Scanning Tunneling Microscopy (STM)

Atomic Force Microscopy (AFM)

Current-Voltage characteristics

Outline

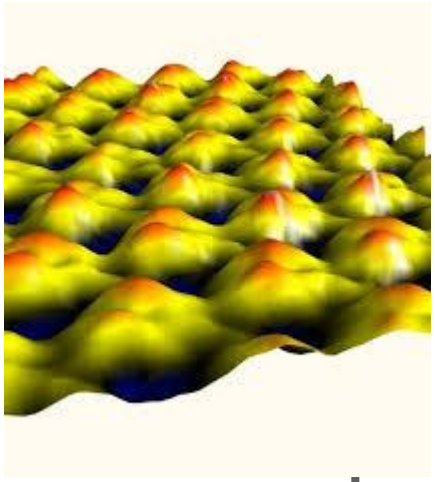
- Scanning probe microscopy
  - STM
  - AFM
  - Basic principles and story
  - AFM nanoeducator
- Current-Voltage (IV) characteristics of a solar cell
  - Equivalent circuit of a solar cell
  - Current-voltage measurements

Scanning Probe Microscopes (SPMs)

STM (scanning Tunnel microscope)

AFM (atomic force microscope)

«*Seeing* at the nanoscale»

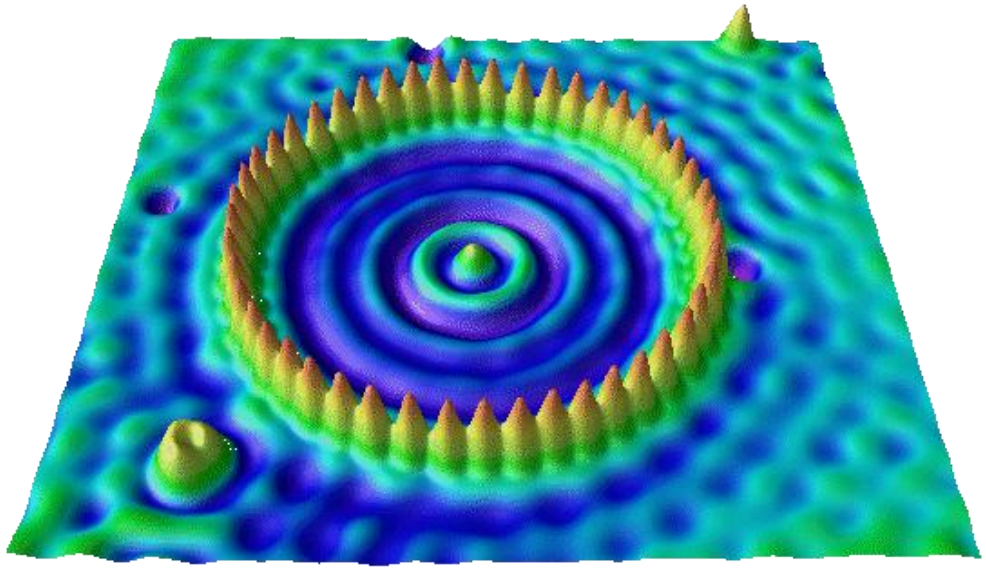


STM and AFM

- STM Scanning Tunnel Microscope
- AFM Atomic Force Microscope

STM was invented by Gerd Binning and Heinrich Rohrer, IBM, Zurich, in 1981, on 1986 they got the Physics Nobel Prize

Scanning Tunneling Microscopy



Surface state electrons on Cu were confined to closed structures (corrals) defined by barriers built from Fe adatoms. The barriers were assembled by individually positioning Fe adatoms using the tip of a low temperature scanning tunneling microscope (STM). A circular corral of radius 71.3 Angstrom was constructed in this way out of 48 Fe adatoms.

http://researcher.watson.ibm.com/researcher/view_group.php?id=4245

STM and AFM

The **crucial role of scanning tunneling microscopy** for **our understanding of the material world**, and its immanent significance for the future of scientific research and technical progress, has been duely appreciated by the awarding of the 1986 Nobel Prize in Physics to its developers ***Gerd Binnig and Heinrich Rohrer***.

