Astronomie et astrophysique pour physiciens CUSO 2015

Instruments and observational techniques – Détecteurs

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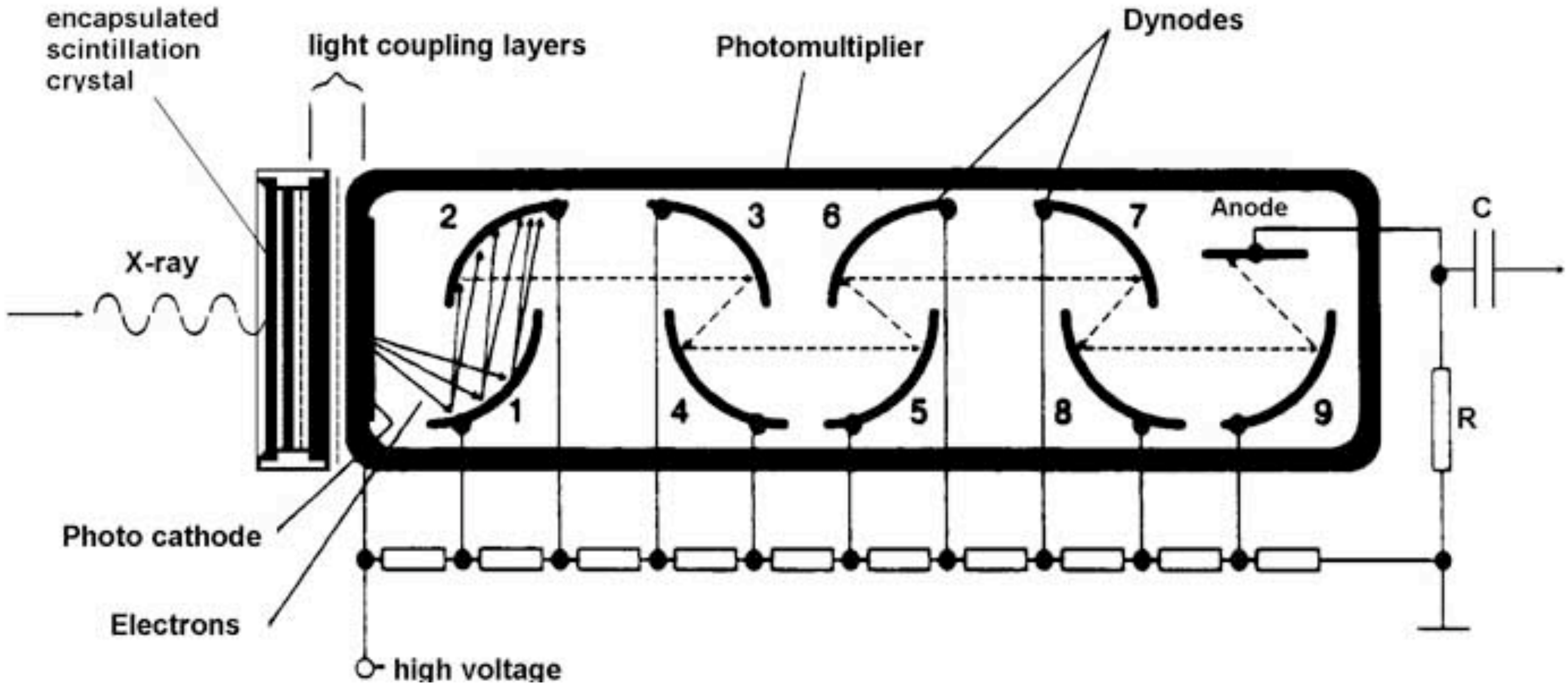
Photomultipliers



Gain of 10^7-10^9

From Bruker-AXS

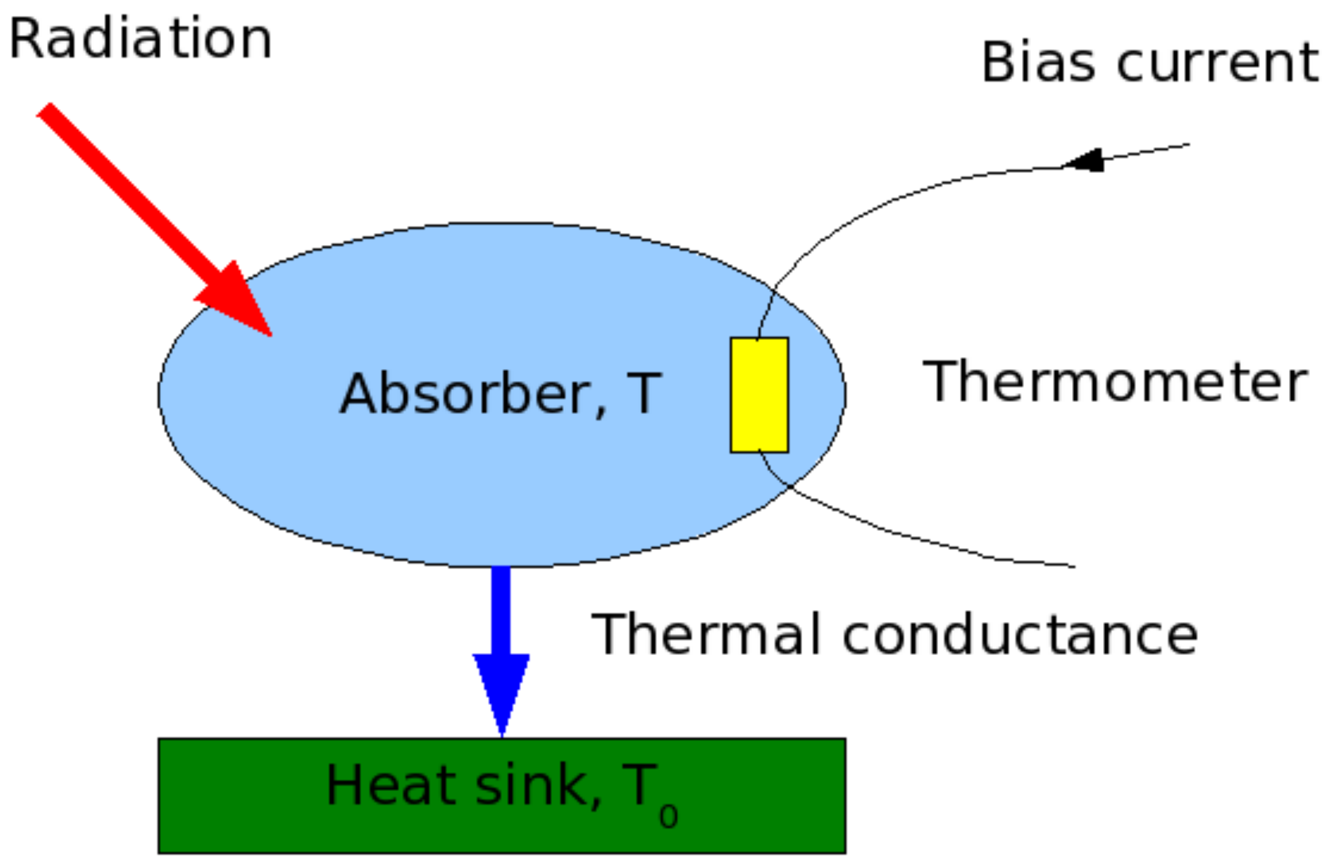
Semi-conductor detectors

- See introduction on semiconductors in previous slides (conduction/valence bands)
- Gamma-ray interaction produces secondary electrons; they produce electron-hole pairs in the conduction/valence bands
- Electric field separates the pairs before recombination, drifting electrons to anode and holes to cathode. Charge is collected, which is proportional to energy deposited in detector
- Energy required to generate electron-hole pair is $\varepsilon=(14/5)E_g+c$, where $0.5\leq c\leq$ eV
- Common detectors made of Ge (e.g., Integral SPI; $E_g=0.74$ eV, $\varepsilon=2.98$ eV), Si ($\varepsilon=3.61$ eV), CdTe (Integral ISGRI; $E_g=1.6$eV, $\varepsilon=4.43$ eV)

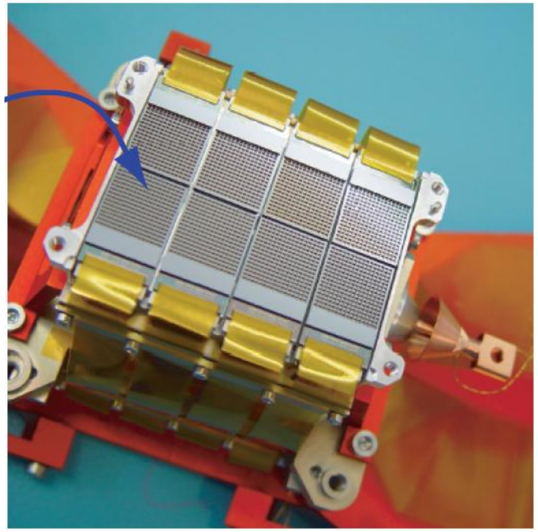
Bolometer principles

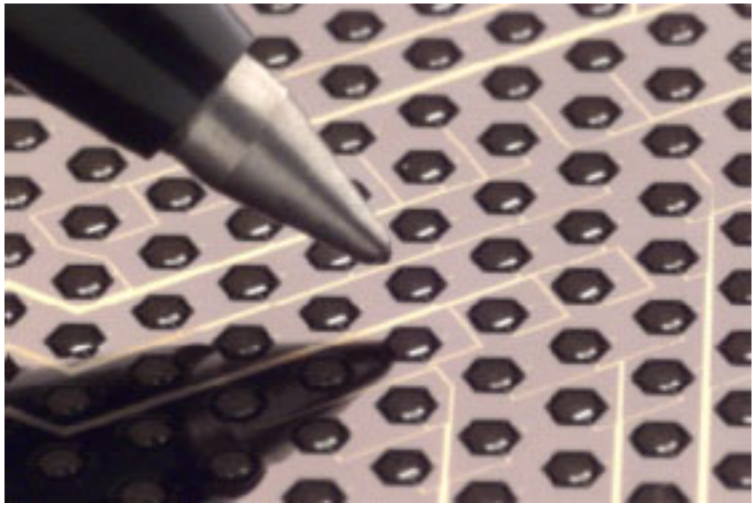
- Sensitive to energy
- Not sensitive to ‘color’
- Suited for almost ANY wavelength
- Particularly suited for IR and FIR to sub-mm (but cooling to mK required)

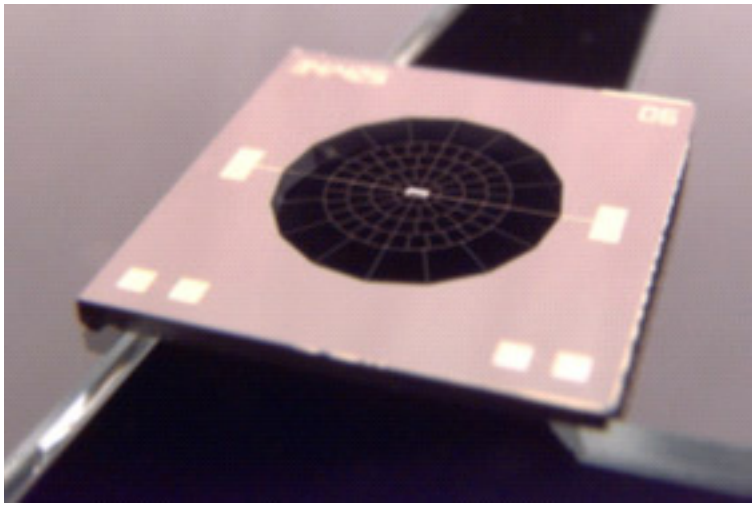
Bolometer priciples



Bolometers

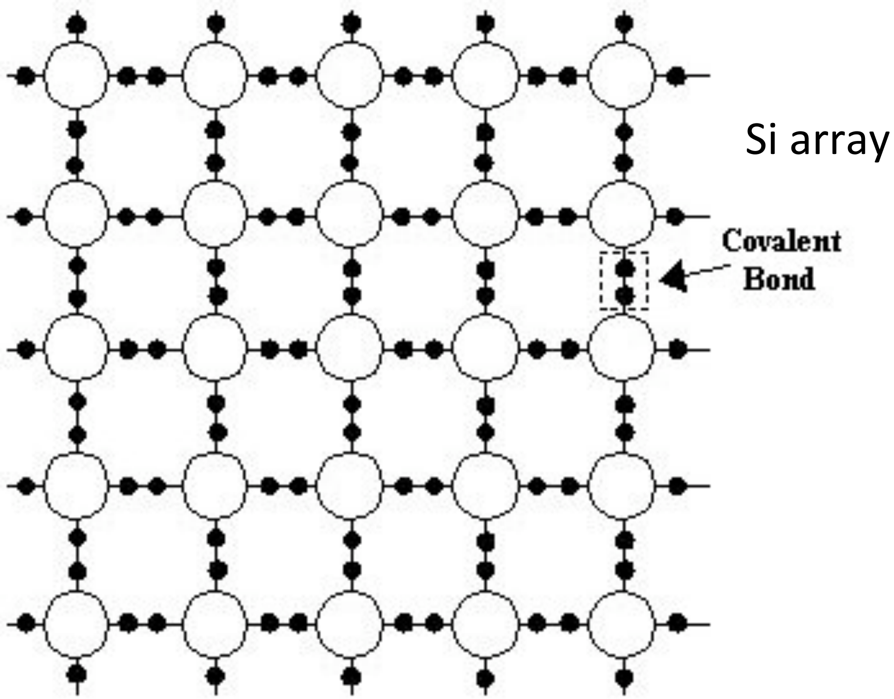


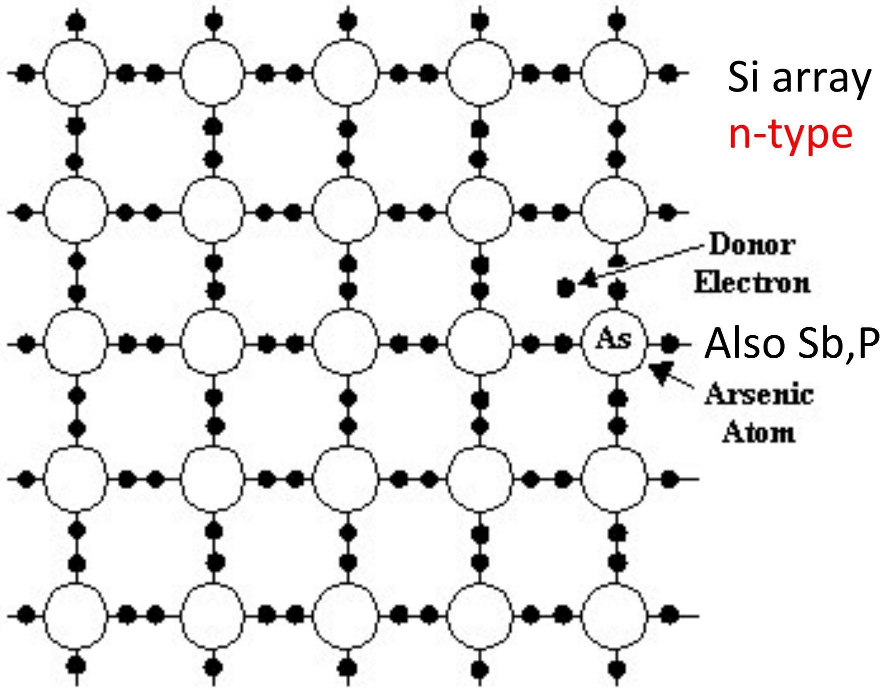


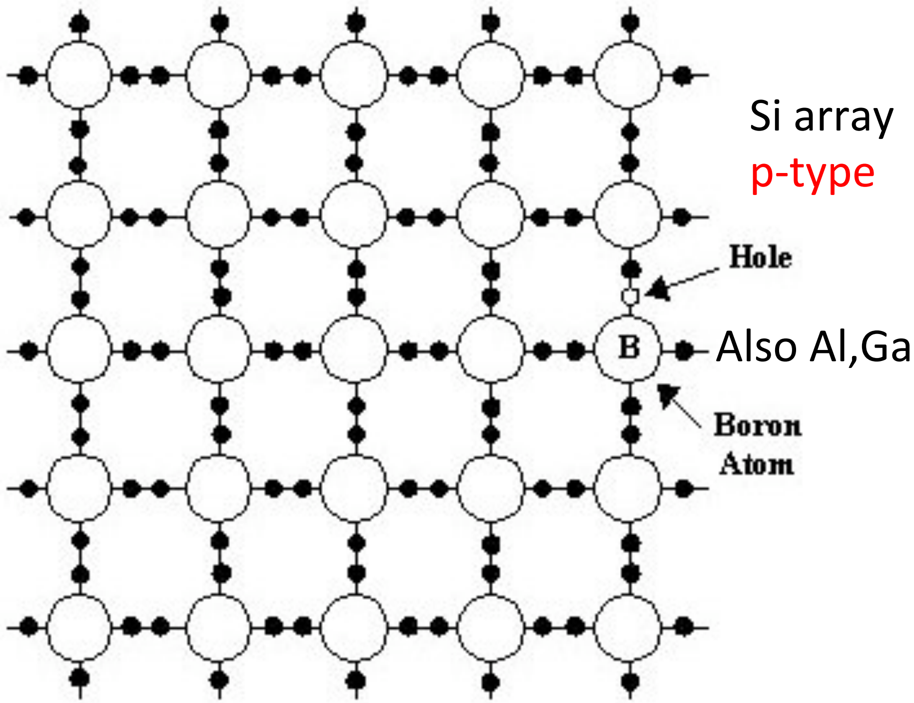


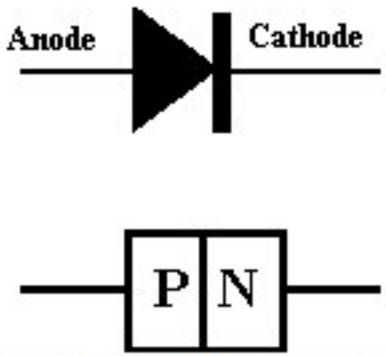
CCDs

- Charge Coupled Devices invented in the 1970s
- Sensitive to light from optical to X-rays
- In practice, best use in optical and X-rays
- CCDs make use of silicon chips
- The CCD consists of (1) a p-type doped silicon substrate, (2) the charge storage (depletion) layer, which is covered by (3) a SiO2 insulating layer; upon this is (4) an array of closely spaced electrodes, which can be set to pre-defined voltage value



