Dye Solar Cells

What is a dye?

dye - noun

a substance used to change the colour of something

Various different names and acroynms

Dye solar cell - DSC
Dye sensitized (sensitised) solar cell - DSSC
Dye sensitized nanocrystalline solar cell – DSNSC
Photoelectrochemical cell – PEC
Solid State DSC

So what is a dye?

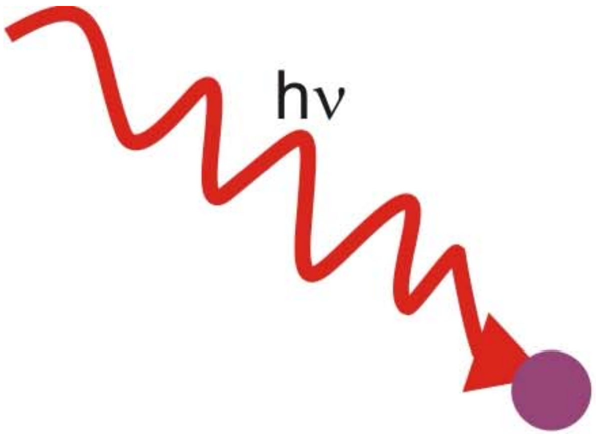
A dye has colour because it absorbes light.

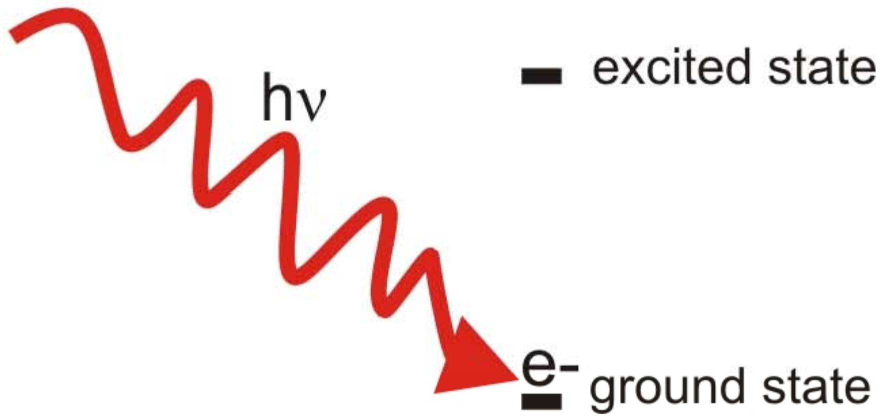
Light is made up of photons, and solar light is made up of a specific distributions of photons – as a reference we use a variant of the AM spectrum (AM1.5G)

dye has ability to absorb light

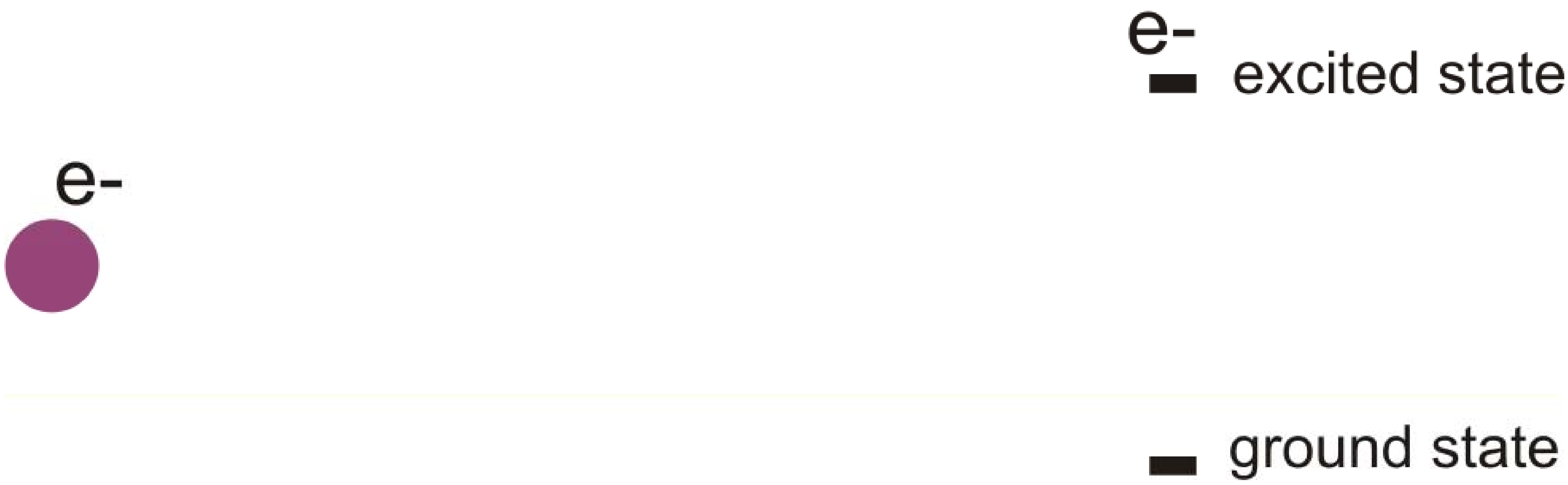
This is possible due to an electron energy transition

Photon is absorbed





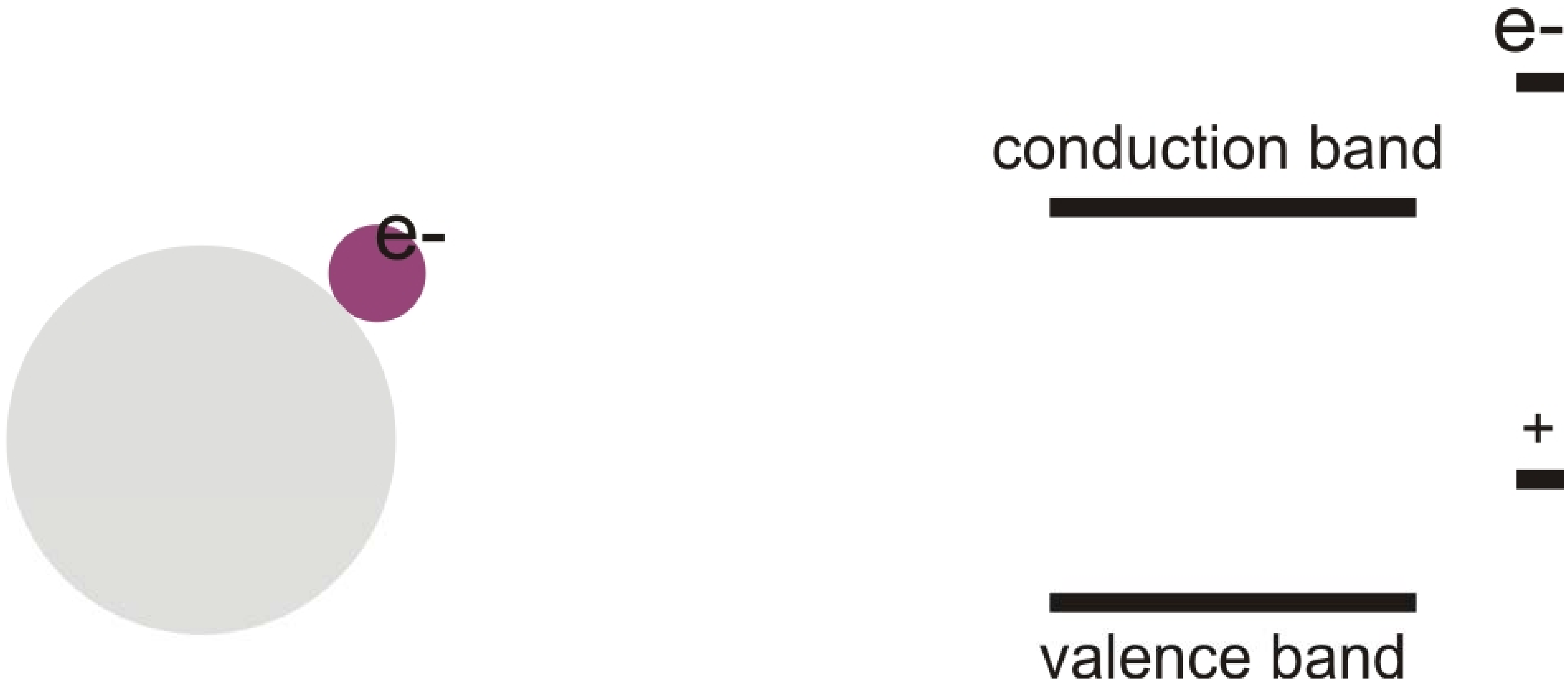
Causing electron to change state, from its ground state to an excited state



So what? What can we do with this?