It represented the latest stage in the series of developments of microscopies not based on light, which started with the development of the electron microscope by Ernst Ruska who shared that years Nobel Prize with them, **opening the way to resolutions way beyond the limits set by the wavelength of light.**

*G. Binning and H. Rohrer, Helvetica Physica Acta **55**, 726 (1982).*

STM

- Tunnel current flowing from the tip to the sample surface is measured
- What is the tunnel current?

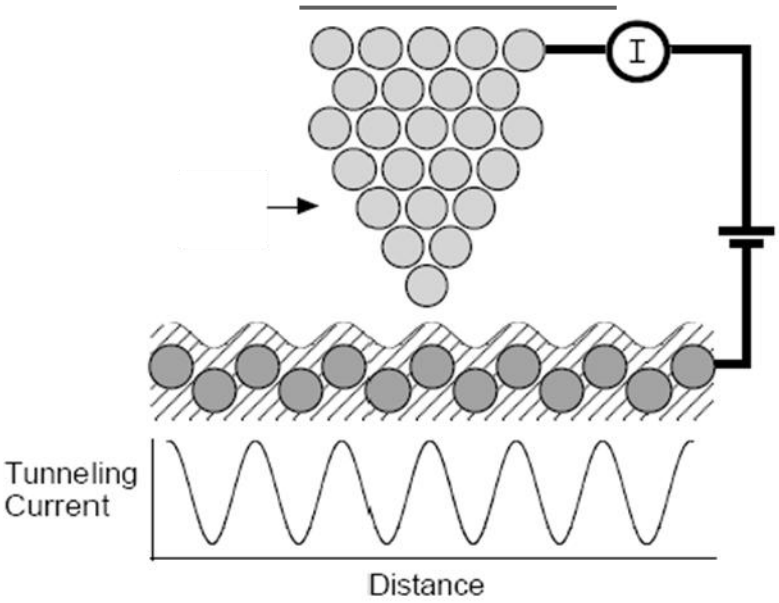
$$I = A \exp(-2kd)$$

d tip-sample distance.

Note that the current decreases around 1 order of magnitude each Angstrom → hugh vertical resolution!!

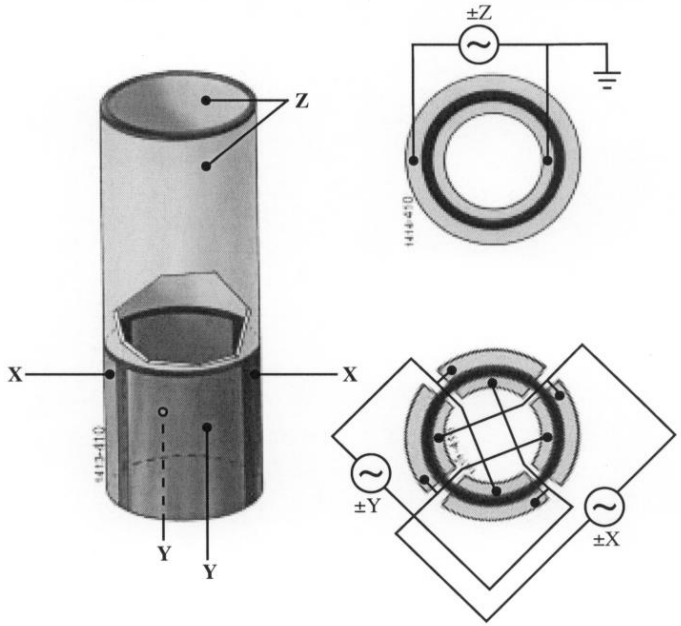
$$k = \frac{\sqrt{2m\varphi}}{\hbar}$$

m mass dell'elettrone, φ local tunneling barrier height o tip – sample average work function.