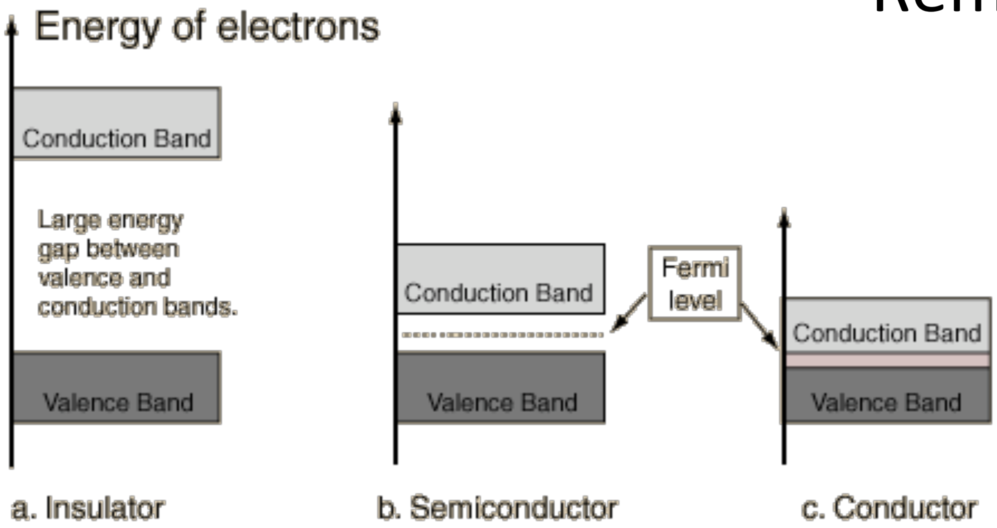


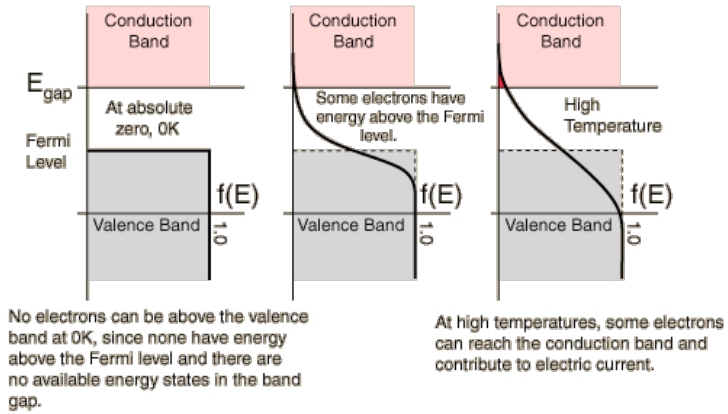




The PN junction as a Diode

Reminder of solid state physics

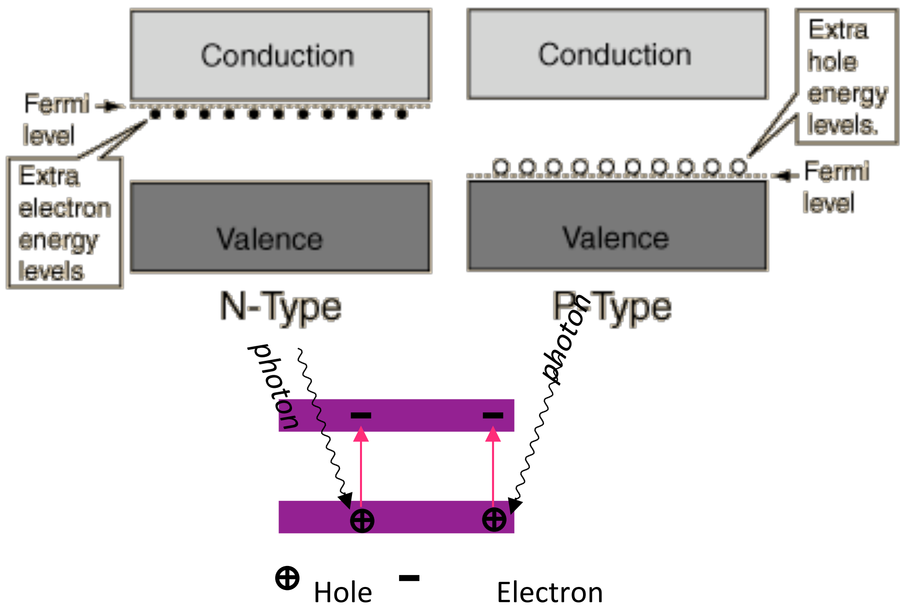




Electrons in a lattice do not have discrete energies. They form energy bands:

- Valence band
- Conduction band

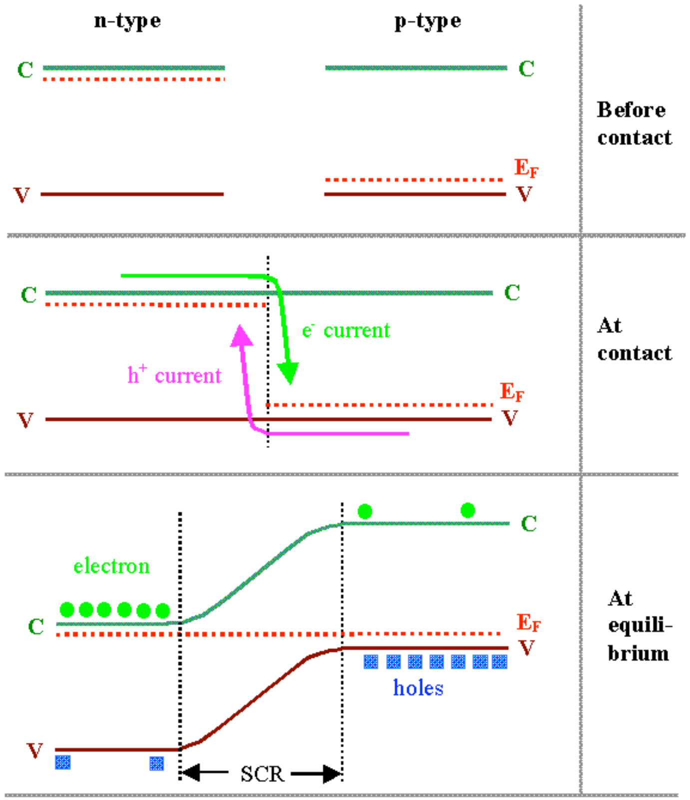
For semi-conductors, the Fermi level is just in the middle of the conduction and valence bands. At finite temperature, some electrons of the valence band can jump into the conduction band (current noise)

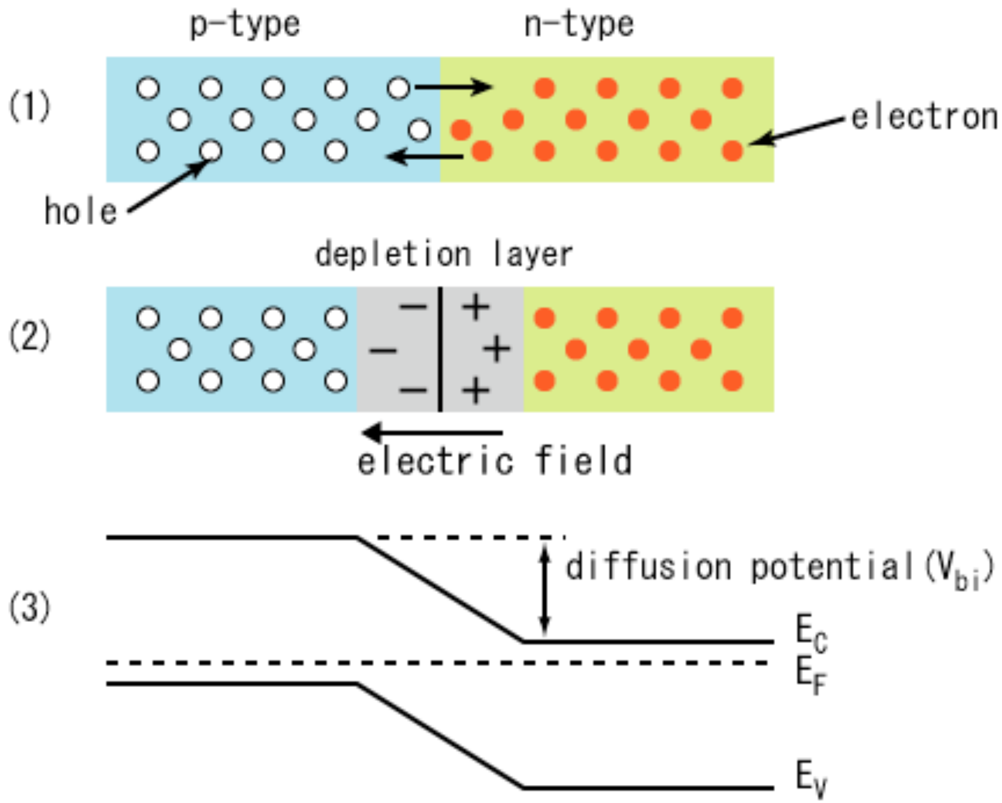


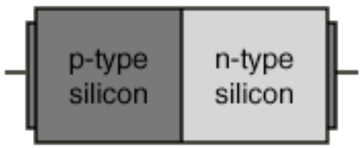
$E_G(Si)$=1.1 eV (IR), $E_G(Ge)$=0.72 eV
$E_G(C)$=5.5 eV (insulator)

(From http://hyperphysics.phy-astr.gsu.edu/hbase/hframe.html)