We have to extract this electron

Dye is adsorbed onto a semiconductor

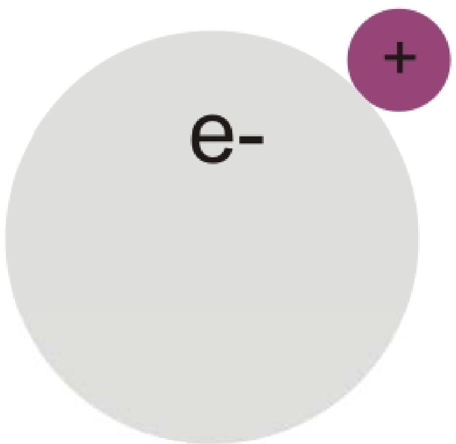


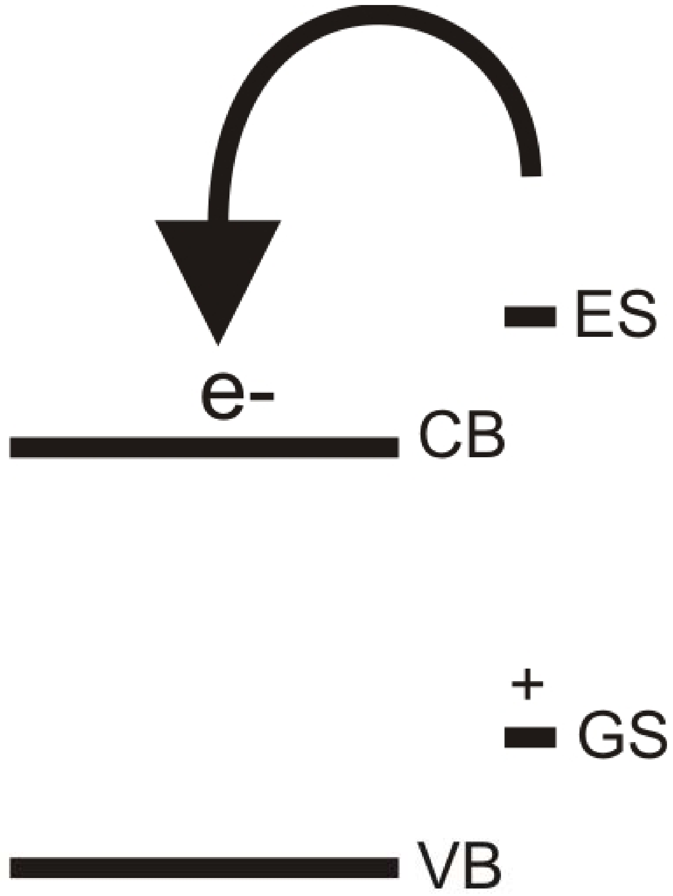
Some simple thermodynamics

Everything tends the lowest energy state possible – this is <u>entropy</u>

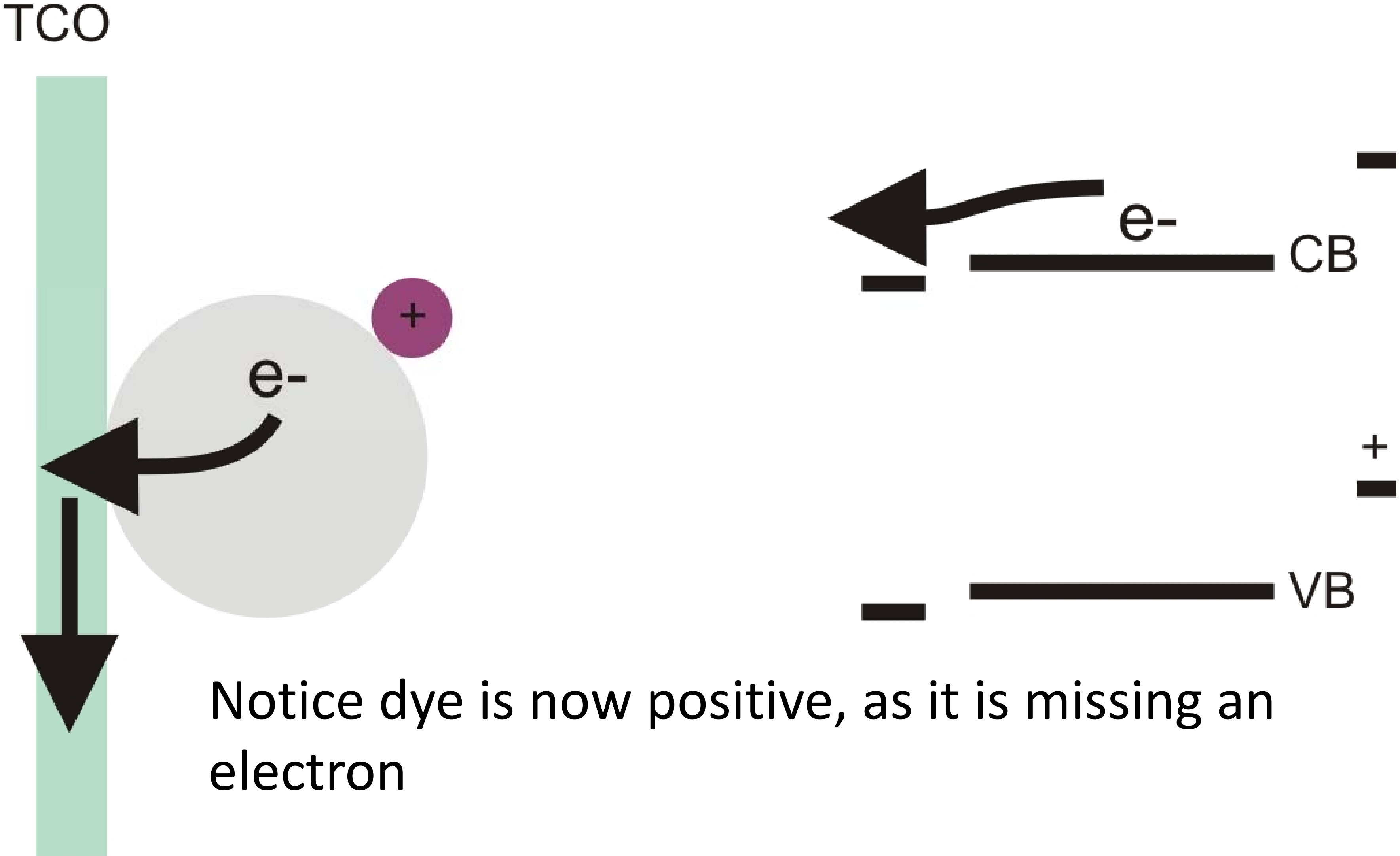
Electron sees a place where it can reduce its energy, moving into the conduction band of the semiconductor