- Bias applied to the tip (10mV to 3 V).
- When the tip is close to the sample (10 Å) a current flows (pA to nA)
- The current is kept constant by a feedback loop which moves the sample in order to keep the current constant. The signal required to keep the current constant is the signal that is plotted against xy coordinates

STM the piezo-electric tube

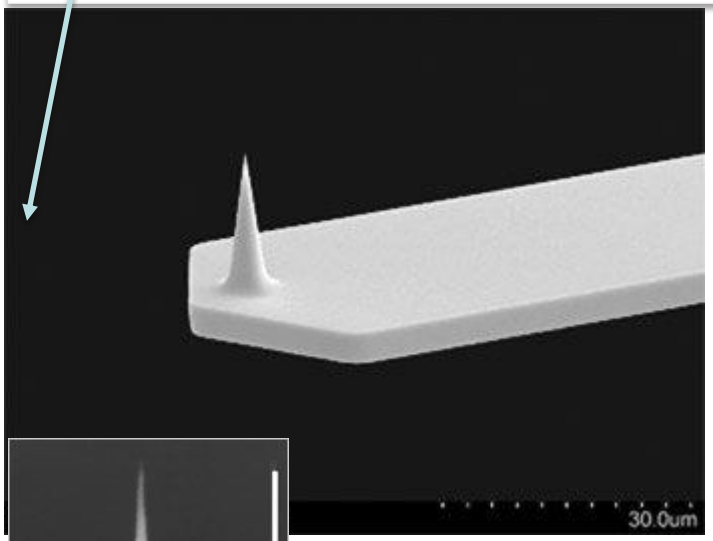


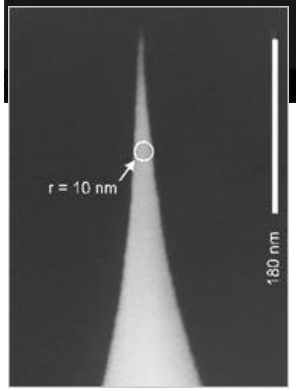
Typical scanner piezo tube and X-Y-Z electrical configurations. AC signals applied to conductive areas of the tube create piezo movement along the three major axes

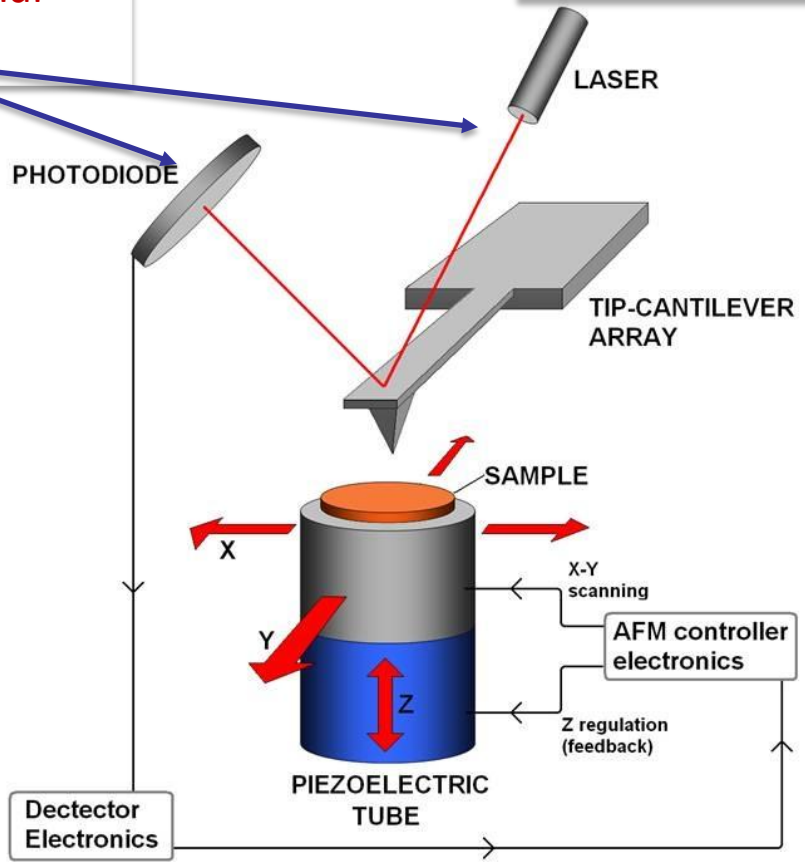
AFM atomic force microscope

- The piezoelectric tube can ove the sample
- A small tip interacts with the sample
- A laser beam and a photodiode → signal detection

The tip – sample interaction measure the force of interaction (mechanical, electrcal..)