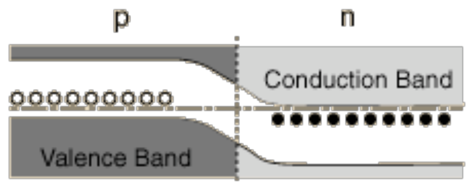
The pn junction



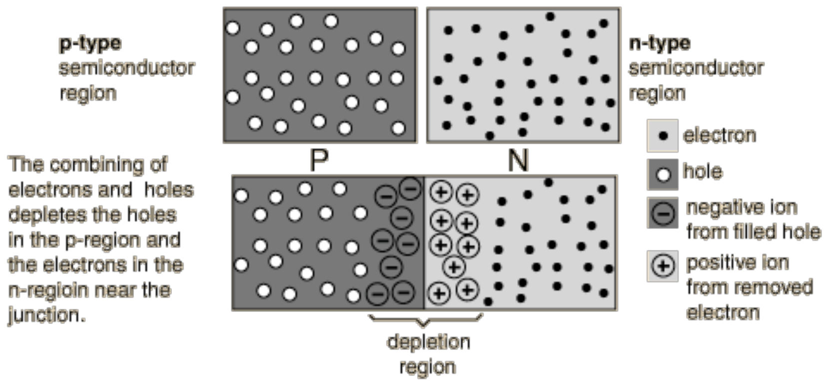




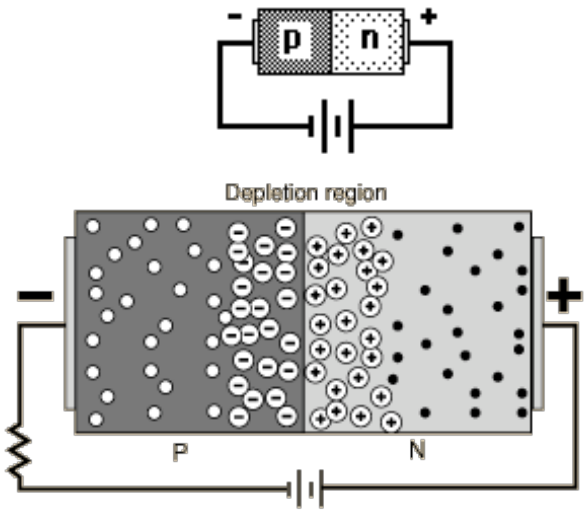
p-n junction

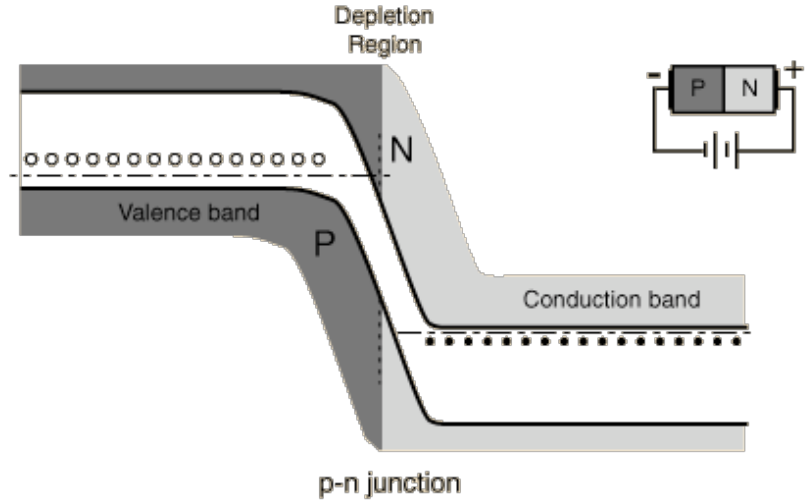


Energy bands at equilibrium

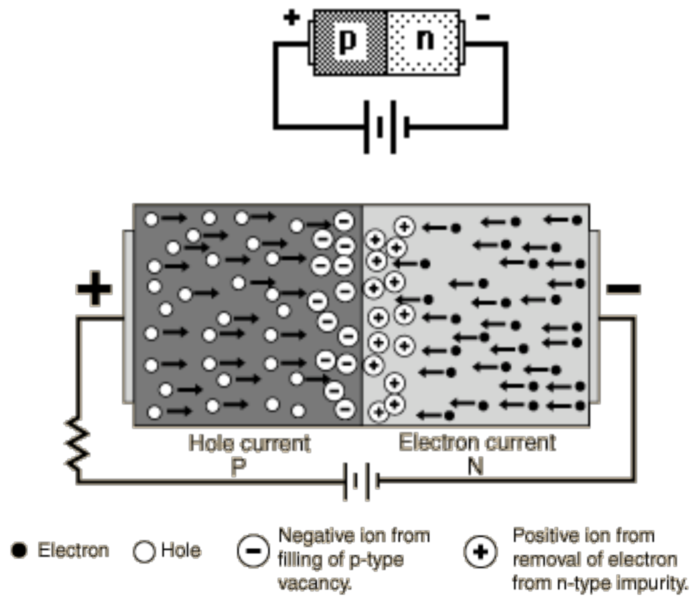


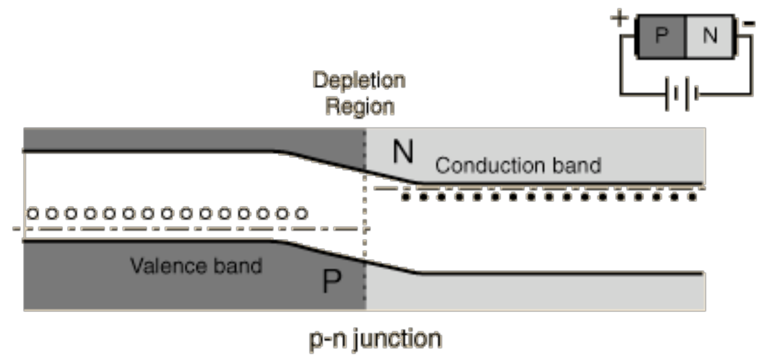
Reverse-biased pn junction

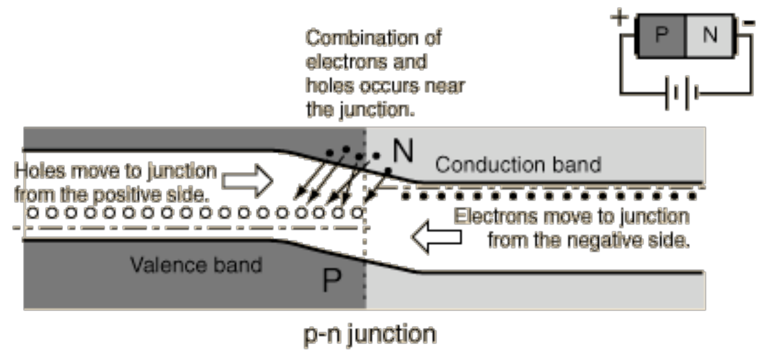


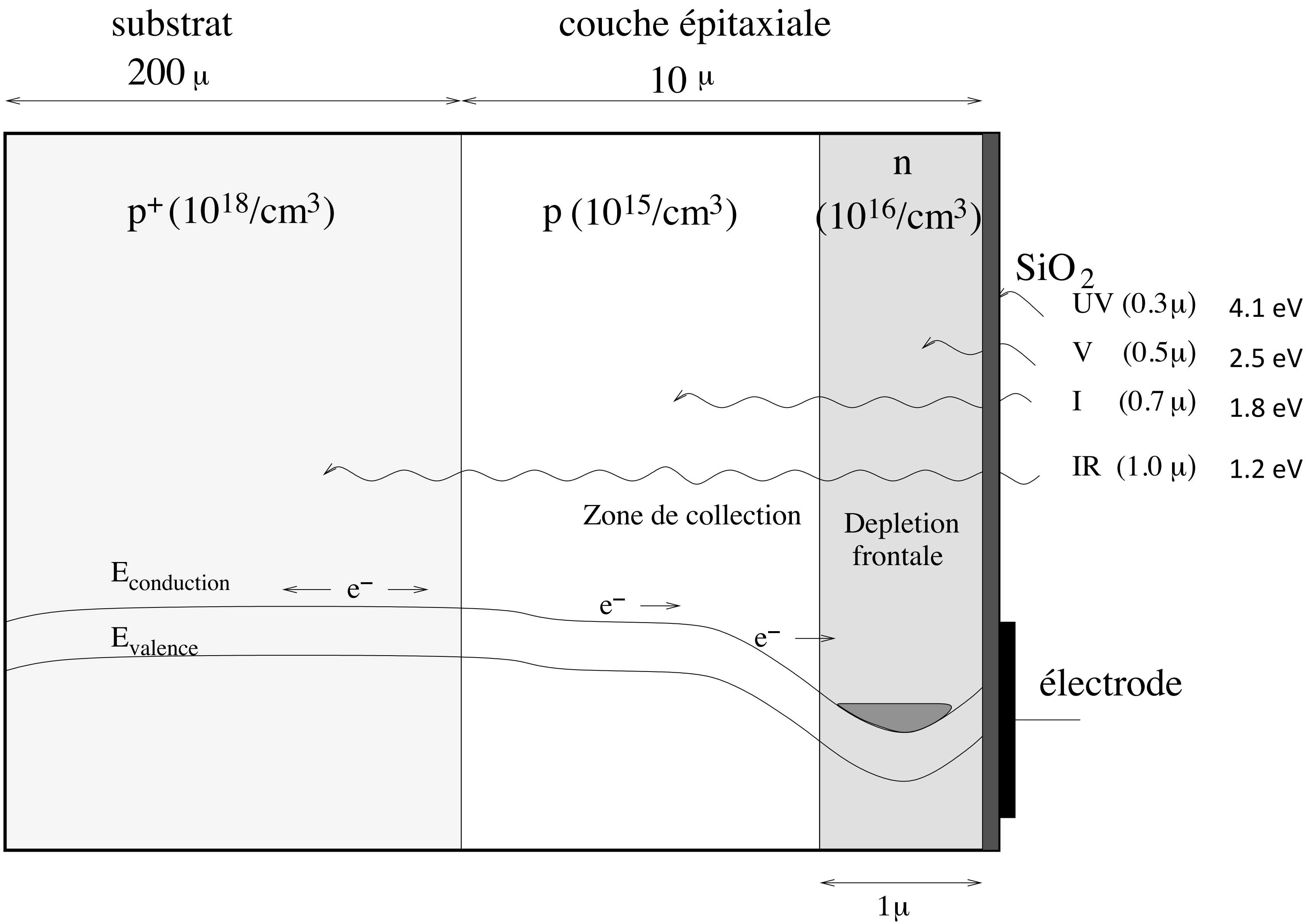


Forward-biased pn junction



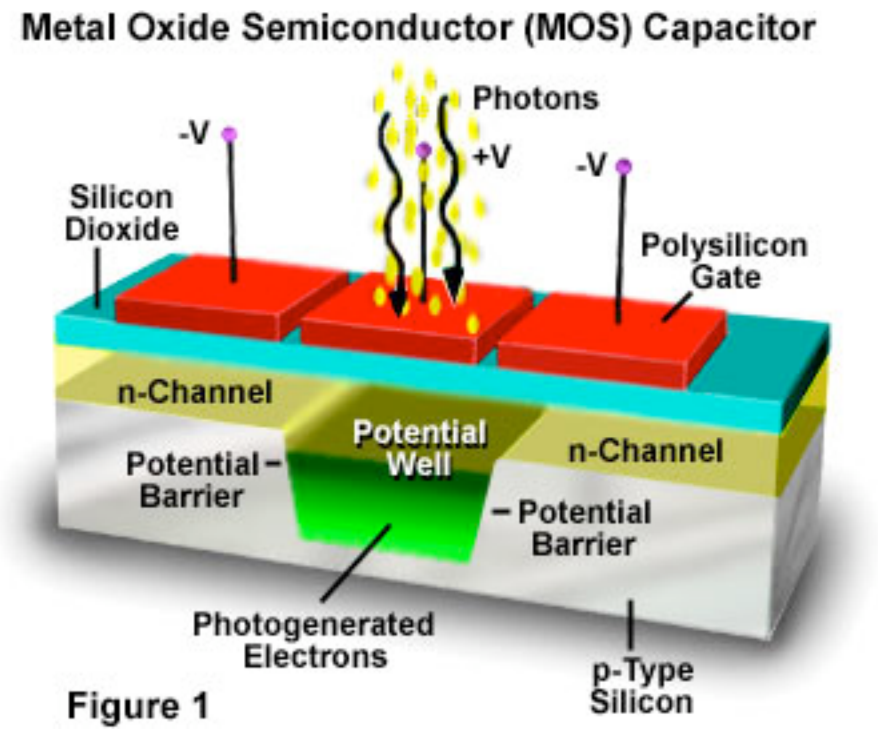






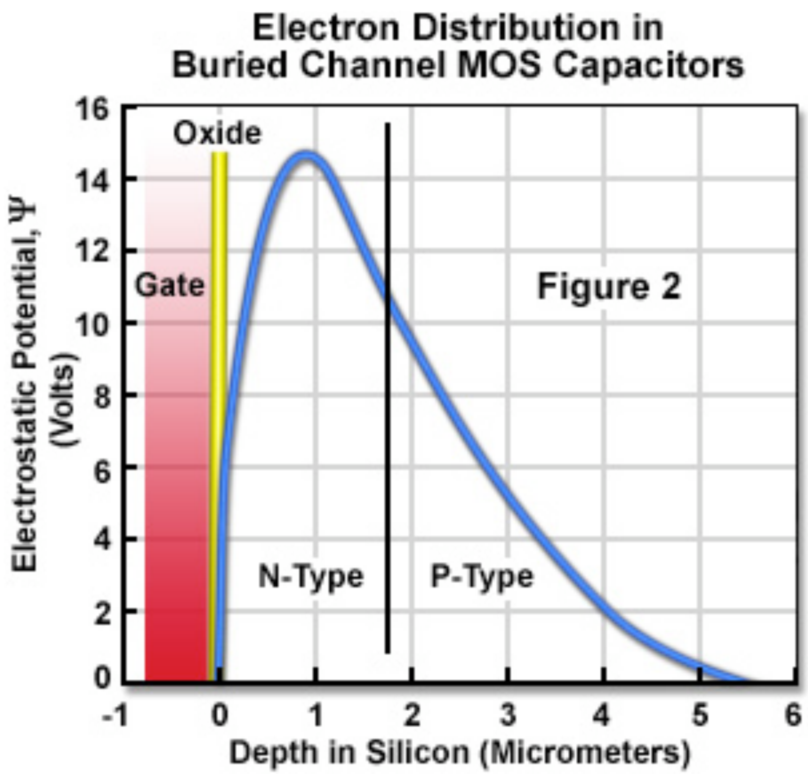
Transverse cut of CCD with buried channel

Blecha (cours instrumentation)

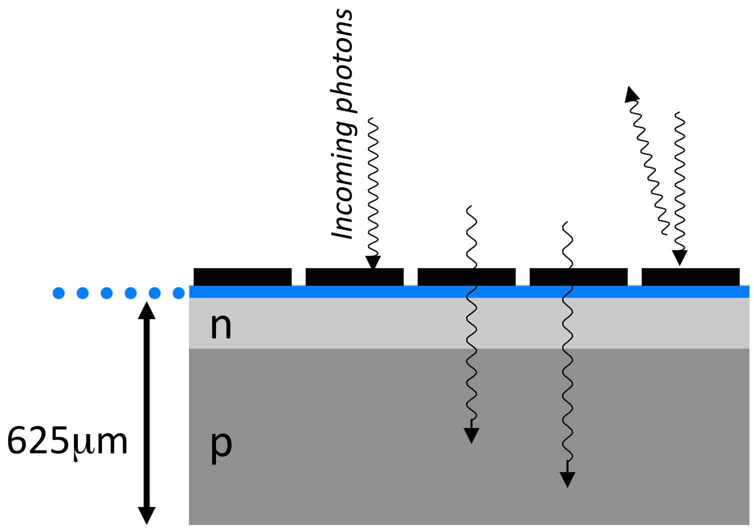


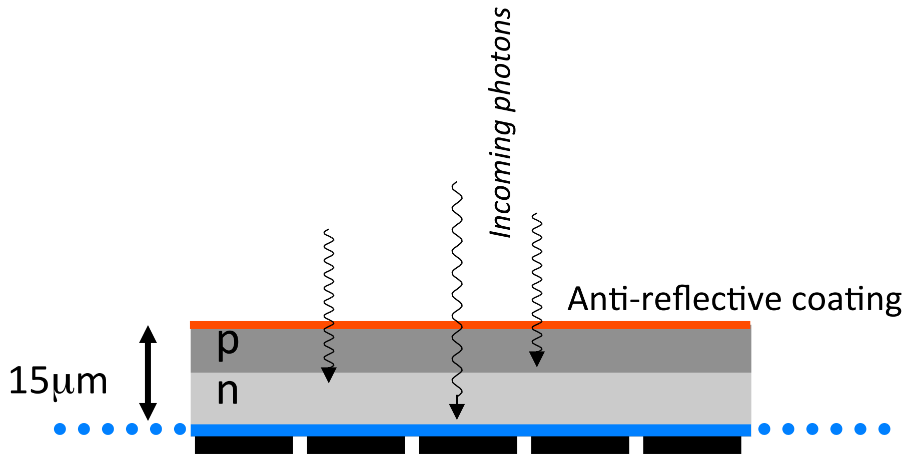
The electrode has positive potential to attract the generated photoelectrons in a potential well

The above MOS capacitor is 1 pixel



Front-illuminated CCDs





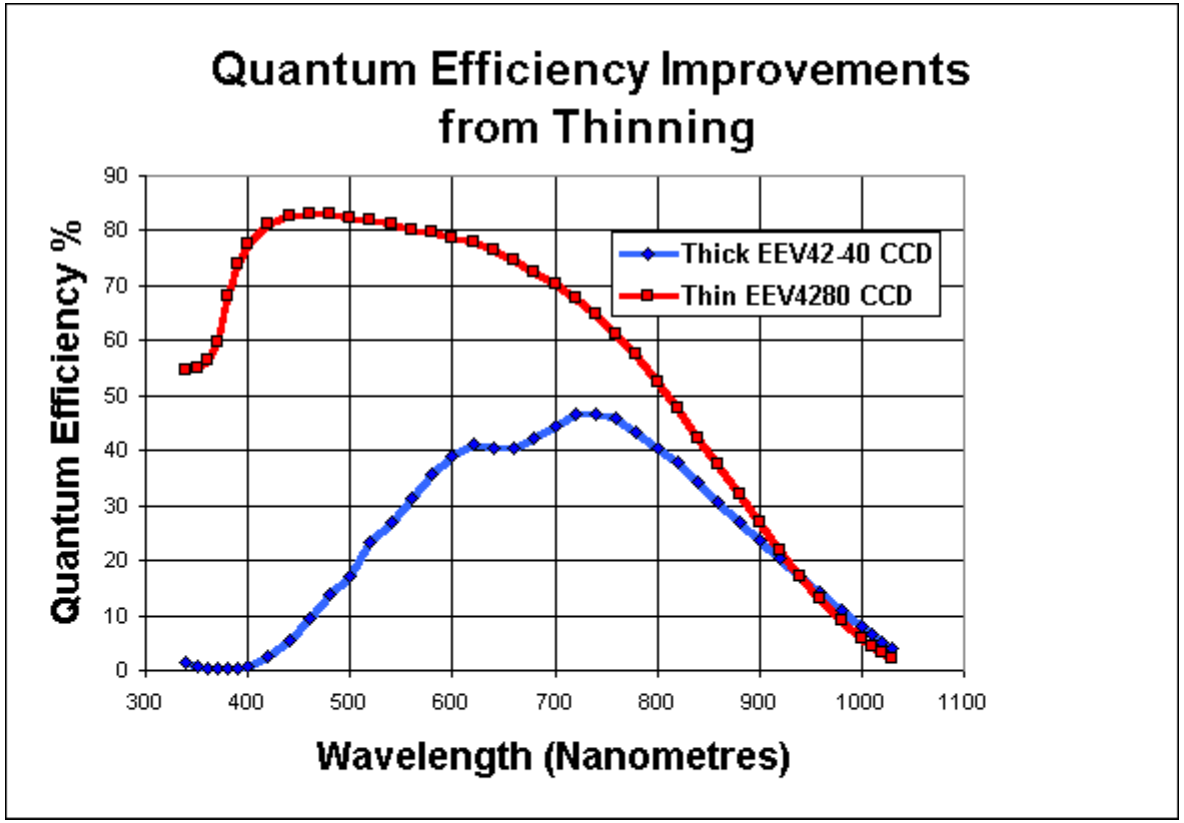
They have a low Quantum Efficiency due to the reflection and absorption of light in the surface electrodes. Very poor blue response. The electrode structure prevents the use of an anti-reflective coating that would otherwise boost performance.

The QE can approach 100% . These thinned CCDs become transparent to near infra-red light and the red response is poor. Response can be boosted by the application of an anti-reflective coating on the thinned rear-side. These coatings do not work so well for front-illuminated CCDs due to the surface bumps created by the surface electrodes

Courtesy of S. Tulloch

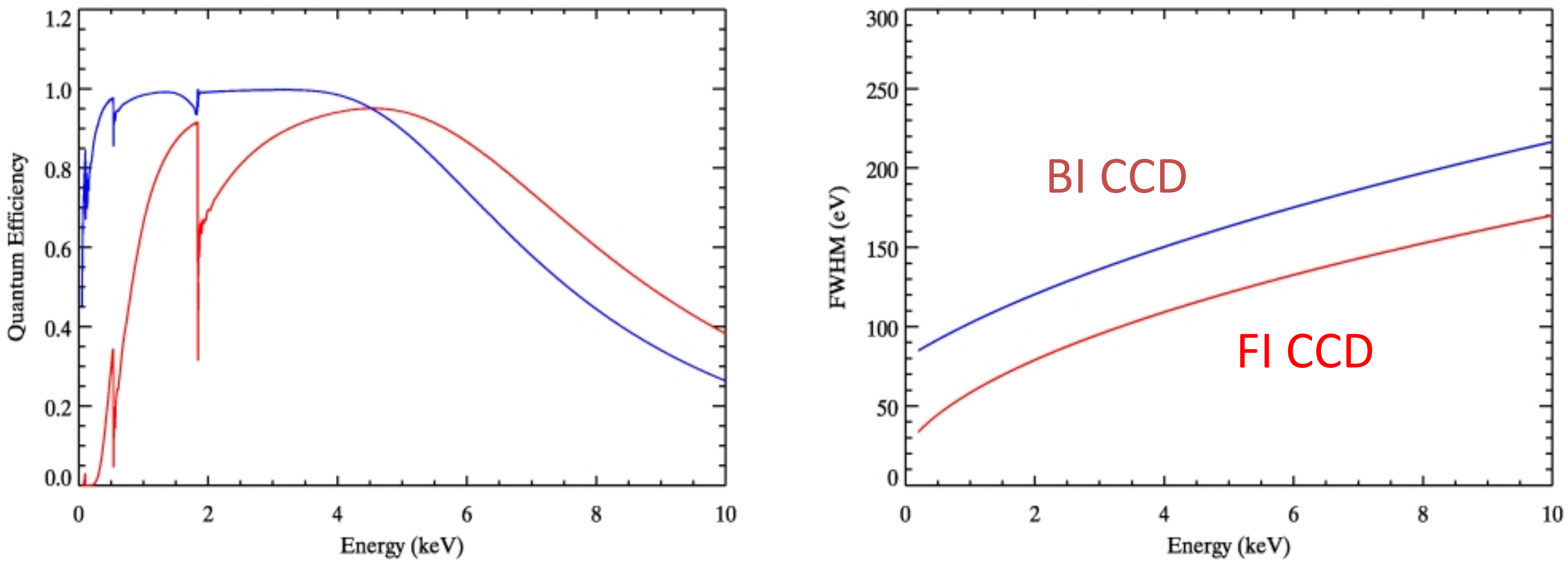
Quantum Efficiency Comparison

The graph below compares the quantum of efficiency of a thick frontside illuminated CCD and a thin backside illuminated CCD.



Courtesy of S. Tulloch

Back-illuminated CCDs

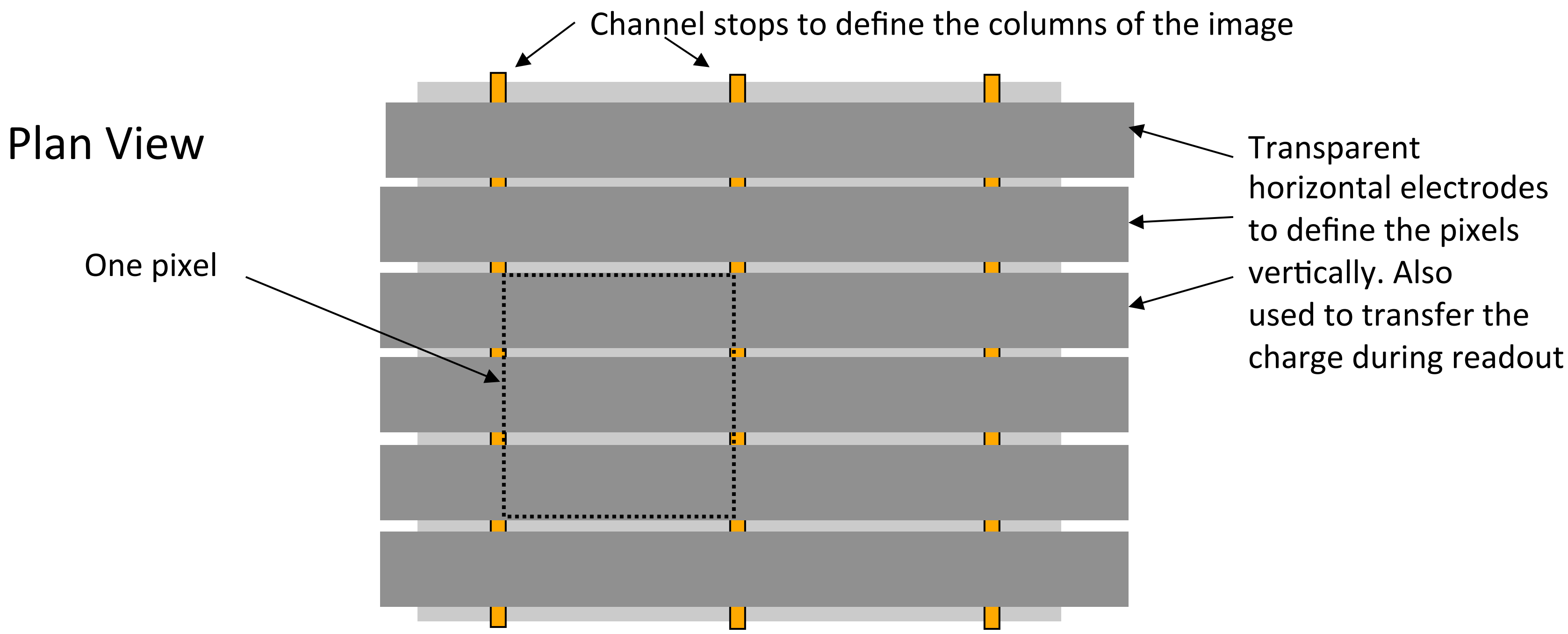


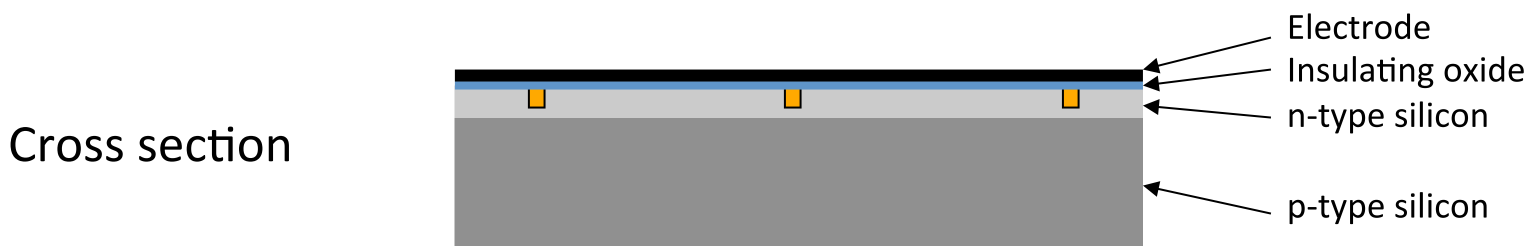
- Thinner deadlayers ⇒ higher low-E QE
- Thinner active region ⇒ lower high-E QE
- Increased noise, charge transfer inefficiency ⇒ higher FWHM

From C. Grant, X-ray Astronomy School 2007

Structure of a CCD

The diagram shows a small section (a few pixels) of the image area of a CCD. This pattern is reapeated.