This is called <u>charge separation</u>



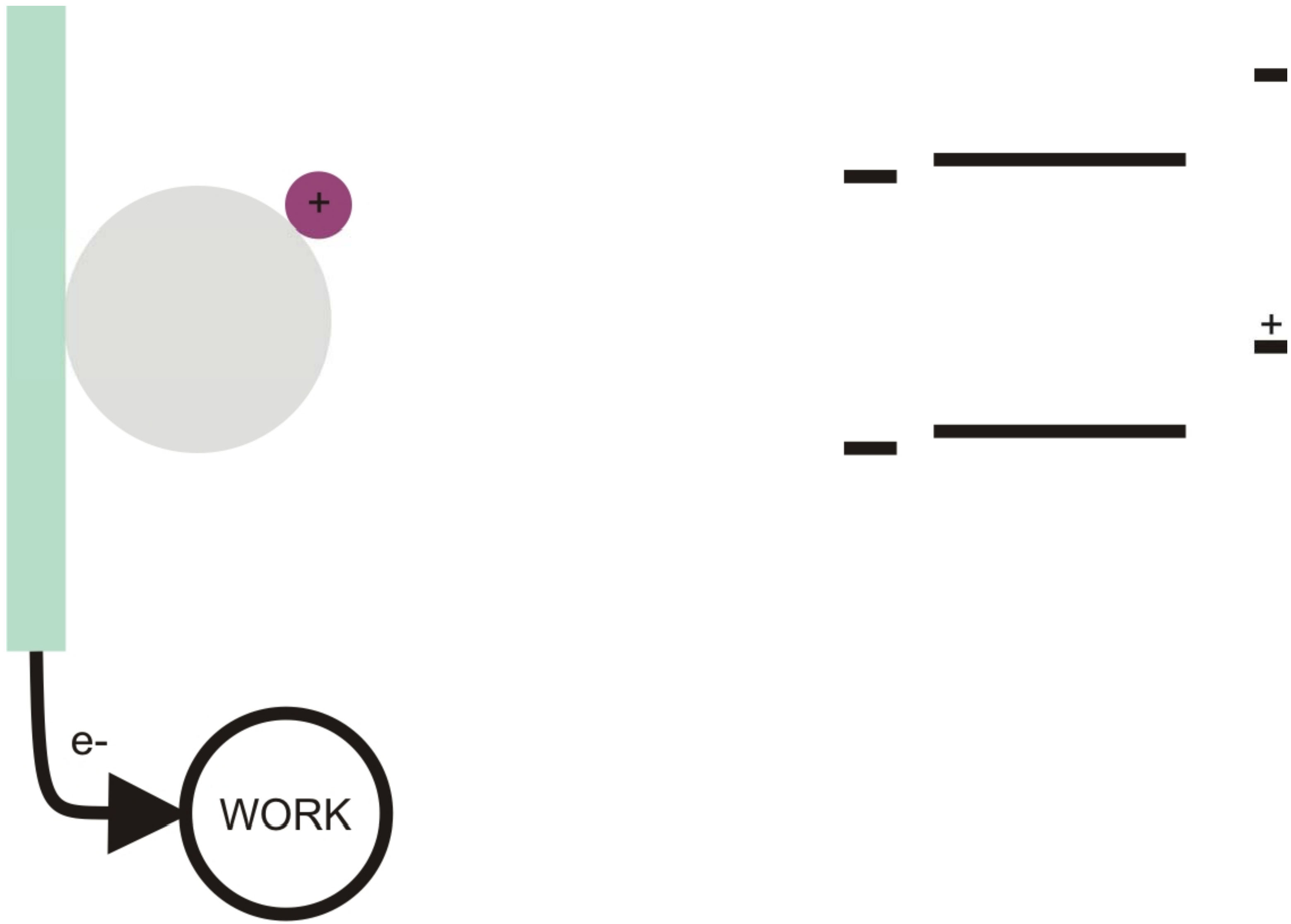


The electron is free to move in the conduction band and extracted by an external contact

