (which has a high resistance) conditioning circuit must have a high input impedance.