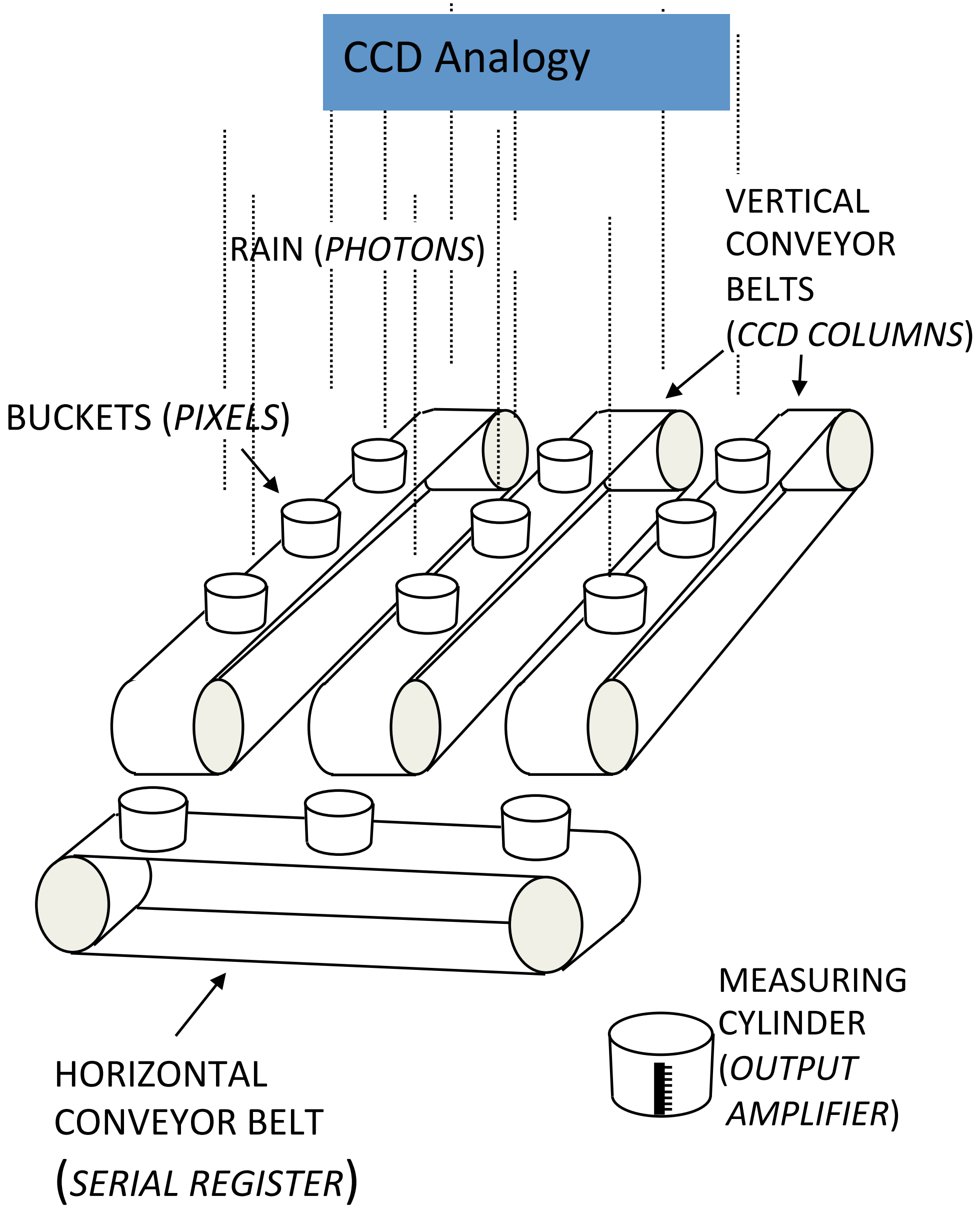




Every third electrode is connected together. Bus wires running down the edge of the chip make the connection. The channel stops are formed from high concentrations of Boron in the silicon.

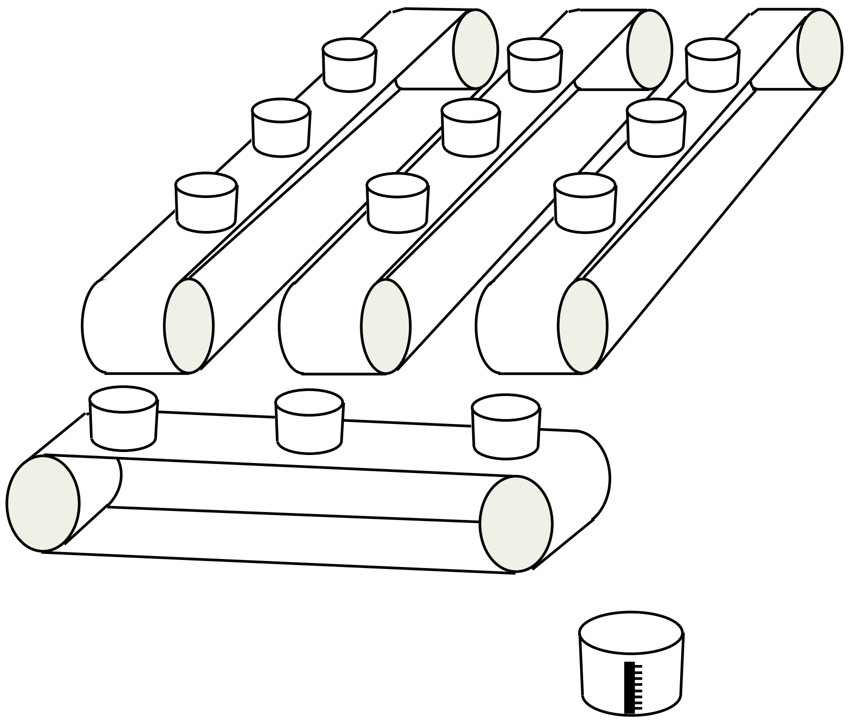
Courtesy of S. Tulloch

CCD Analogy



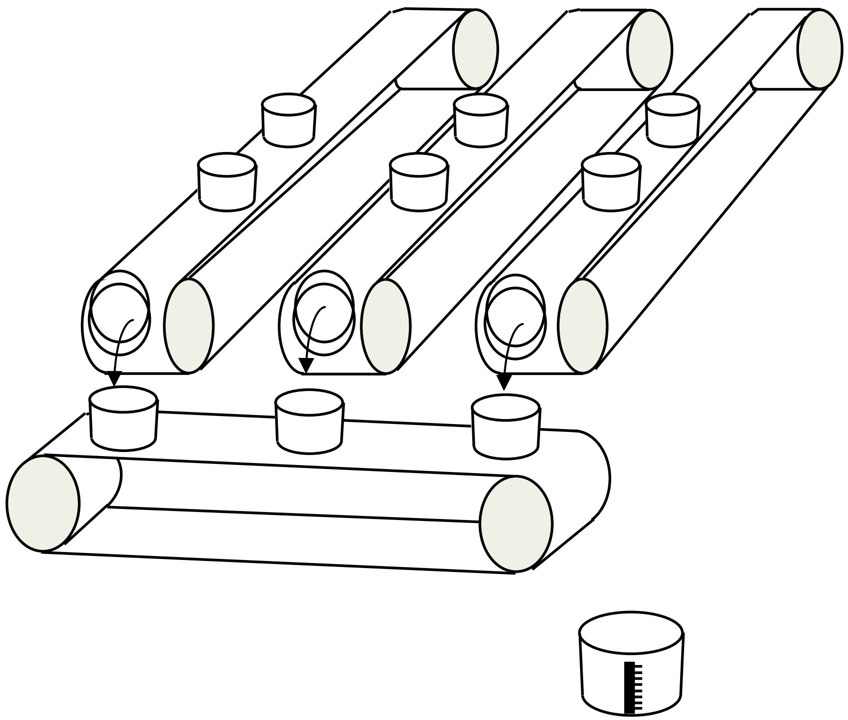
Courtesy of S. Tulloch

Exposure finished, buckets now contain samples of rain.



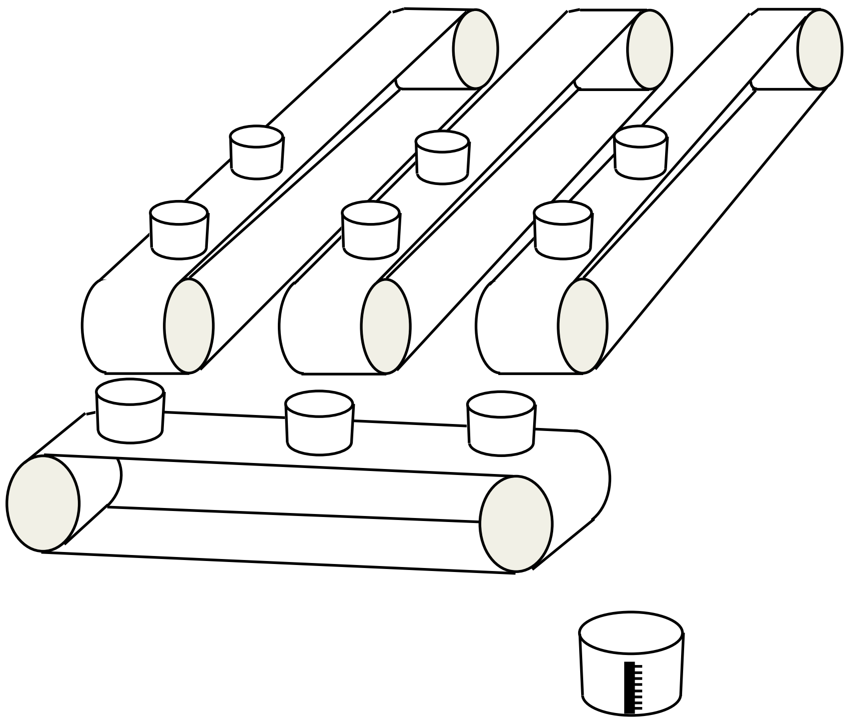
Courtesy of S. Tulloch

Conveyor belt starts turning and transfers buckets. Rain collected on the vertical conveyor is tipped into buckets on the horizontal conveyor.



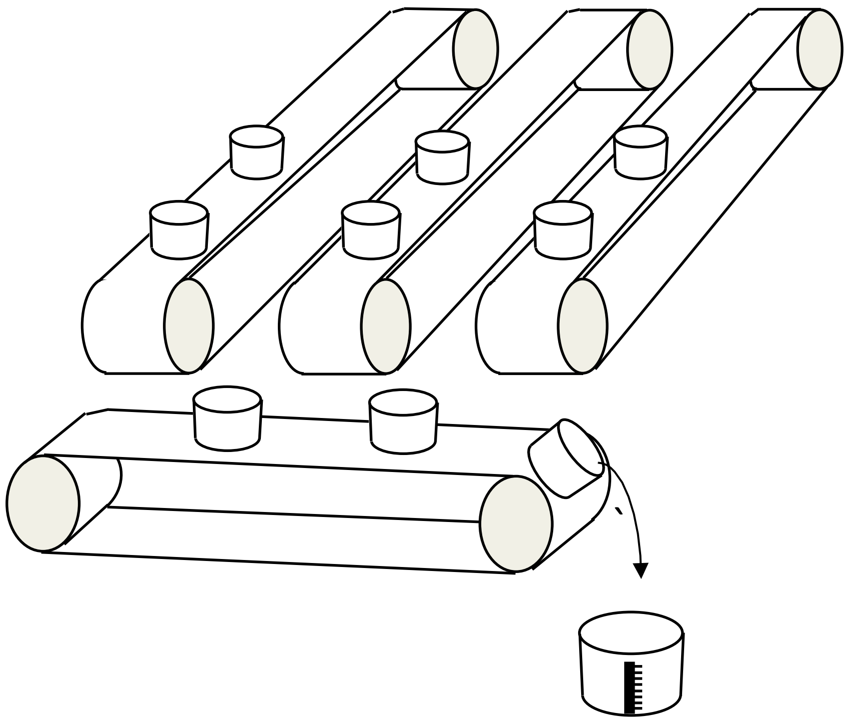
Courtesy of S. Tulloch

Vertical conveyor stops. Horizontal conveyor starts up and tips each bucket in turn into the measuring cylinder .

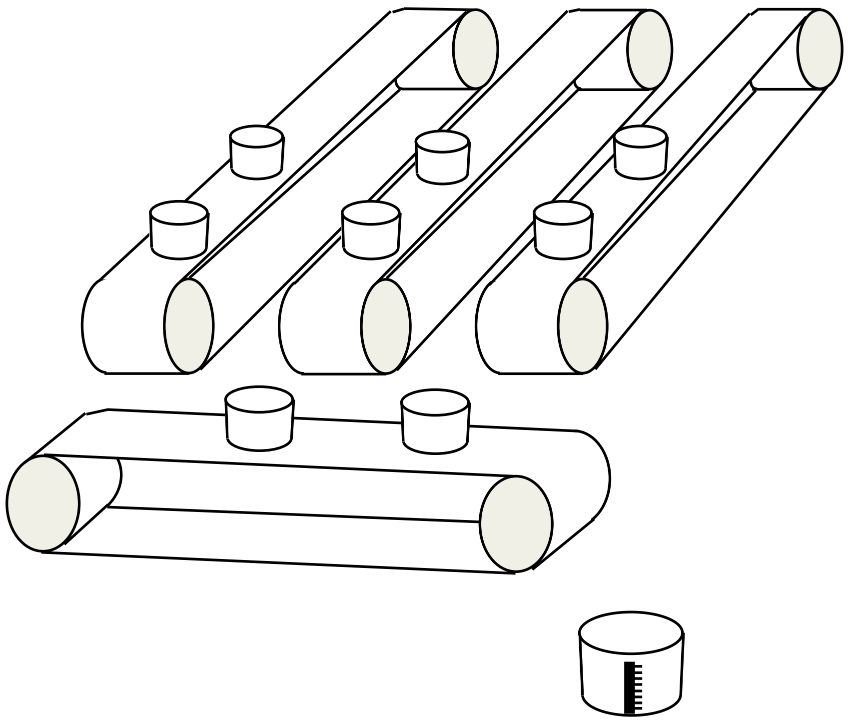


Courtesy of S. Tulloch

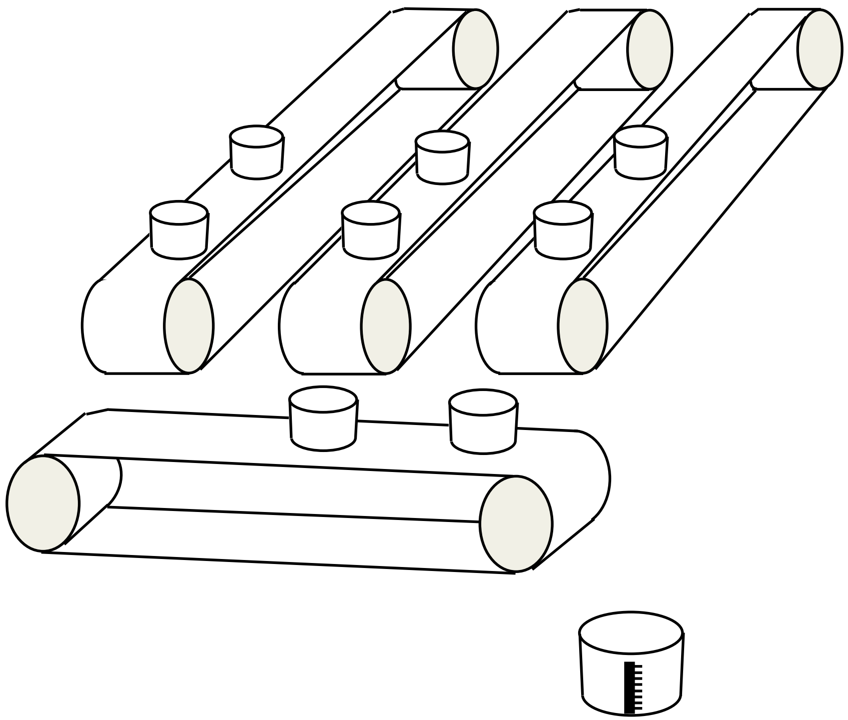
After each bucket has been measured, the measuring cylinder is emptied , ready for the next bucket load.