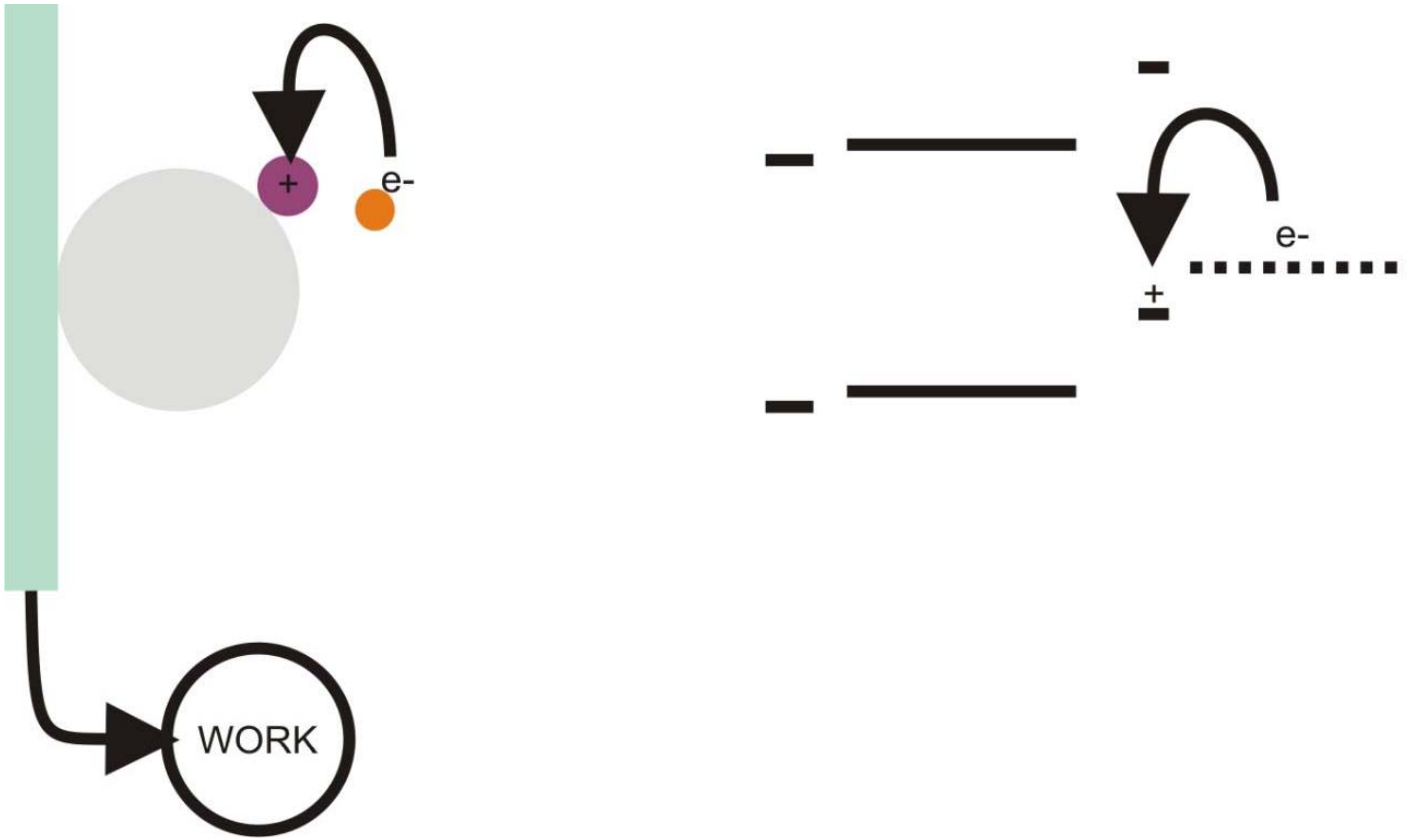


Notice dye is now positive, as it is missing an electron

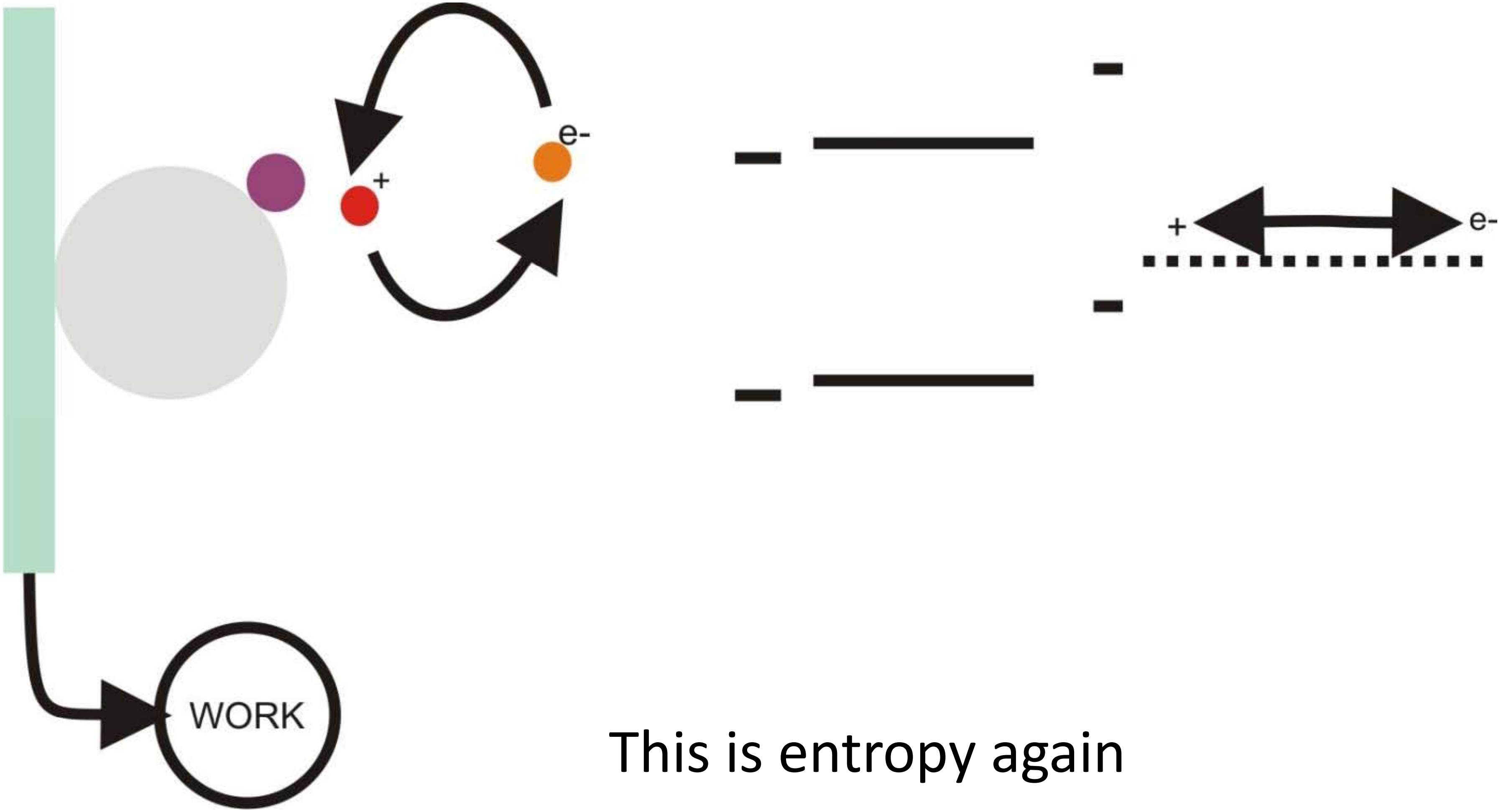
Once extracted, we can use the electron to do useful work



For the dye to be able to absorb another photon it requires another electron – the dye is regenerated by a reducing species – i.e. by an electron donator

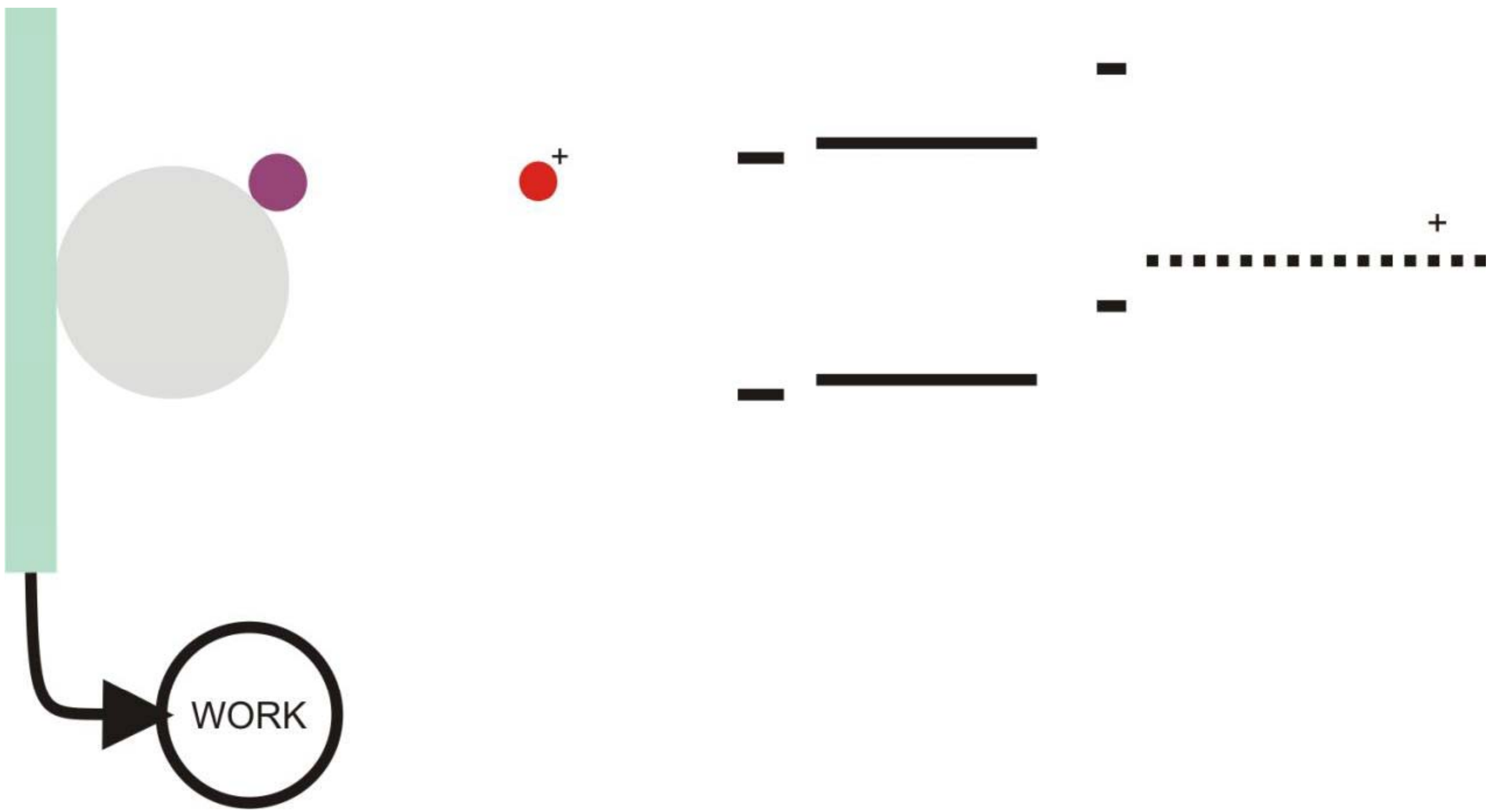


with continued regeneration of the dye molecules there is a build up of oxidised species – these will diffuse away