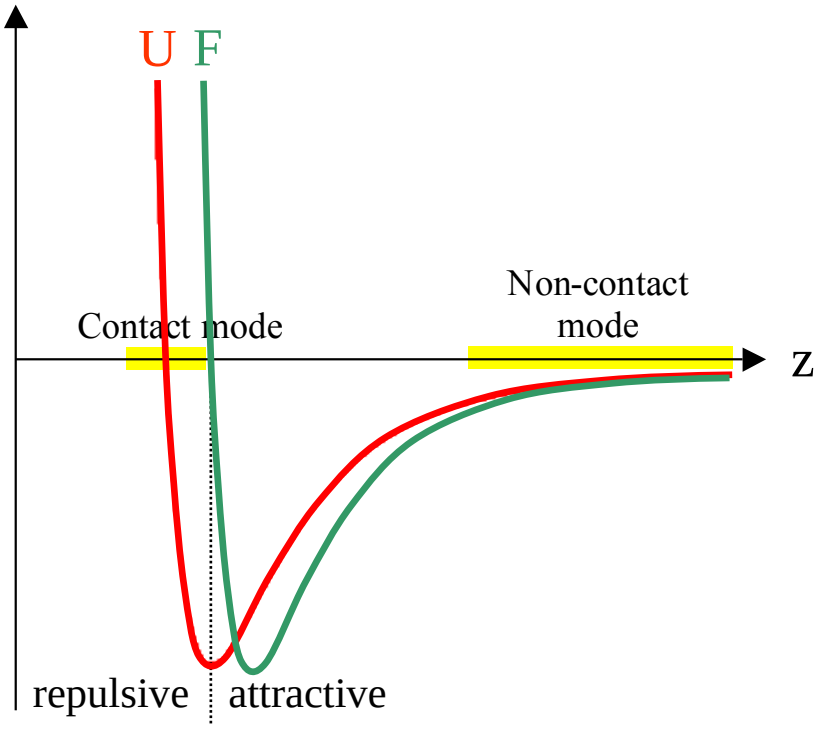


AFM

Potential energy U
Force F
between tip and sample

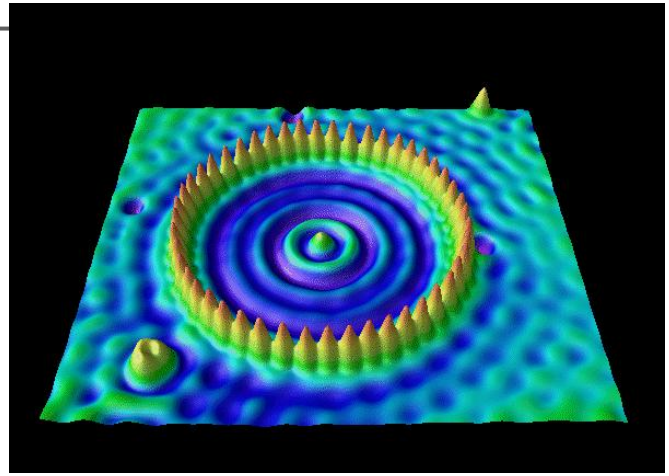
High distance attractive force *(van der Waals force, non-contact mode)*
Low distances repulsive force and very intense force when electrons of the tip repel the electrons of the sample (Pauli repulsion, contact mode).

AFM : the interaction force is kept constant,
STM : the interaction current is kept constant

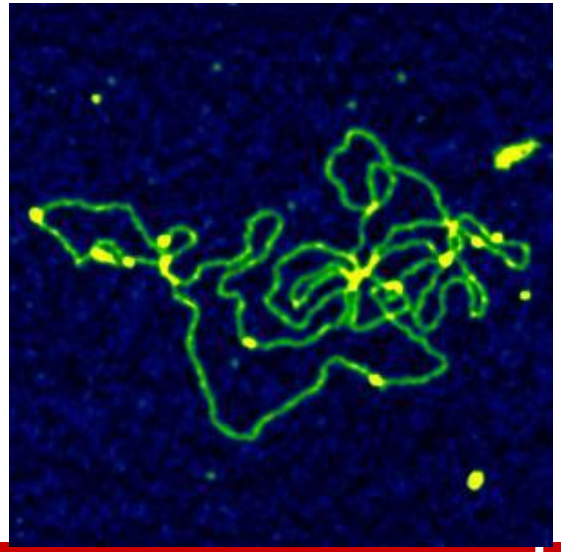


AFM *or* STM ?