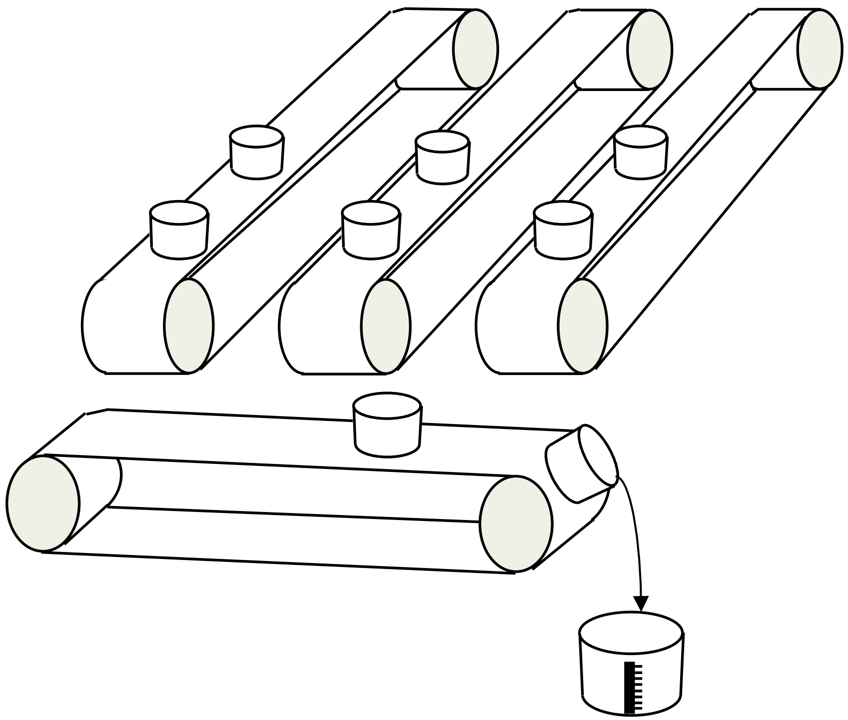
Courtesy of S. Tulloch



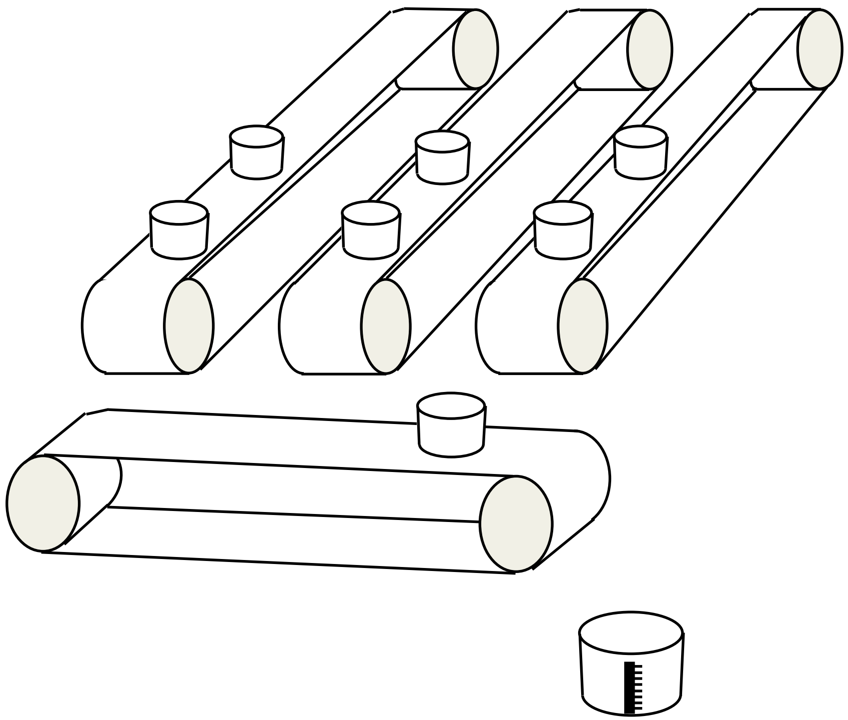
Courtesy of S. Tulloch



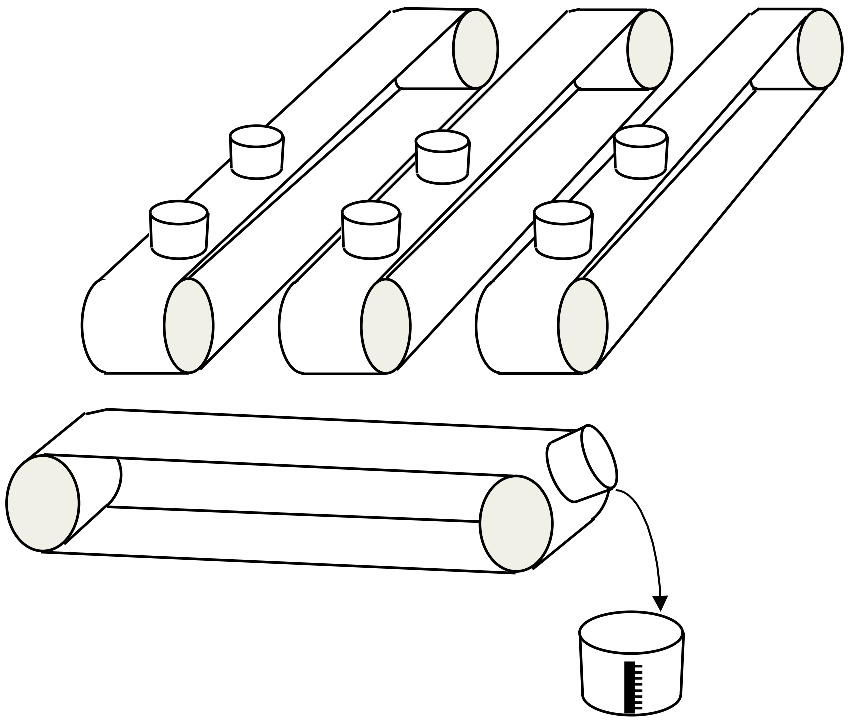
Courtesy of S. Tulloch



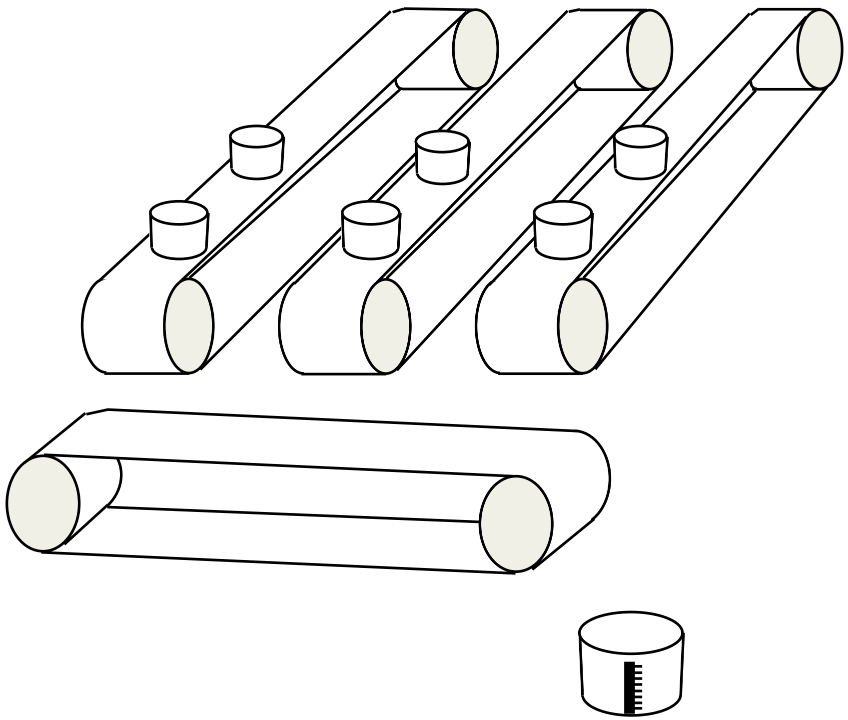
Courtesy of S. Tulloch



Courtesy of S. Tulloch

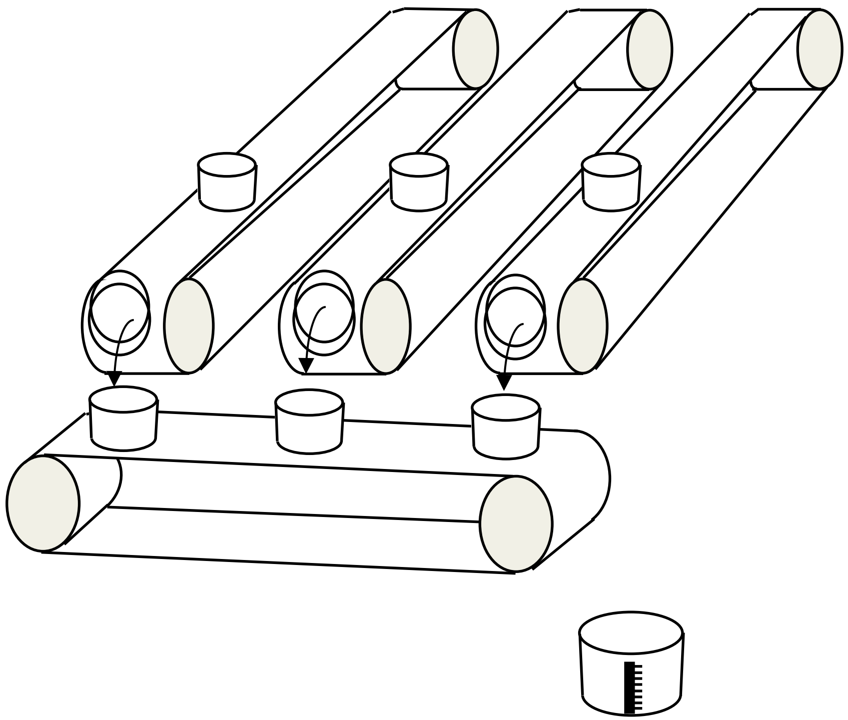


Courtesy of S. Tulloch



Courtesy of S. Tulloch

A new set of empty buckets is set up on the horizontal conveyor and the process is repeated.



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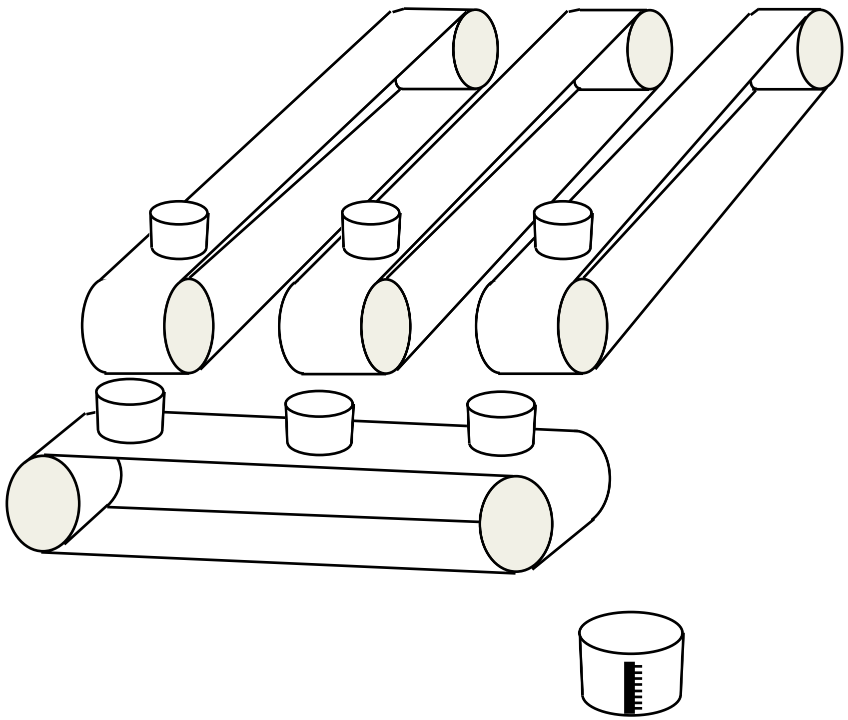

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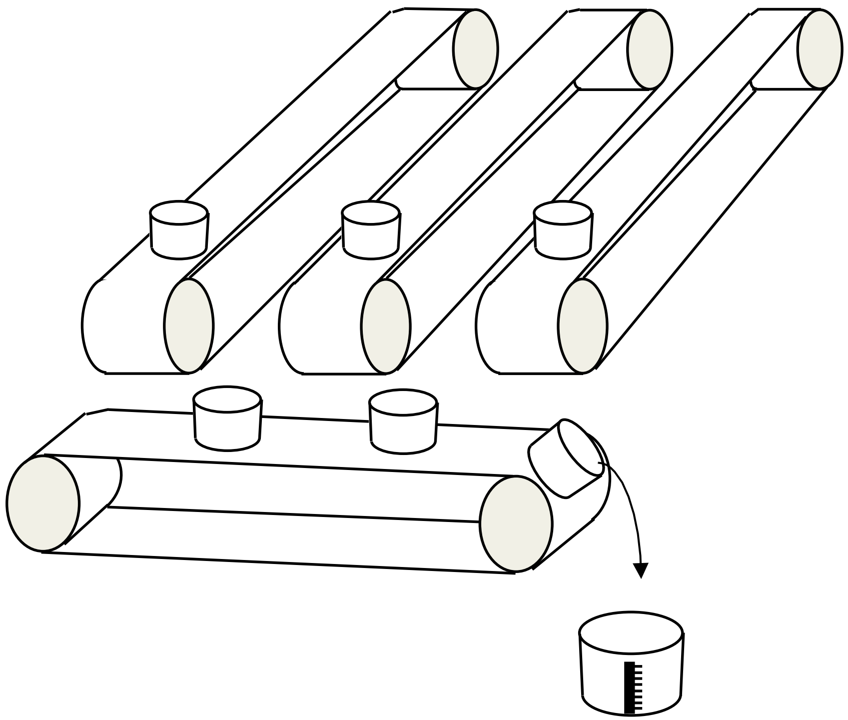

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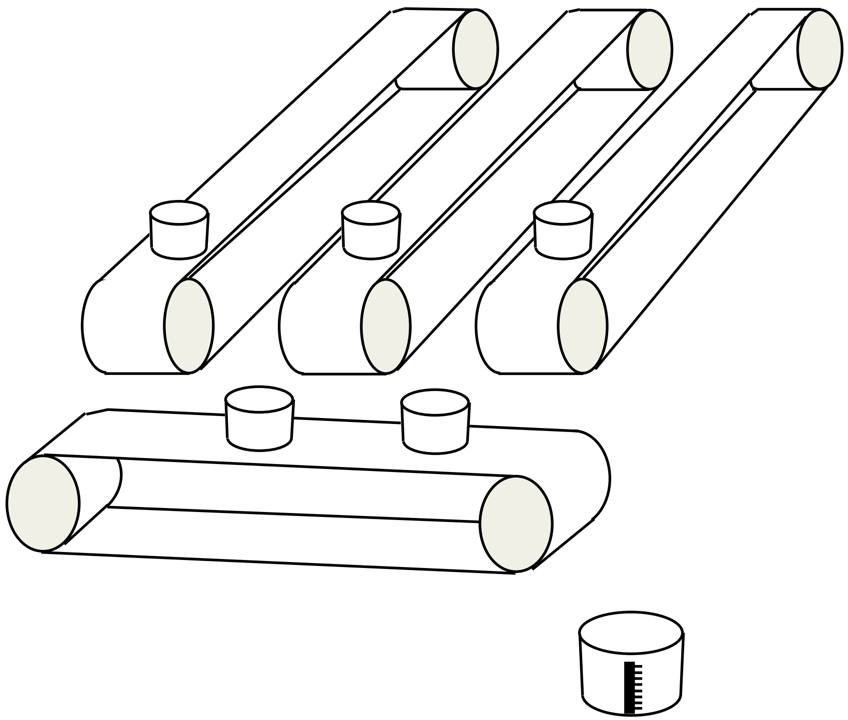

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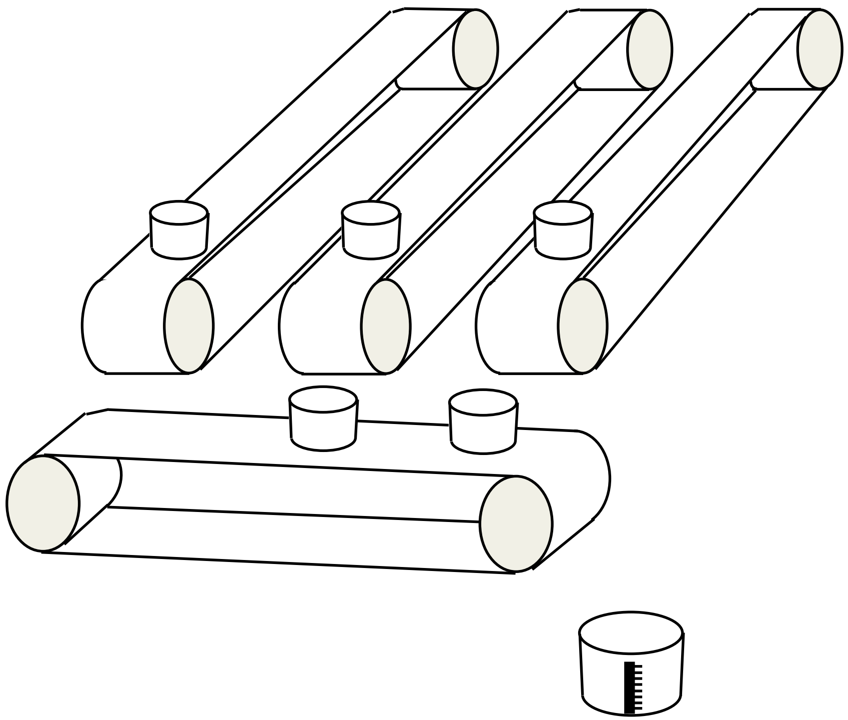