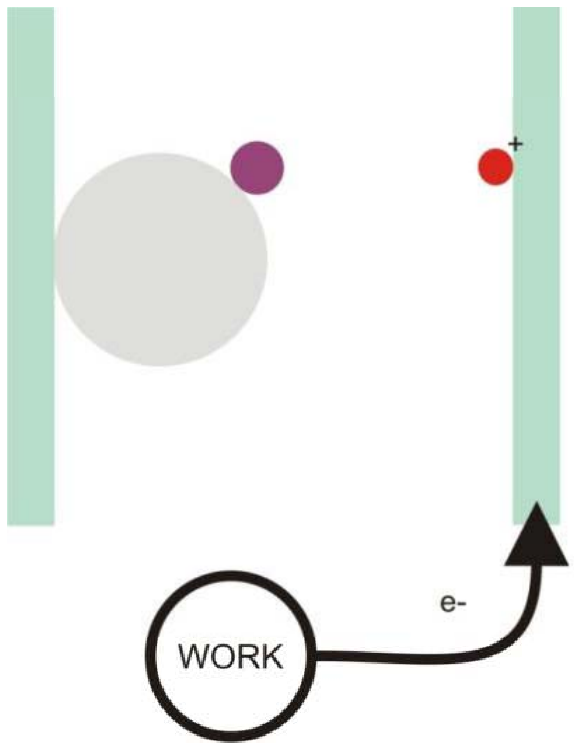


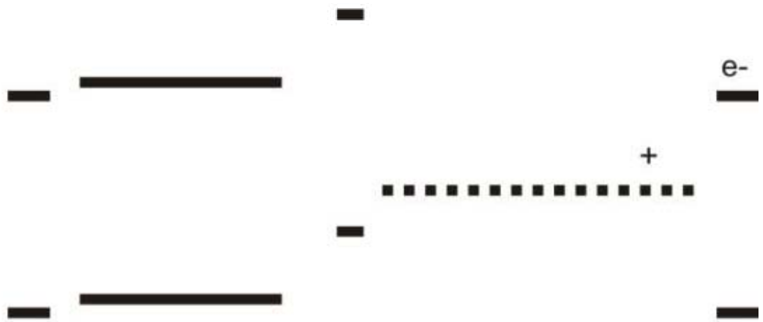
This is entropy again

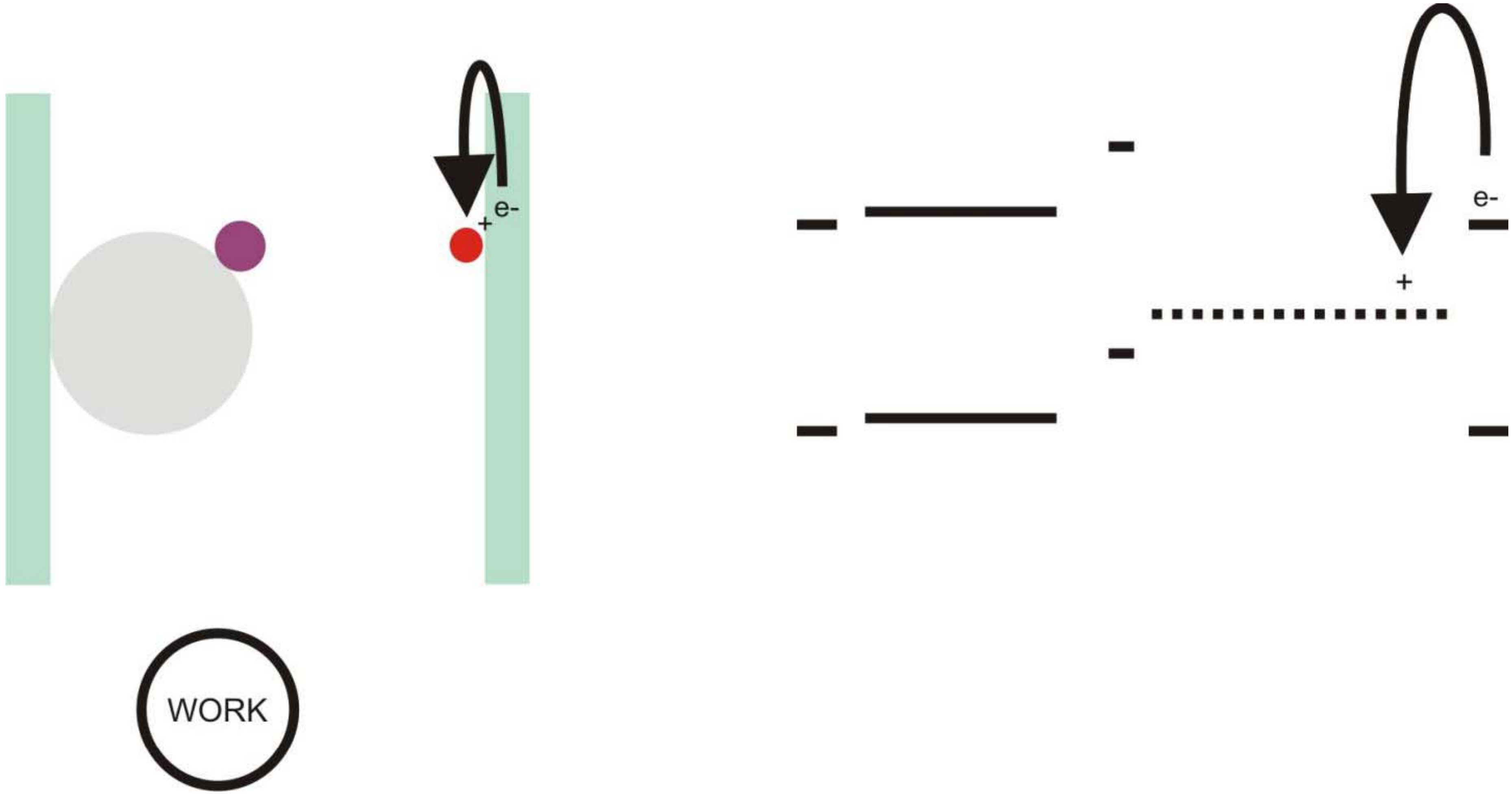
What do we do with the oxidised species?



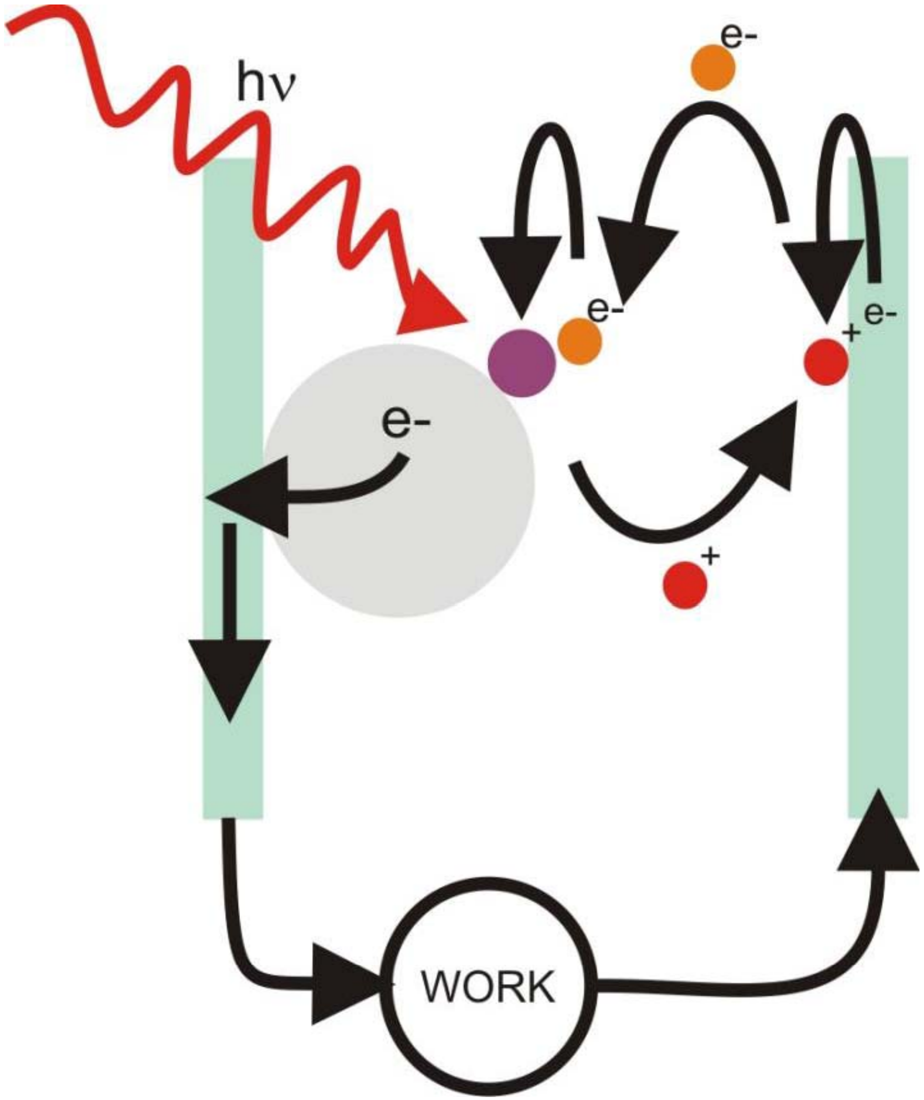
We have to close the circuit, by reducing the oxidised species