STM you can reveal electron clouds at the sample surface, good for conducting samples
Ex: Quantum corral (IBM web site)

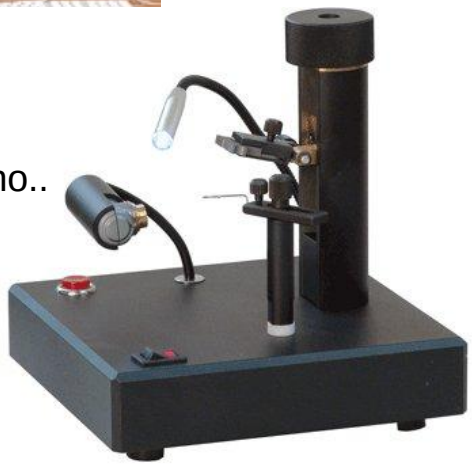


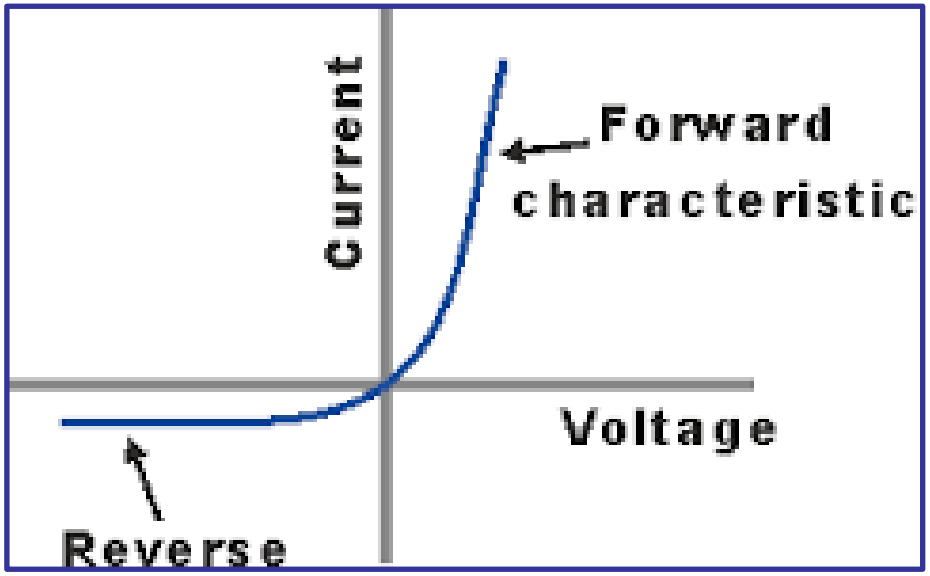
AFM you can «see» insulating samples
Ex: DNA over MICA surface



Educational AFM (nanoeducator NT-MDT)

Dove le punte si costruiscono..