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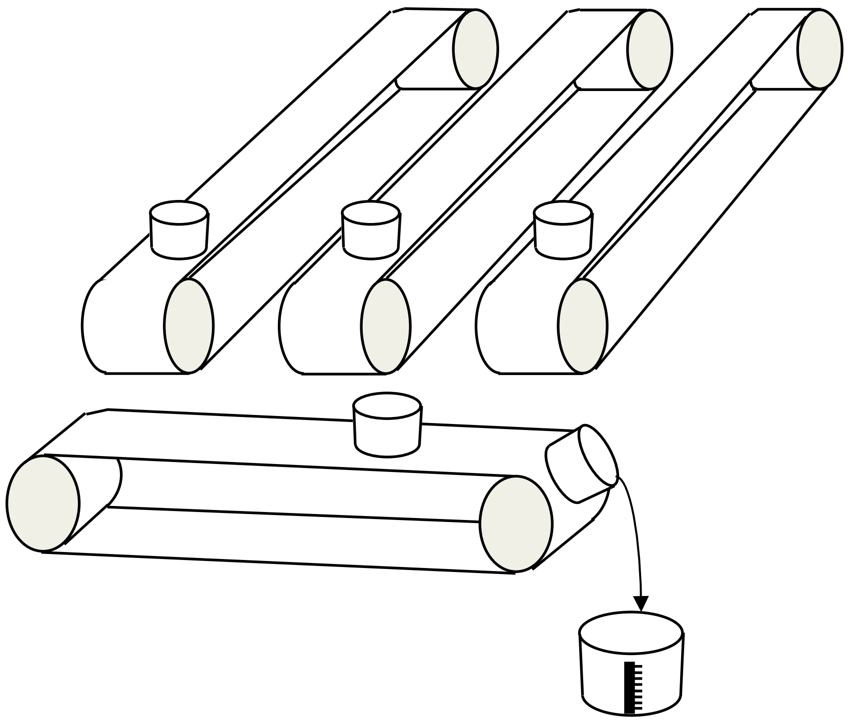

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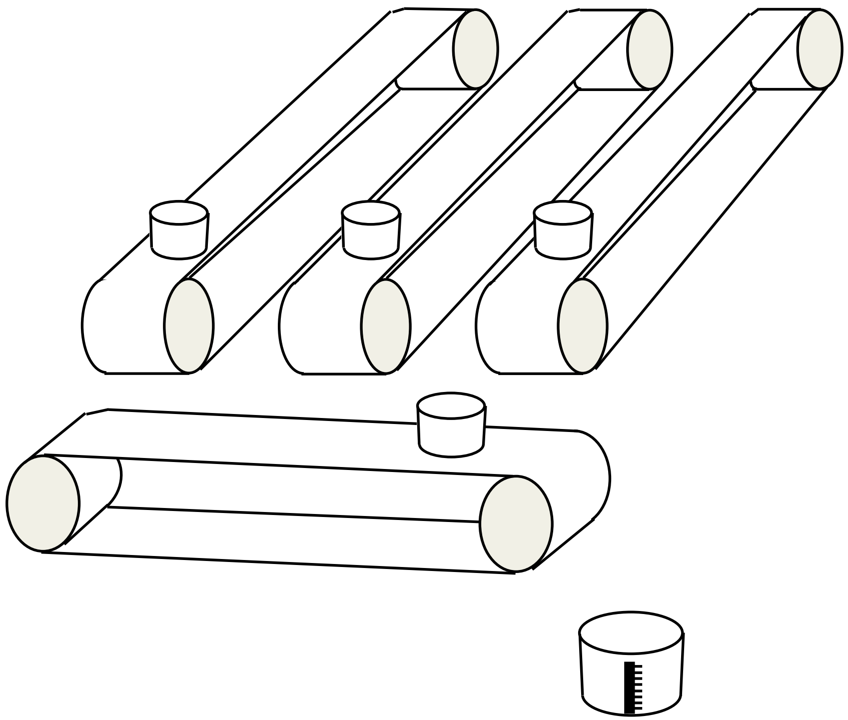

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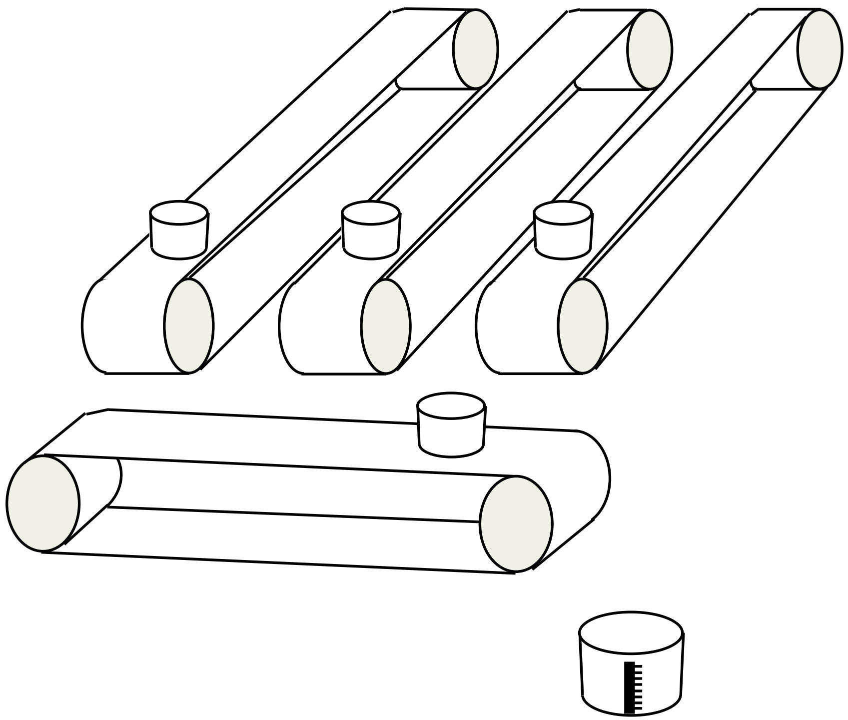

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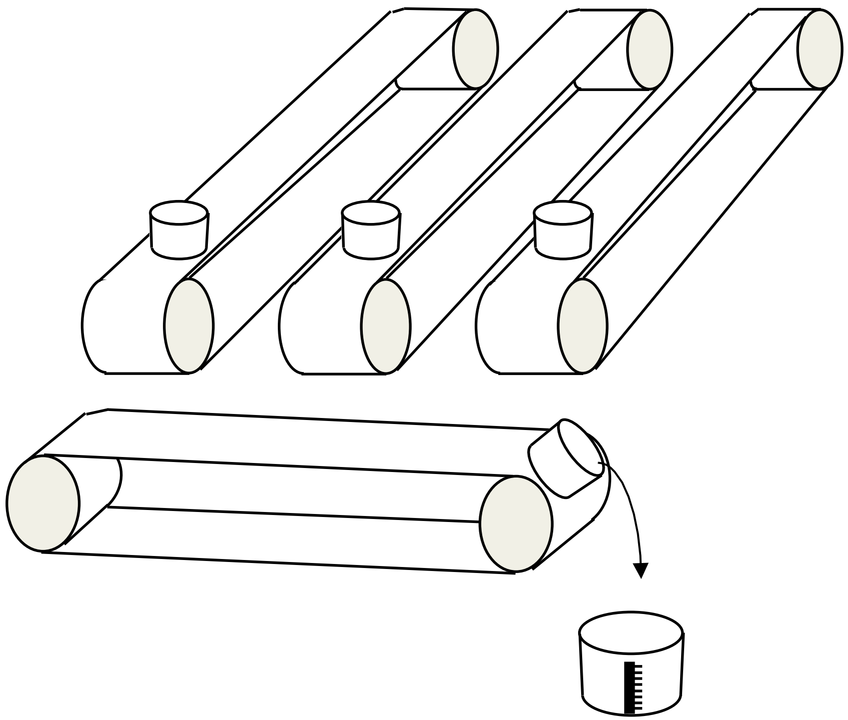

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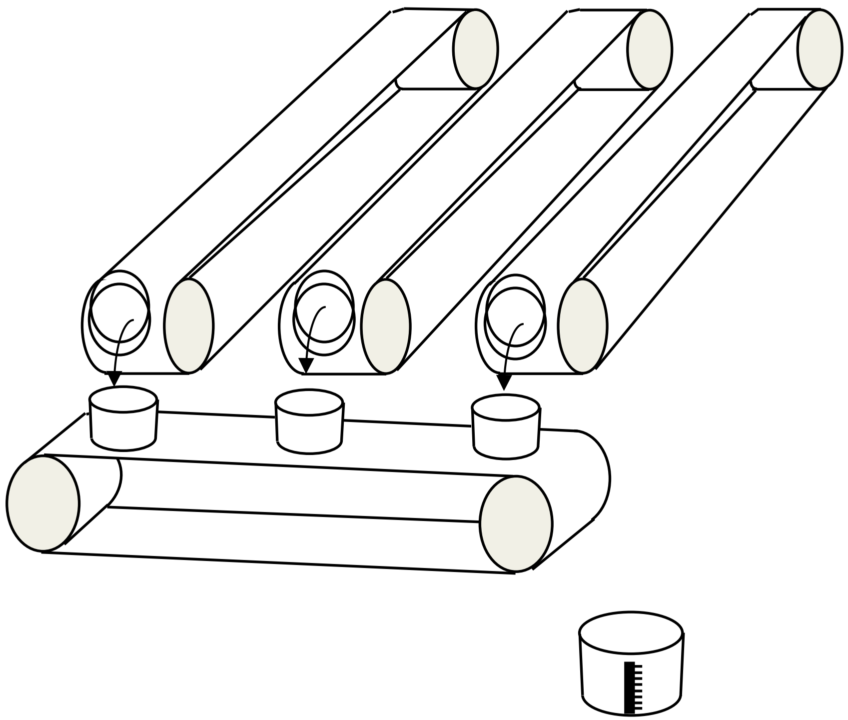

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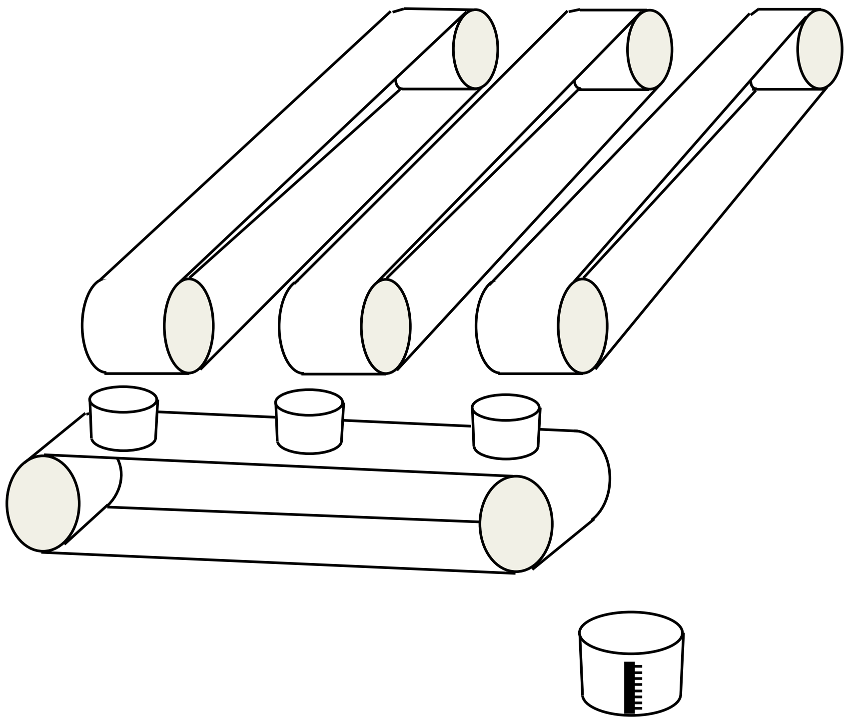

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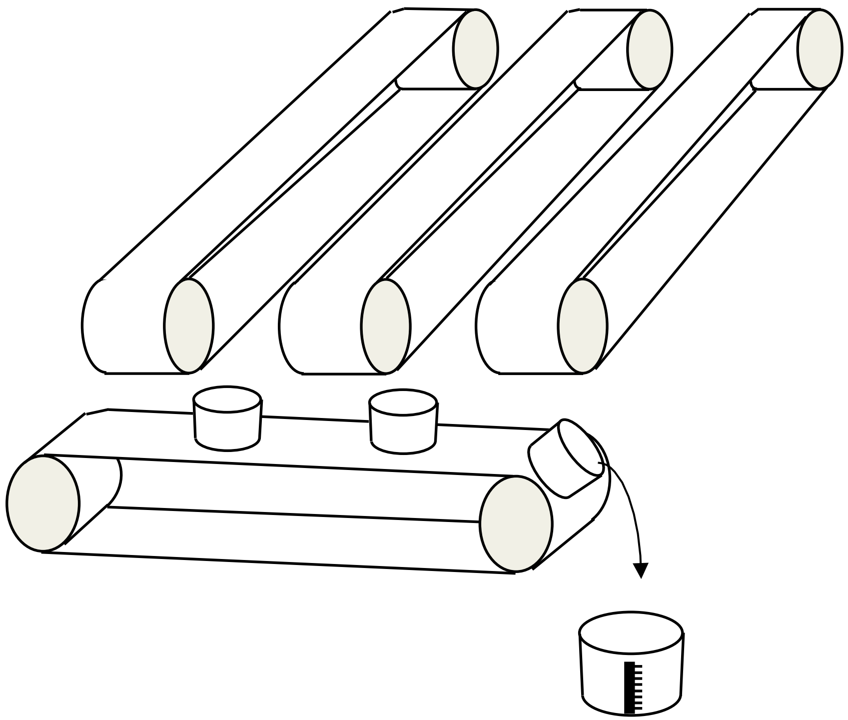

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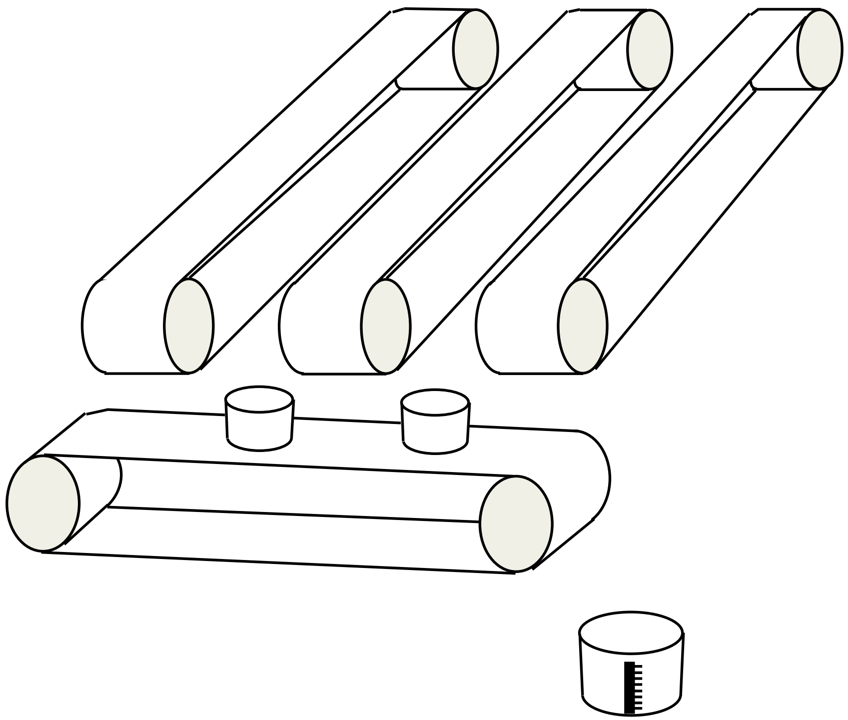

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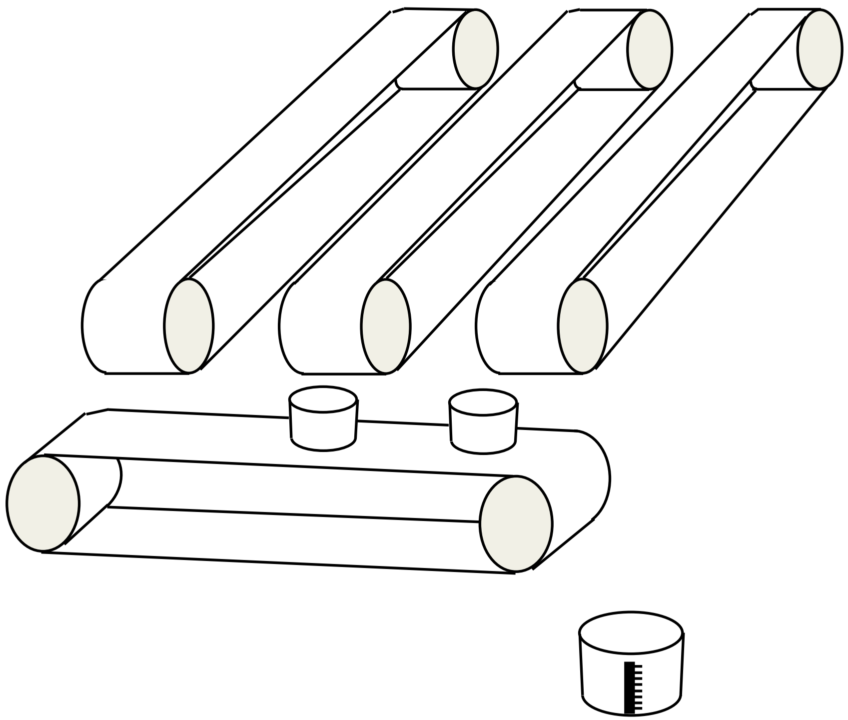

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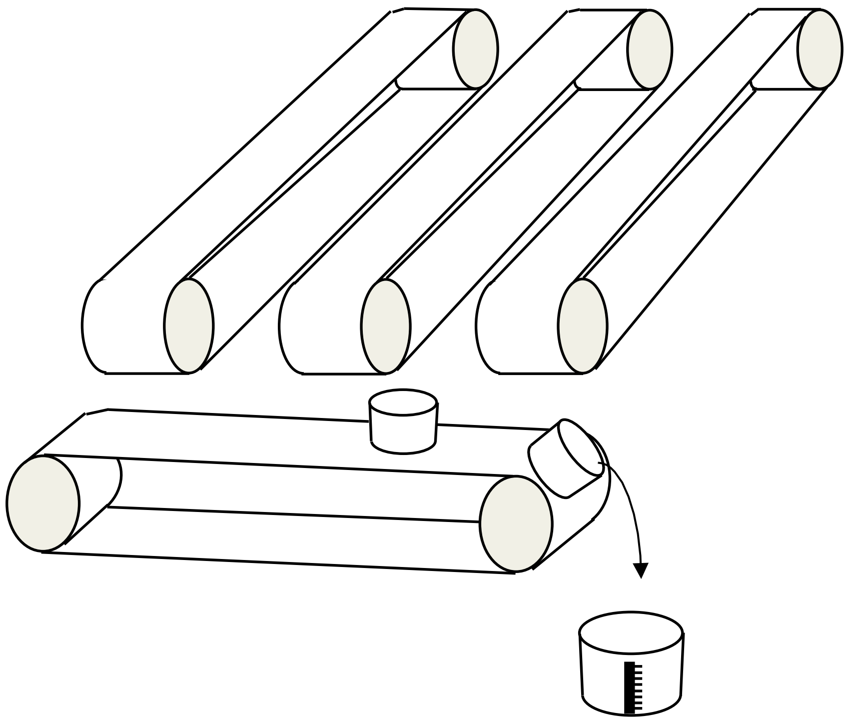