e-
+
WORK
e-
+


hν
e-
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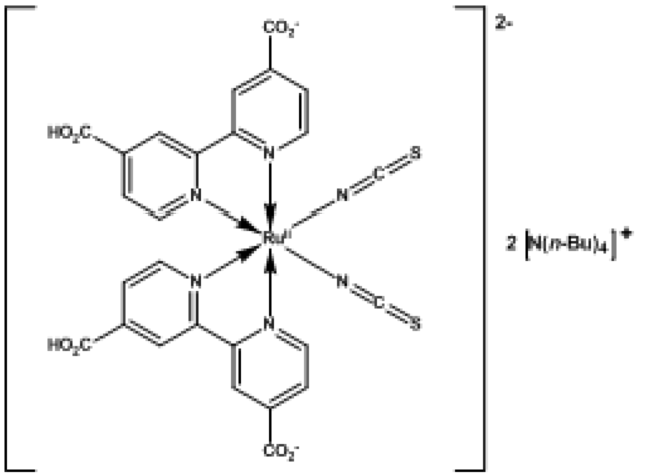
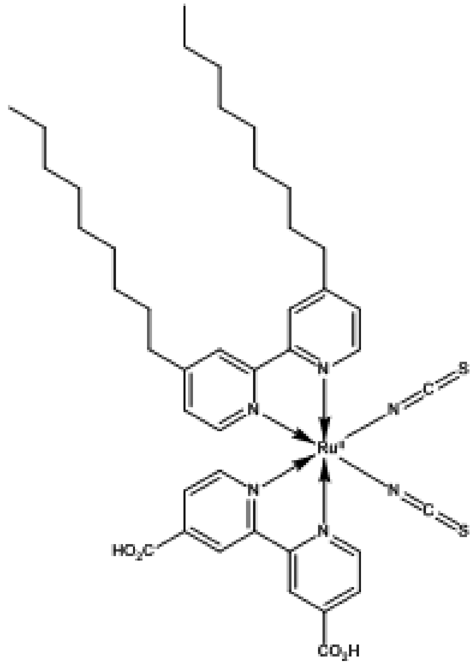
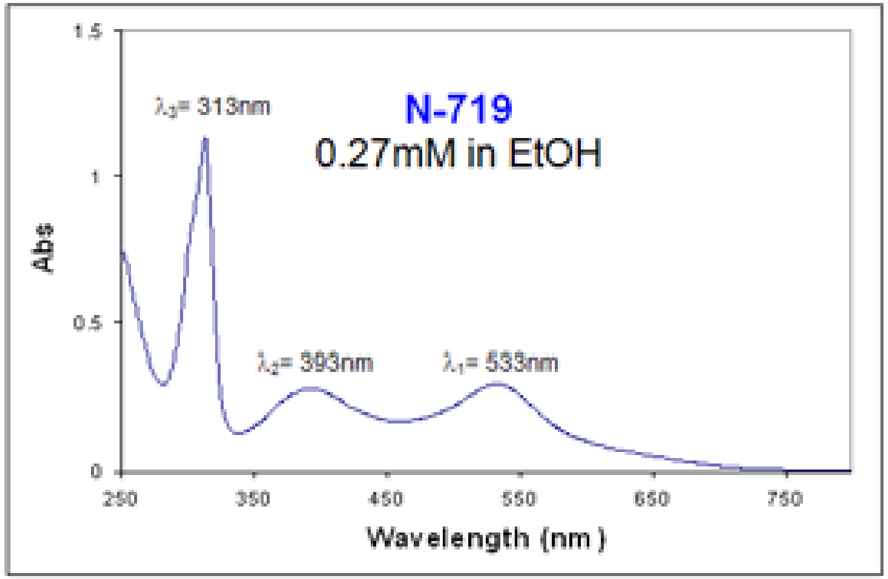
+
e-
+
WORK

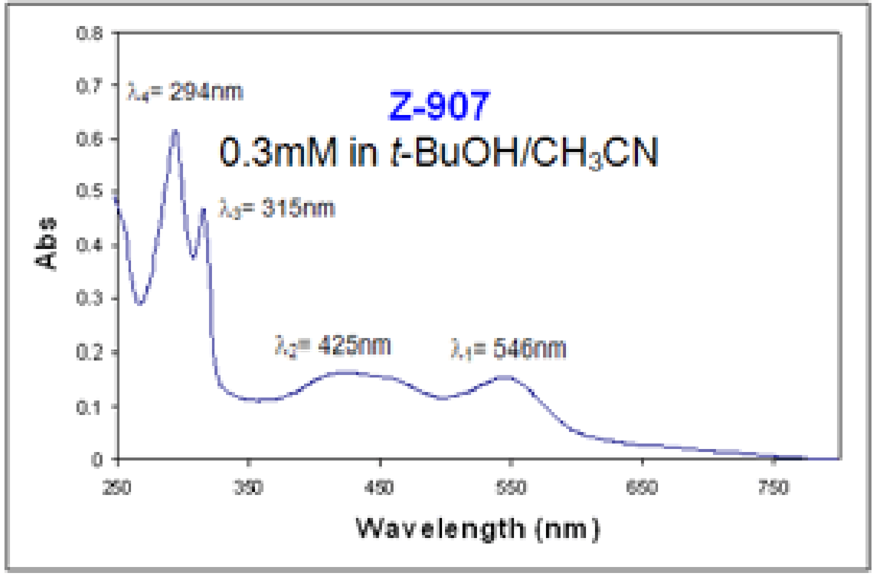
What are the materials?

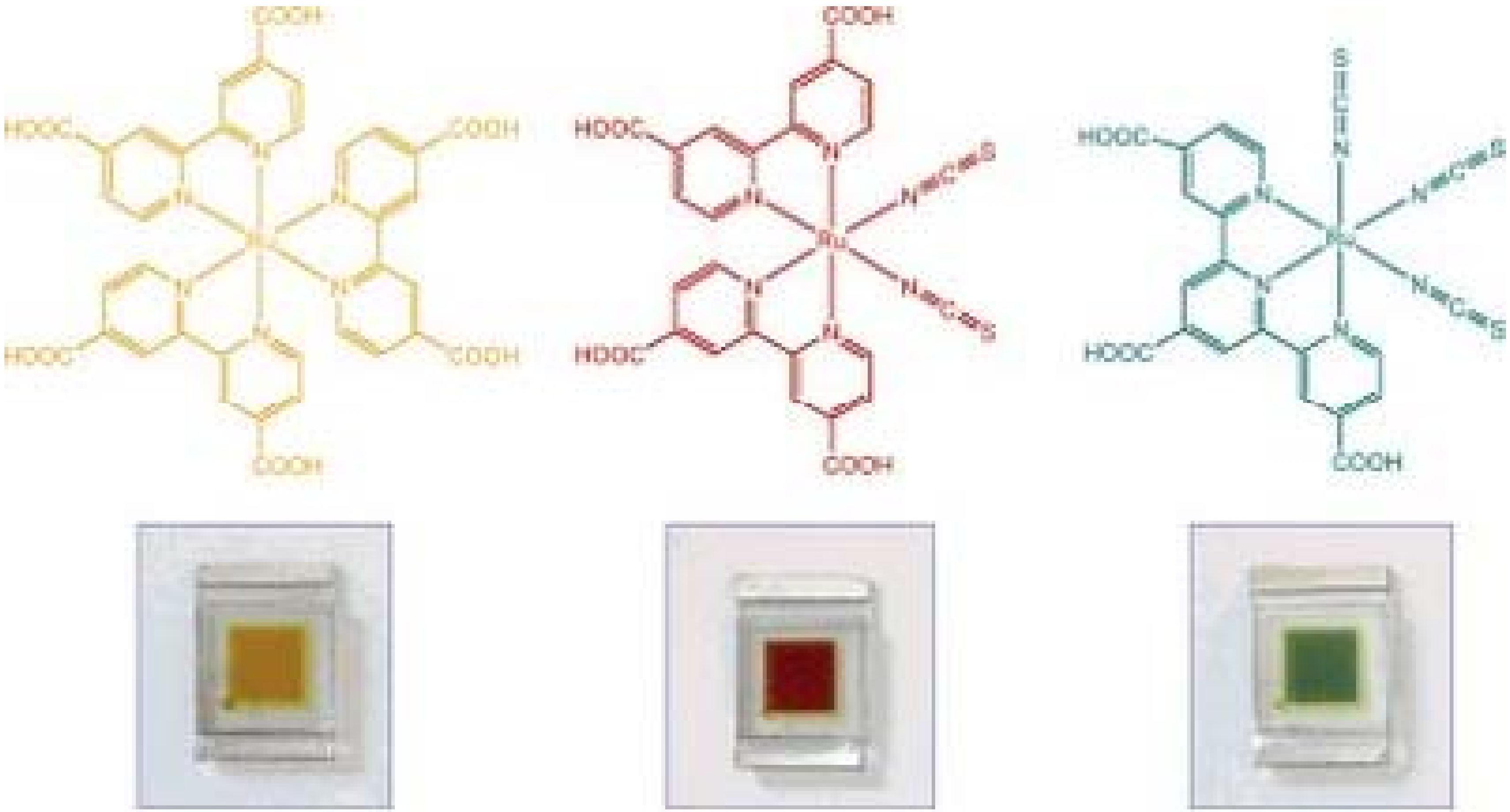
Dyes – metalorganic, or purely organic (i.e. no metals)