Current-voltage characteristics

How does a solar cell work? Current voltage characteristics

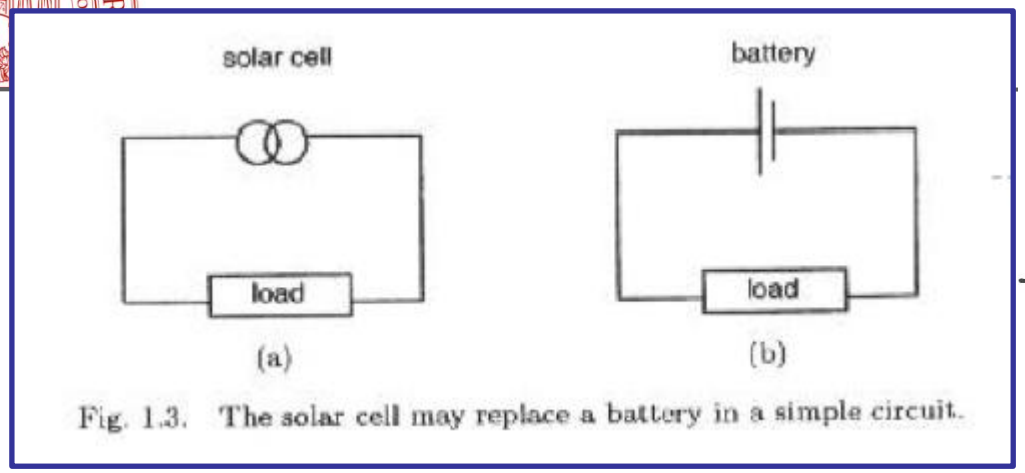
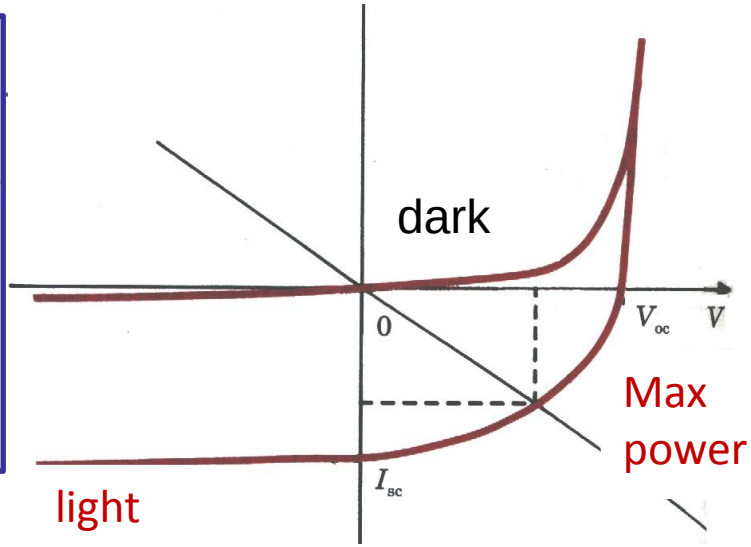


Fig. 1.3. The solar cell may replace a battery in a simple circuit.



Dark? Nothing happens in (a)

Illuminated? Behaves like (b) as if there is a battery

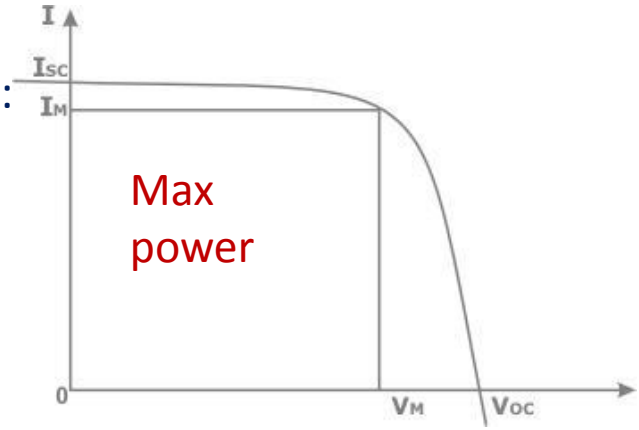
Two extreme cases:

- Terminals isolated (open circuit, oc) = Infinite load resistance:
  V = Voc and I = 0
- Terminals closed (short circuit, sc) = zero load resistance:
  V= 0 and I = Isc

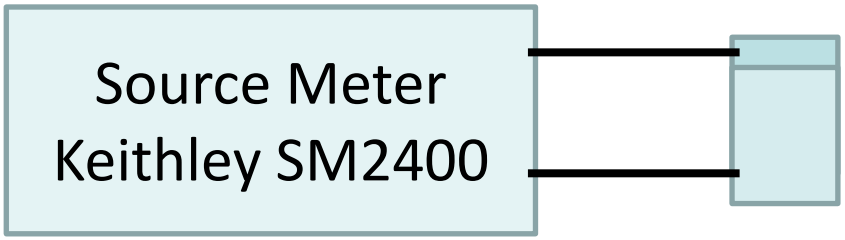
For any intermediate load resistance, R_L, the cell develops a voltage V and current I such that **$V = I / R_L$**