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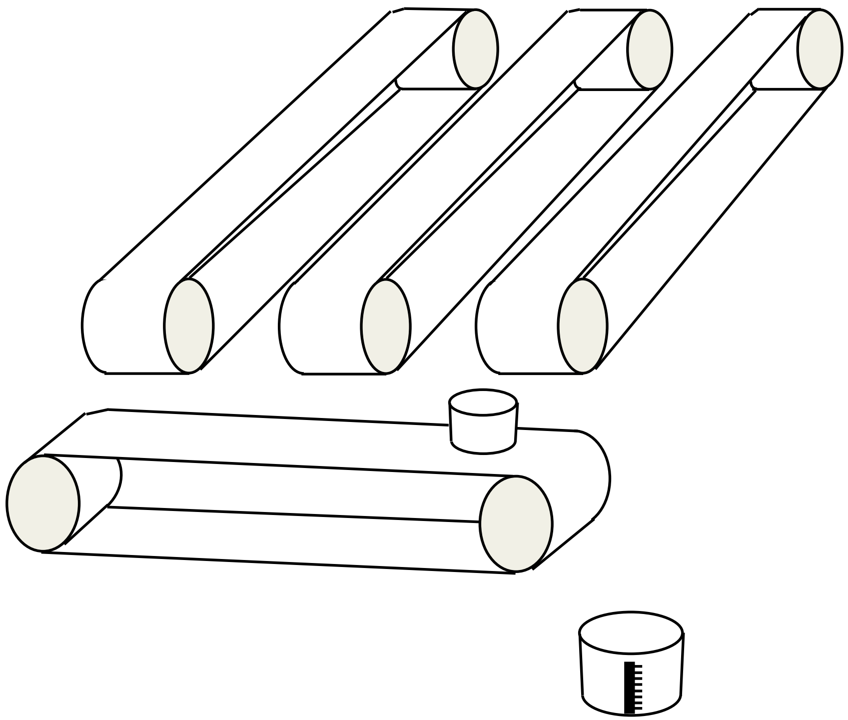

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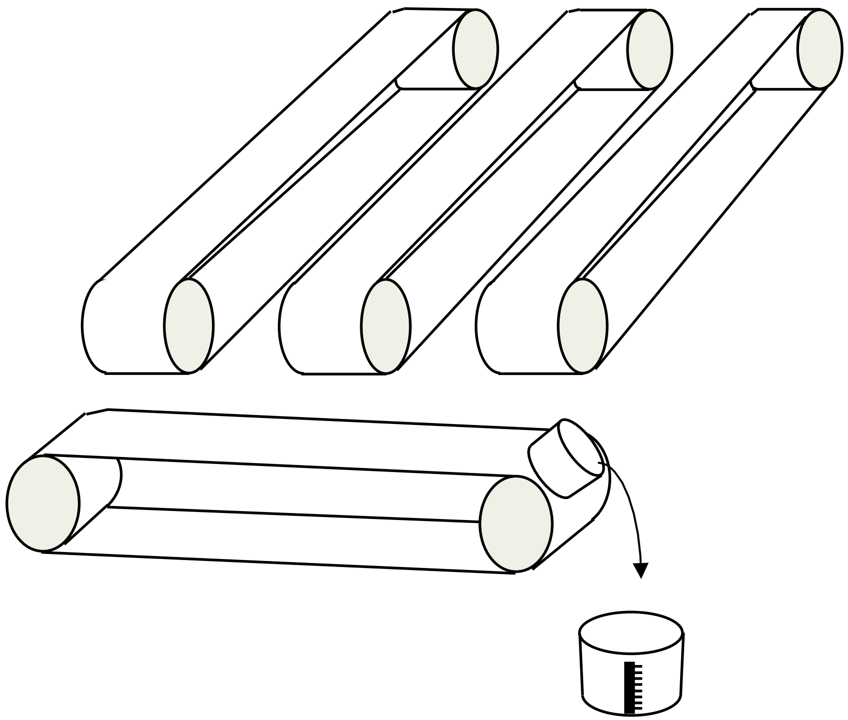
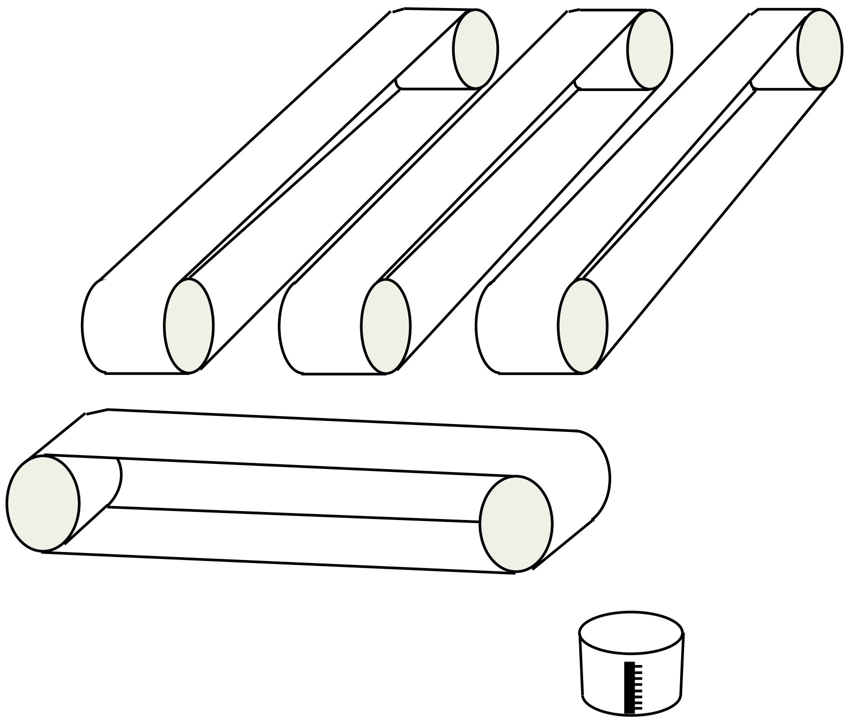


Courtesy of S. Tulloch

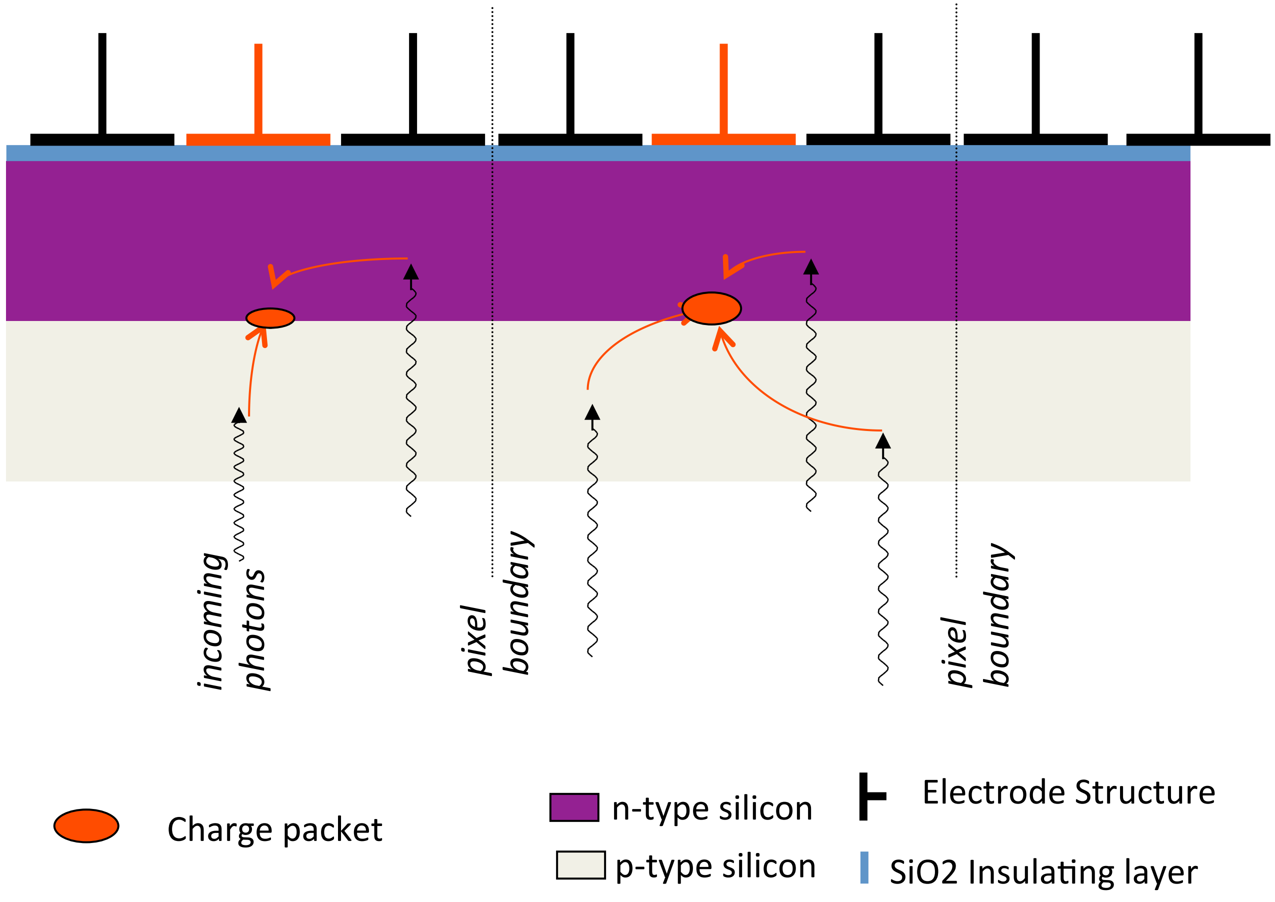
Eventually all the buckets have been measured, the CCD has been read out.



Courtesy of S. Tulloch

Charge Collection in a CCD.

Photons entering the CCD create electron-hole pairs. The electrons are then attracted towards the most positive potential in the device where they create 'charge packets'. Each packet corresponds to one pixel

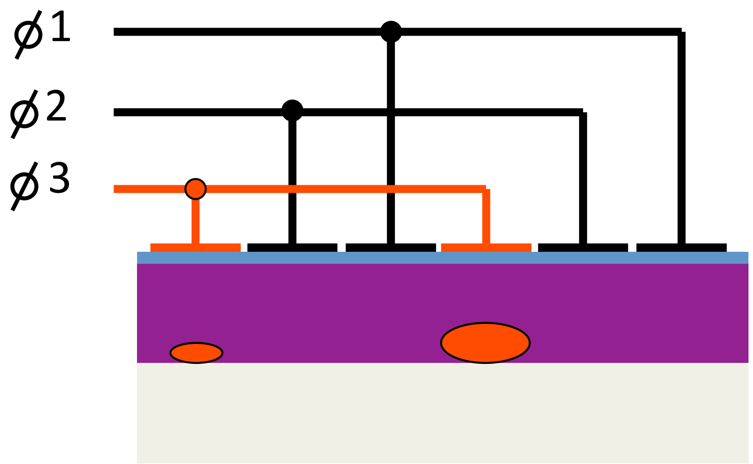


Courtesy of S. Tulloch

Charge Transfer in a CCD 1.

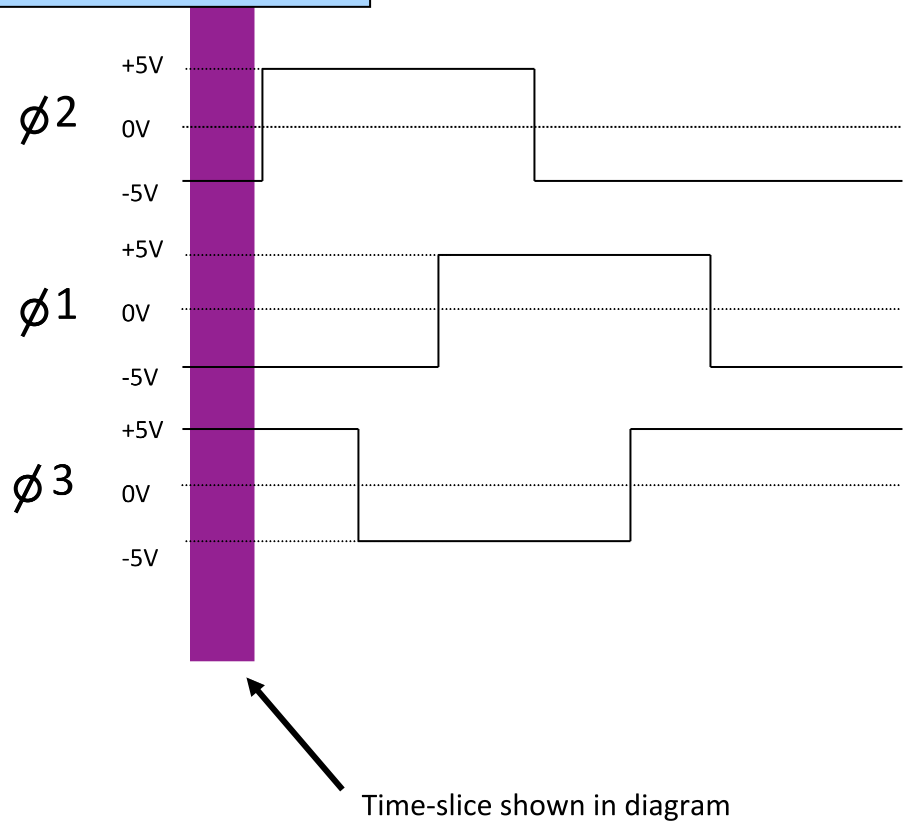
In the following few slides, the implementation of the 'conveyor belts' as actual electronic structures is explained.

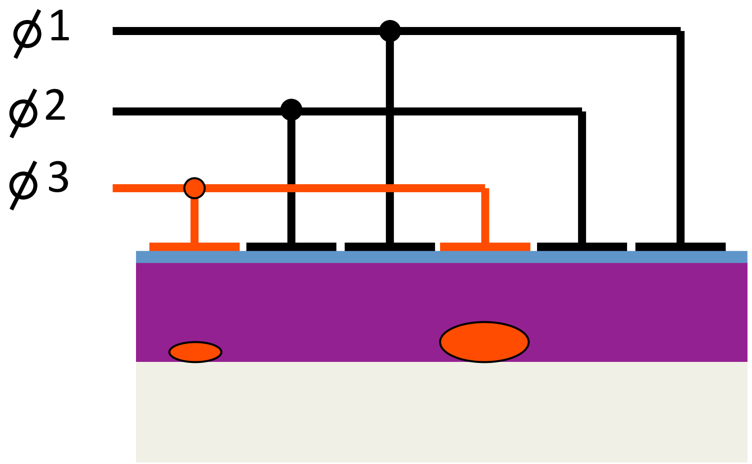
The charge is moved along these conveyor belts by modulating the voltages on the electrodes positioned on the surface of the CCD. In the following illustrations, electrodes colour coded red are held at a positive potential, those coloured black are held at a negative potential.



Courtesy of S. Tulloch

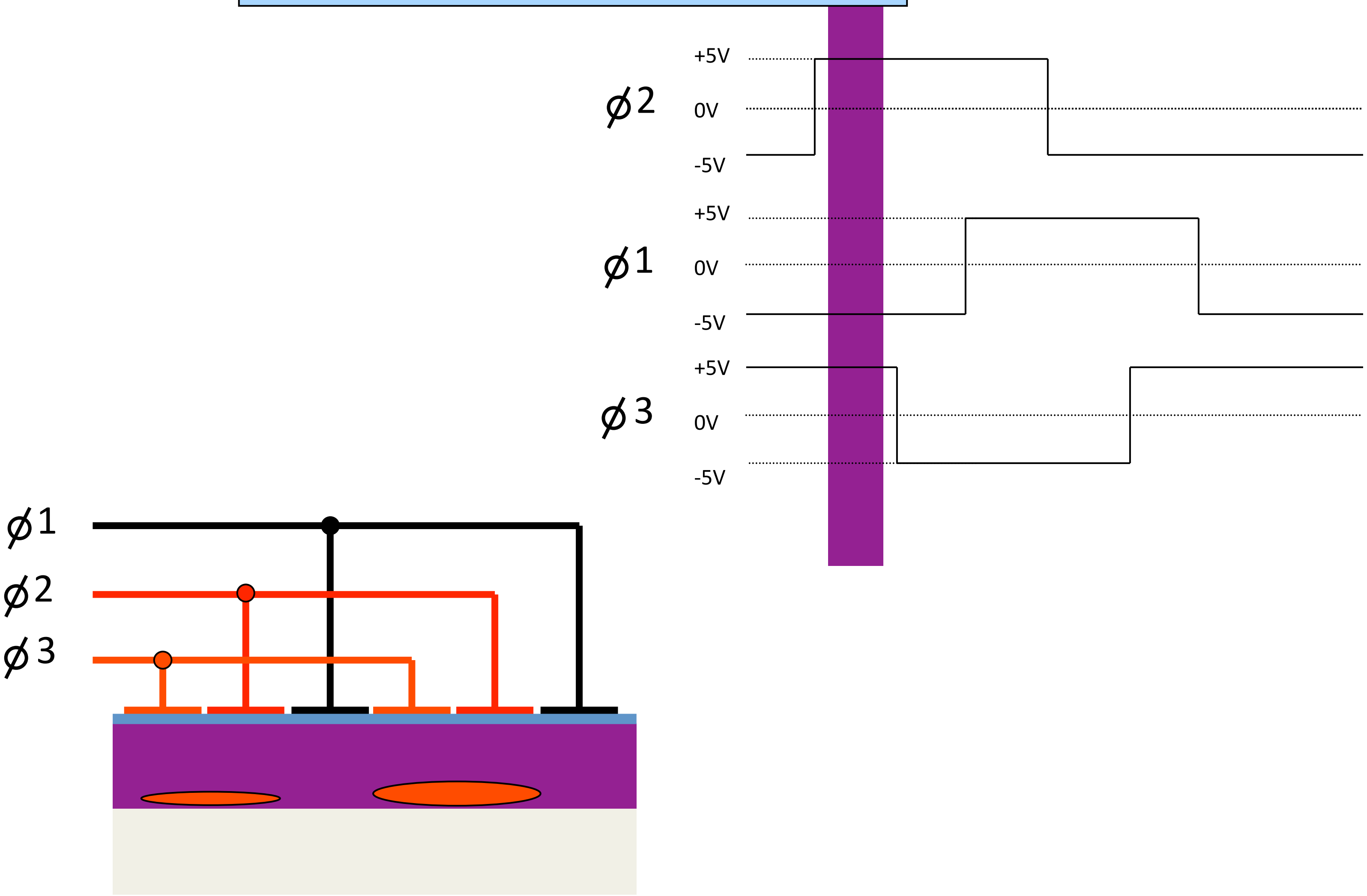
Charge Transfer in a CCD 2.