N-719
0.27mM in EtOH
λ3= 313nm
λ2= 393nm
λ1= 533nm
Abs
Wavelength (nm)
0
0.5
1
1.5
250
350
450
550
650
750

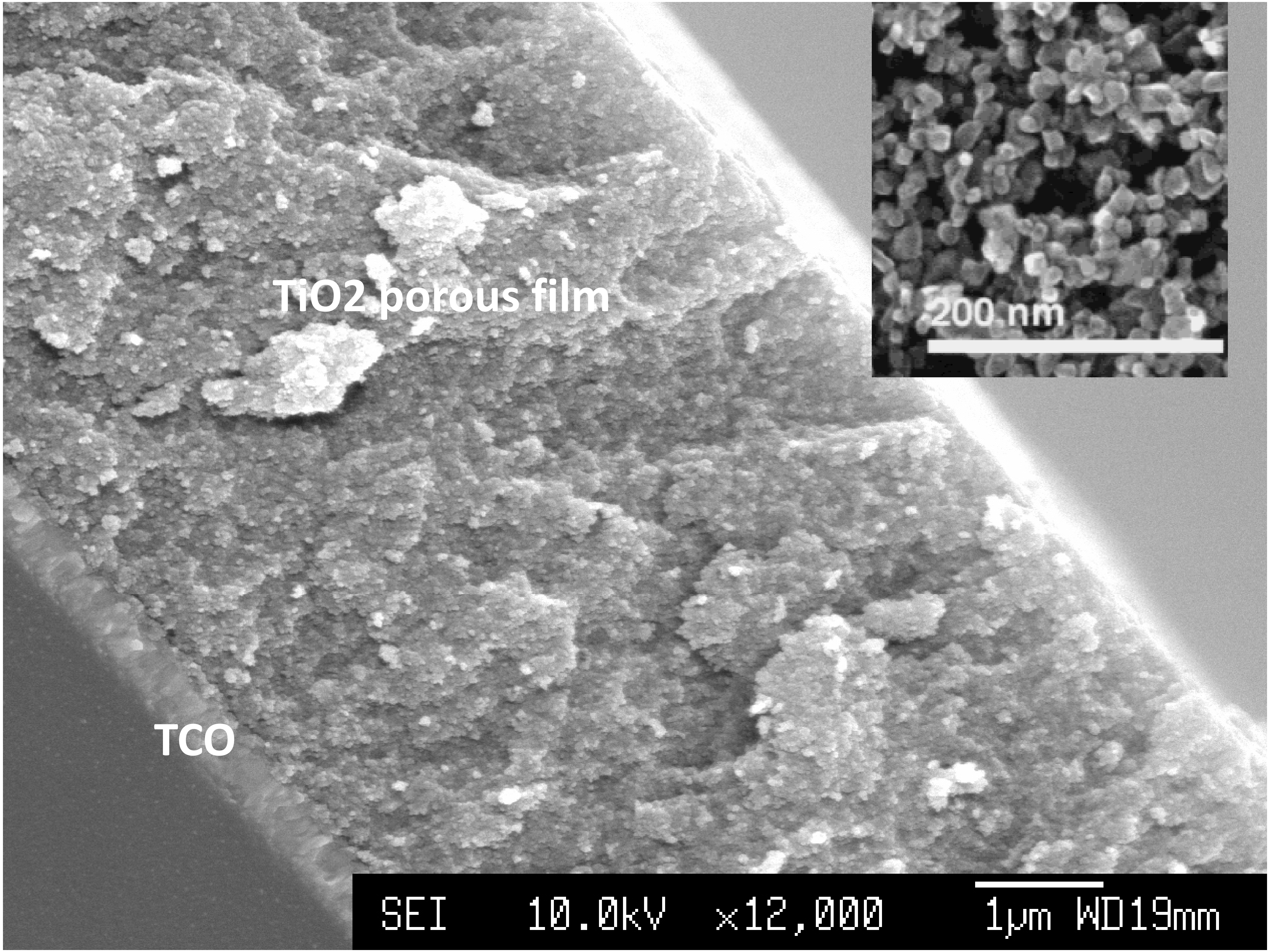

Z-907
0.3mM in t-BuOH/CH3CN
λ4= 294nm
λ3= 315nm
λ2= 425nm
λ1= 546nm
Abs
Wavelength (nm)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
250
350
450
550
650
750



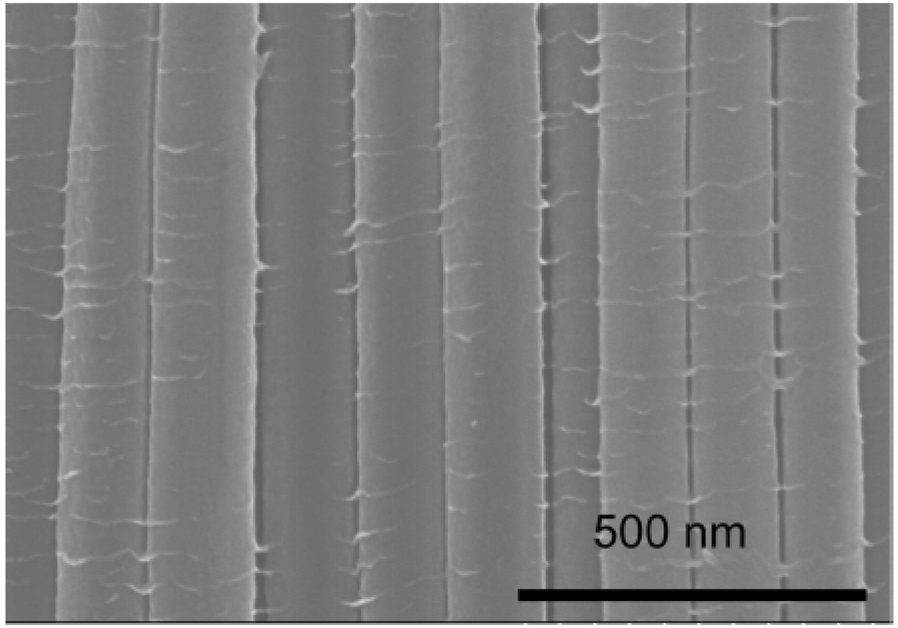
To what is the dye attached to?

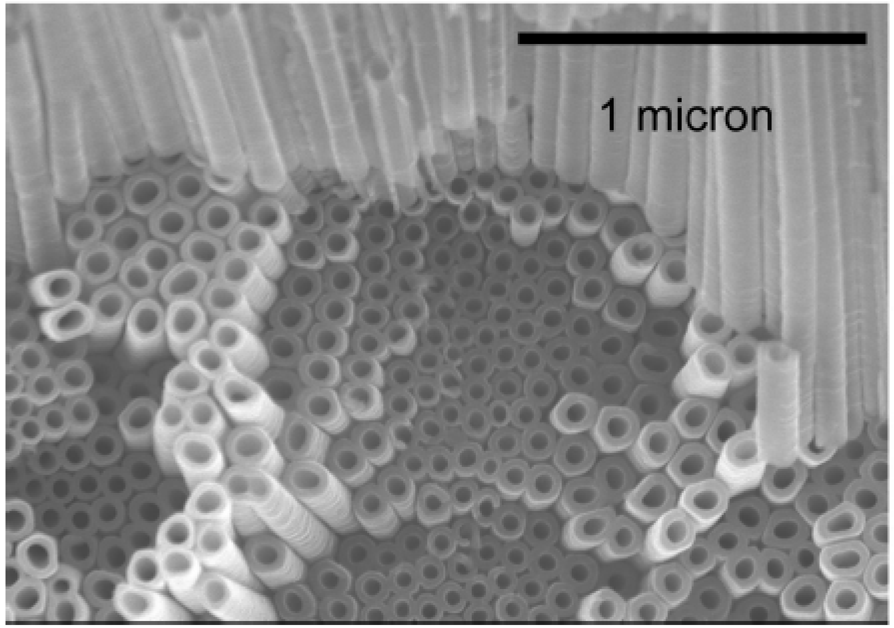
a transparent semiconductor, TiO_2, ZnO, SnO