Battery = voltage generator

Solar cell = current generator

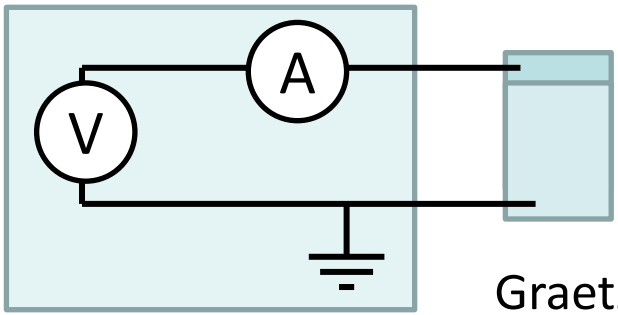


Current-voltage measurements



Graetzel Cell

At first approx:



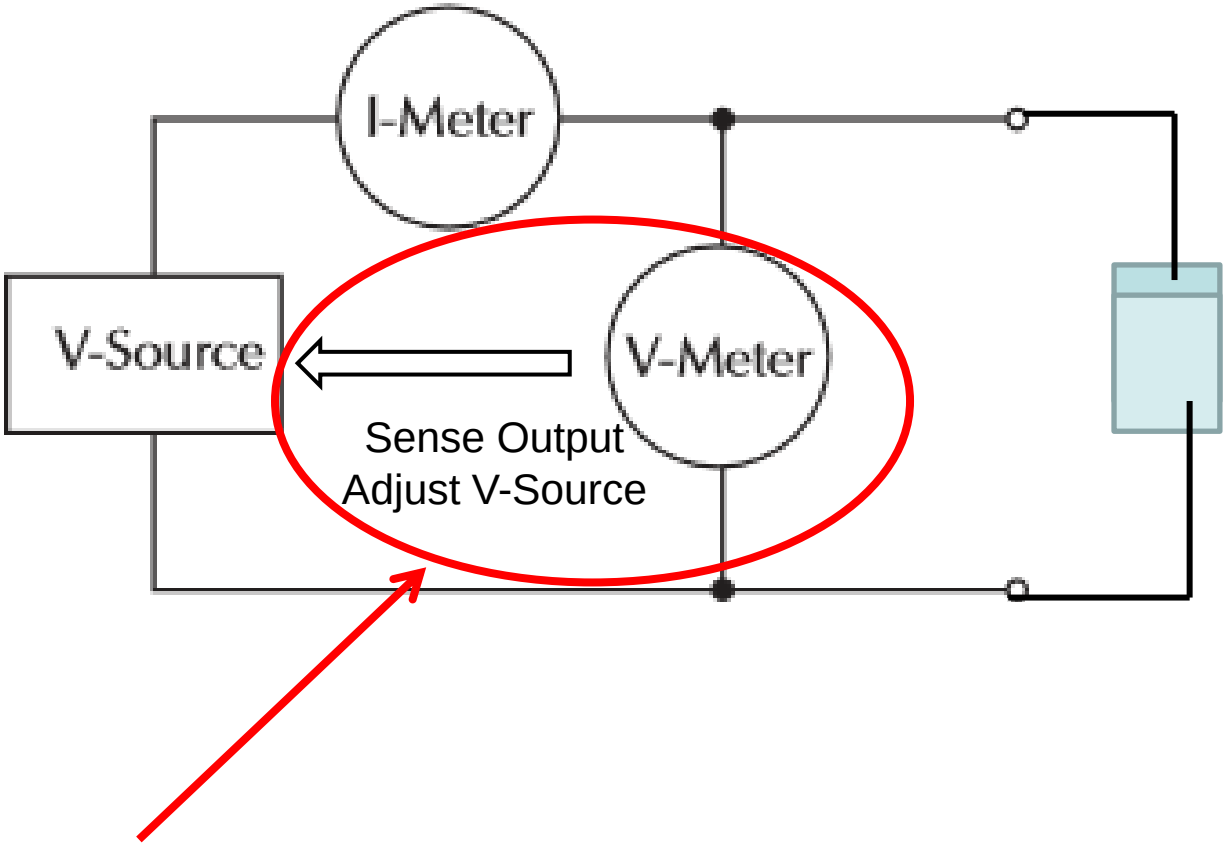
Graetzel Cell

Source Meter

Two terminal measurement:

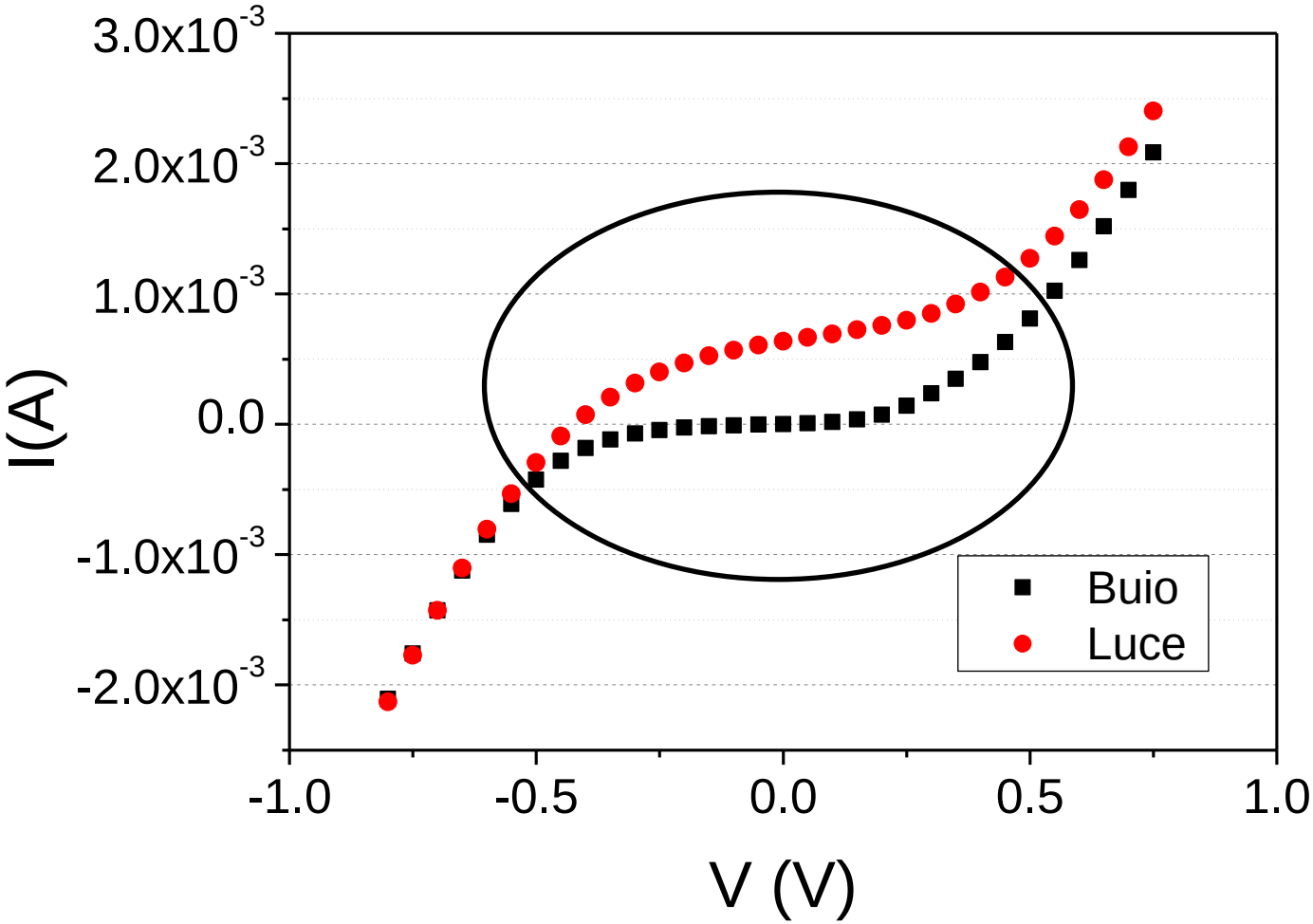
the Source Meter generates the voltage and measures the current.

Current-voltage measurements



Control system: if the bias applied to the sample is different from the one that has been selected a correction is applied.

A typical measurement



Data analyses