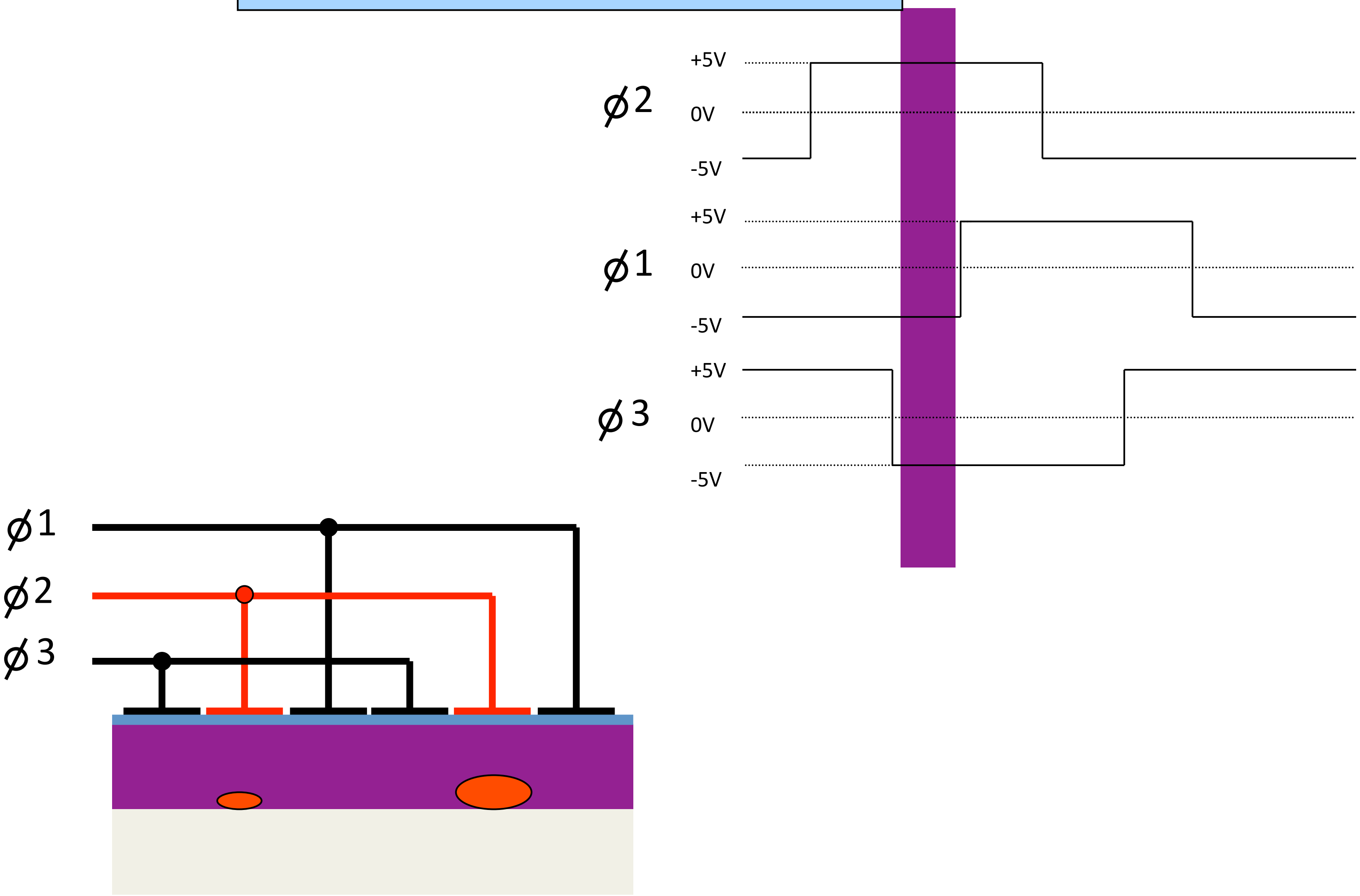
Courtesy of S. Tulloch

Charge Transfer in a CCD 3.



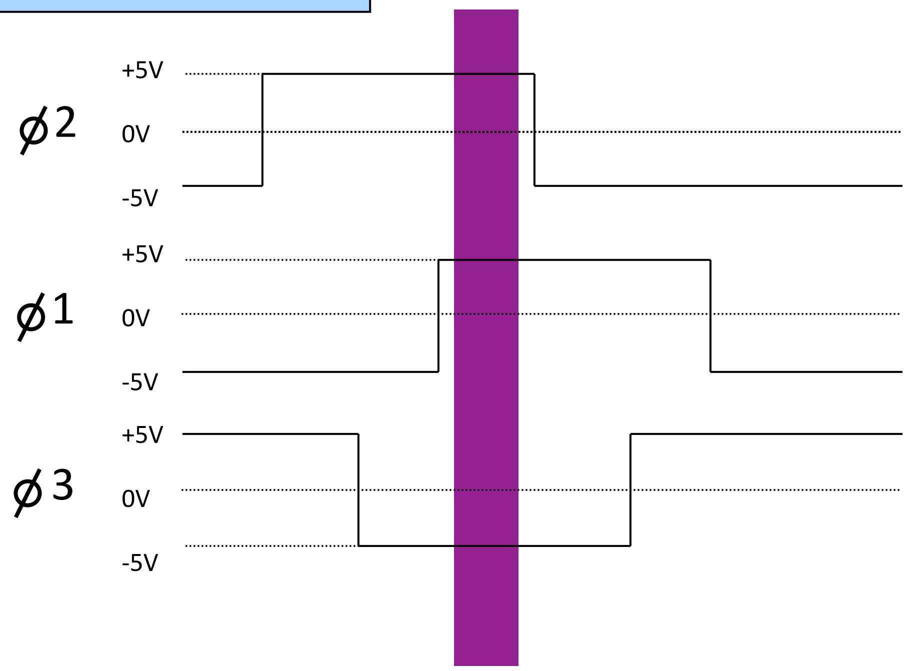
Courtesy of S. Tulloch

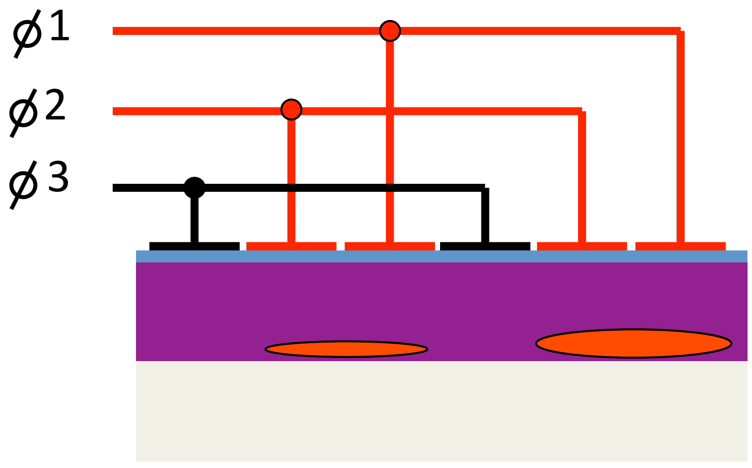
Charge Transfer in a CCD 4.



Courtesy of S. Tulloch

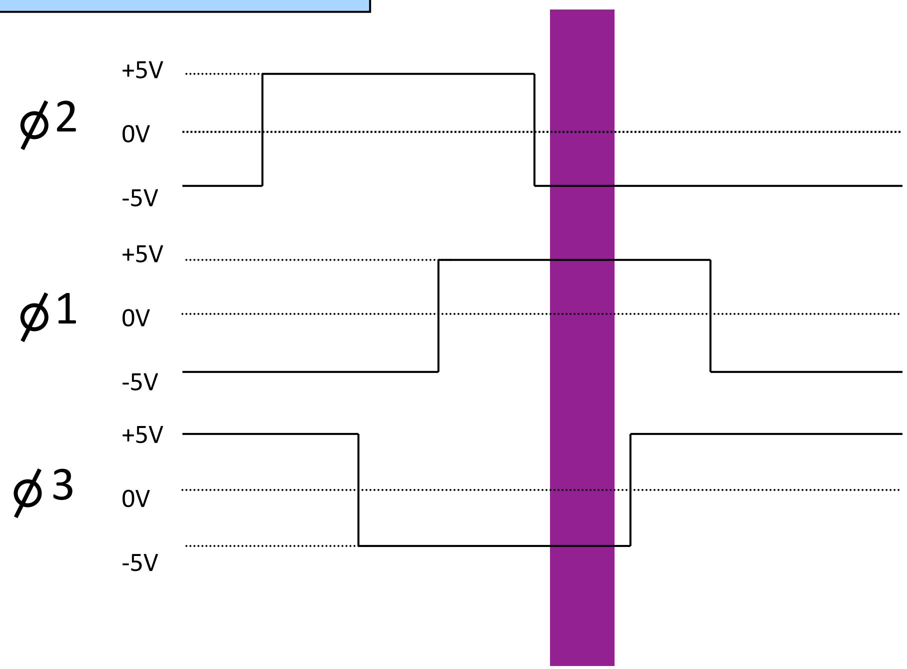
Charge Transfer in a CCD 5.

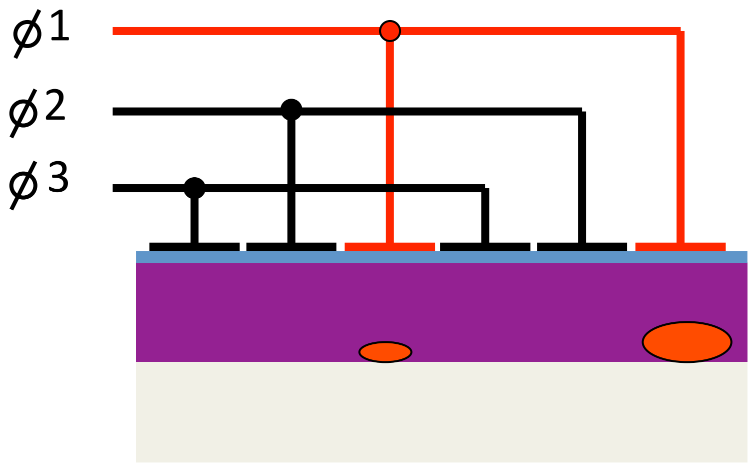




Courtesy of S. Tulloch

Charge Transfer in a CCD 6.

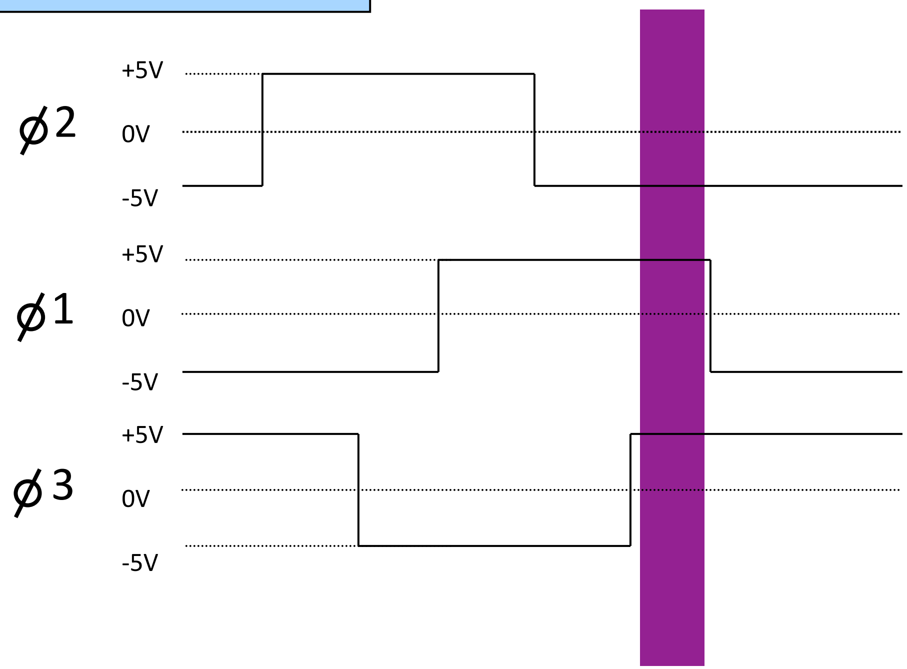


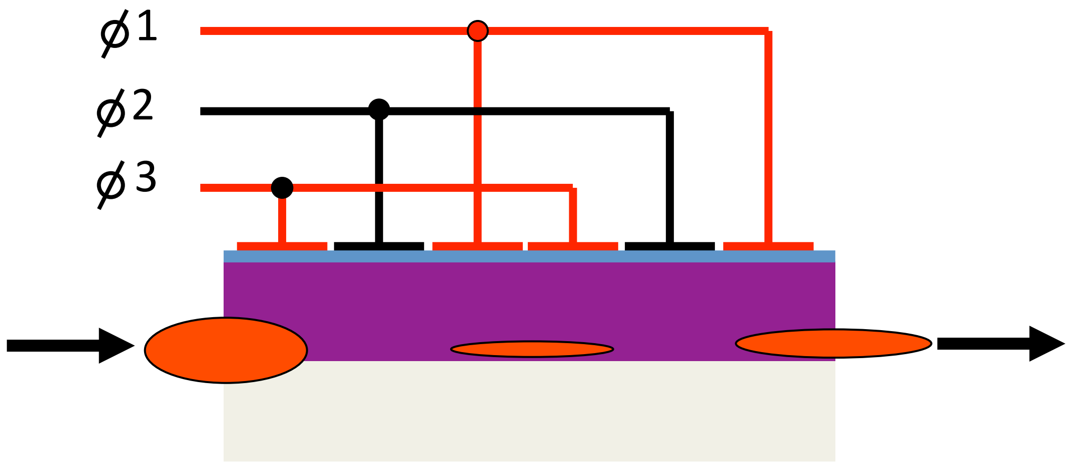


Courtesy of S. Tulloch

Charge Transfer in a CCD 7.

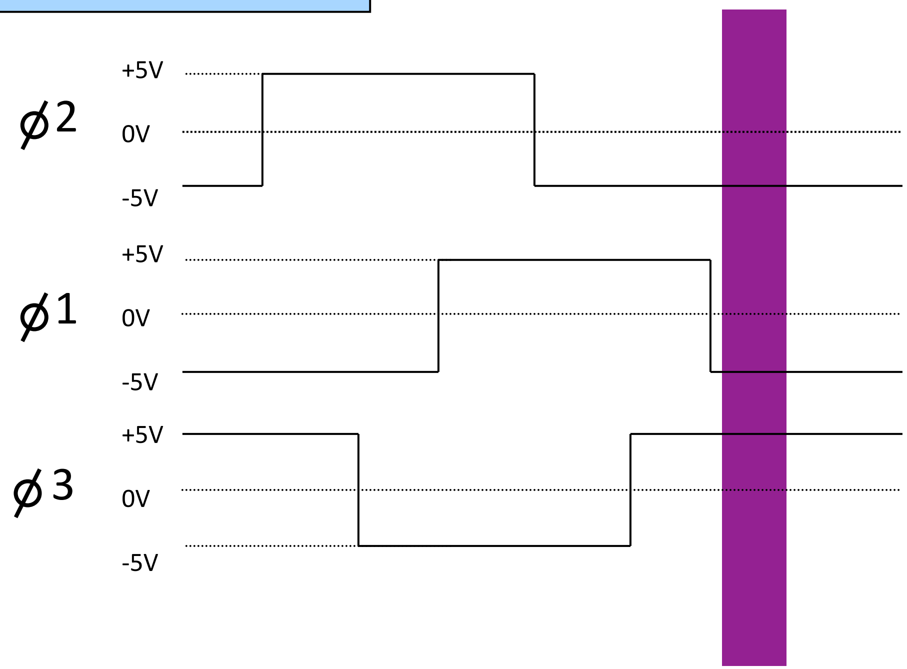
Charge packet from subsequent pixel enters from left as first pixel exits to the right.

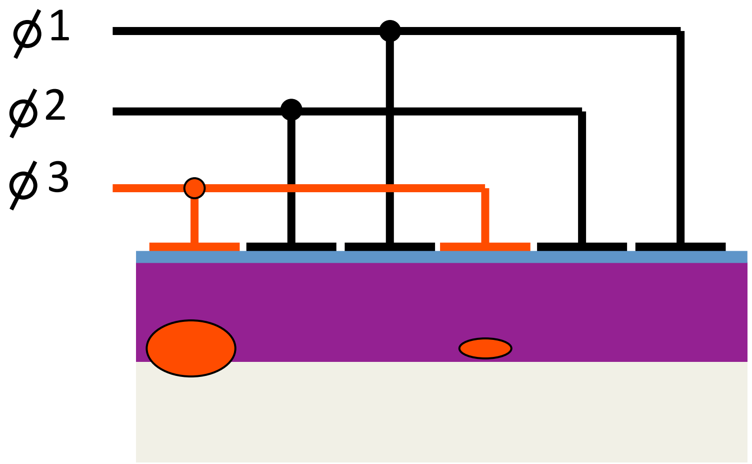




Courtesy of S. Tulloch

Charge Transfer in a CCD 8.





Courtesy of S. Tulloch