Band gap is c.a. 3eV – transparent to visible light

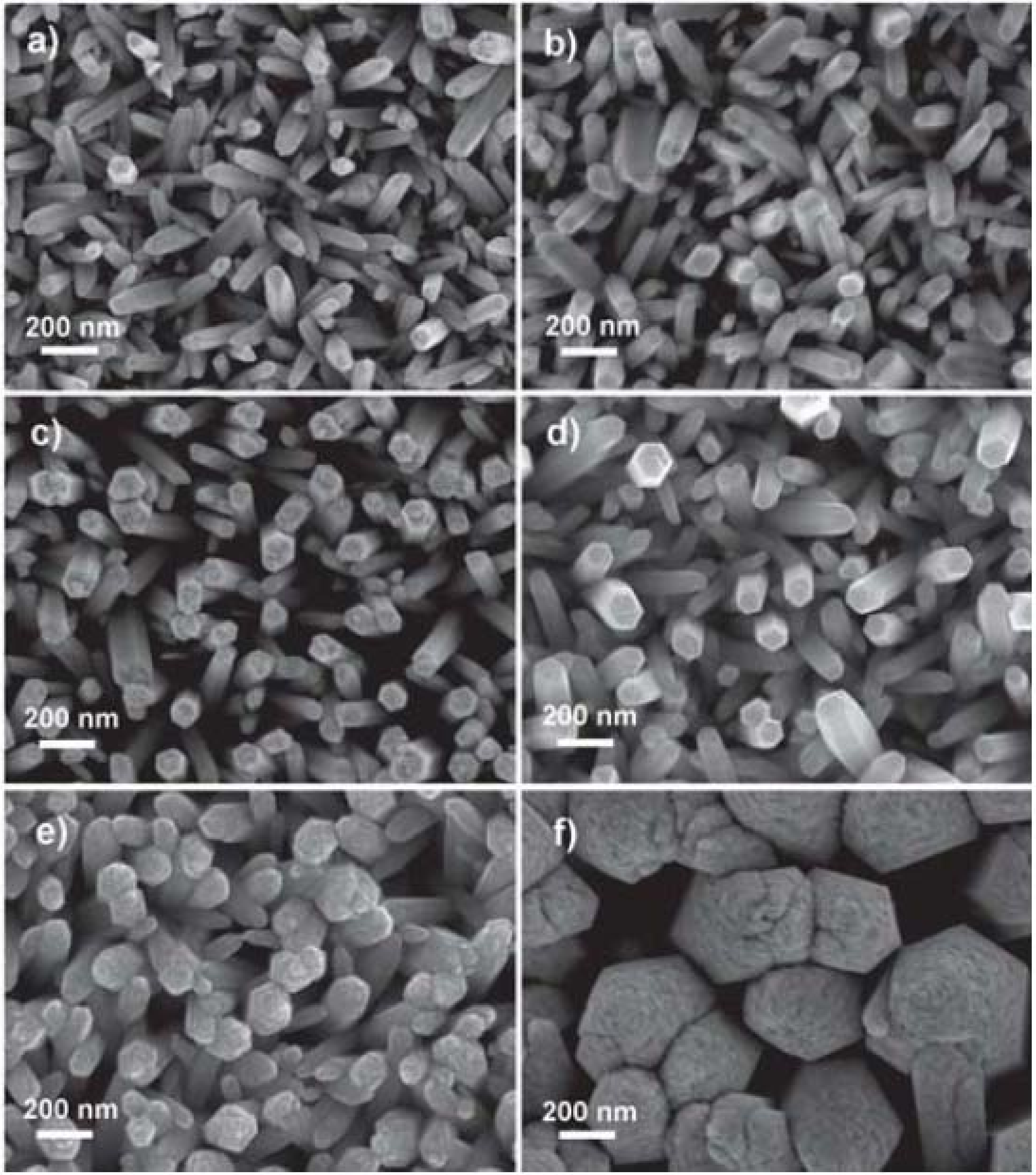

TiO2 porous film
200 nm
TCO
SEI 10.0kV ×12,000 1μm WD19mm

TiO2
Also possible
to make
nanotubes



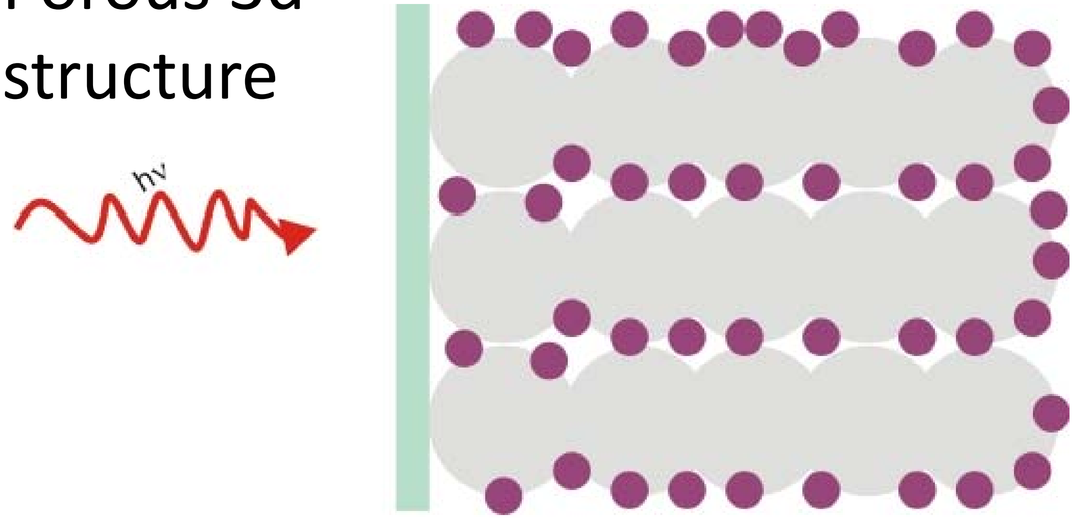


ZnO
It is easy to grow nanorod like structures



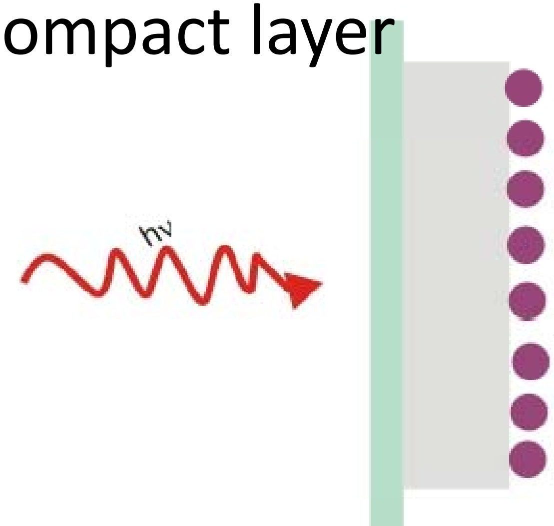
The dye is attached to a porous electrode so as to increase the internal surface area, and thus increase the chance of a photon being absorbed.

Porous 3d structure



With a porous 3d structure the total internal surface area can be increased easily by a factor of 1000x

Compact layer



A compact layer can only form a 2d structure (sheet) to adsorb the dye. Internal area is the same as the geometrical cross section

What is the oxide layer attached to?

Transparent conducting oxide – is a metal like contact but is transparent – materials that can do this well are highly doped oxides

- fluorine doped tin oxide (FTO)
- Indium/Tin Oxide

Not very interesting except for one aspect

ITO can be deposited at low temperatures, making it viable to deposit on transparent substrates other than glass, such at PET (polyethylene terephthalate) a cheep transparent plastic substrate

How is the "dye" regenerated?

Many ways, but can be classified into three groups:

- REDOX species electrolyte – liquid, gel/solid, ionic liquid
- solid state p-type semiconductor
- p-type organic hole conductor

E.g. Iodide/tri-Iodide redox system (I^-/I_3^-)

If you dissolve I_2 in a solvent, e.g. ethanol you obtain the ions in solution I^- and I_3^-

$S^0+h\nu \rightarrow S^+$	dye (S) is oxidised, i.e. becomes more positive by loss of an electron
$S^+ + 1.5I^- \rightarrow S^0+3I^-$	dye is reduced, i.e. becomes less negative by gaining a negatively charged electron

The half reactions are:

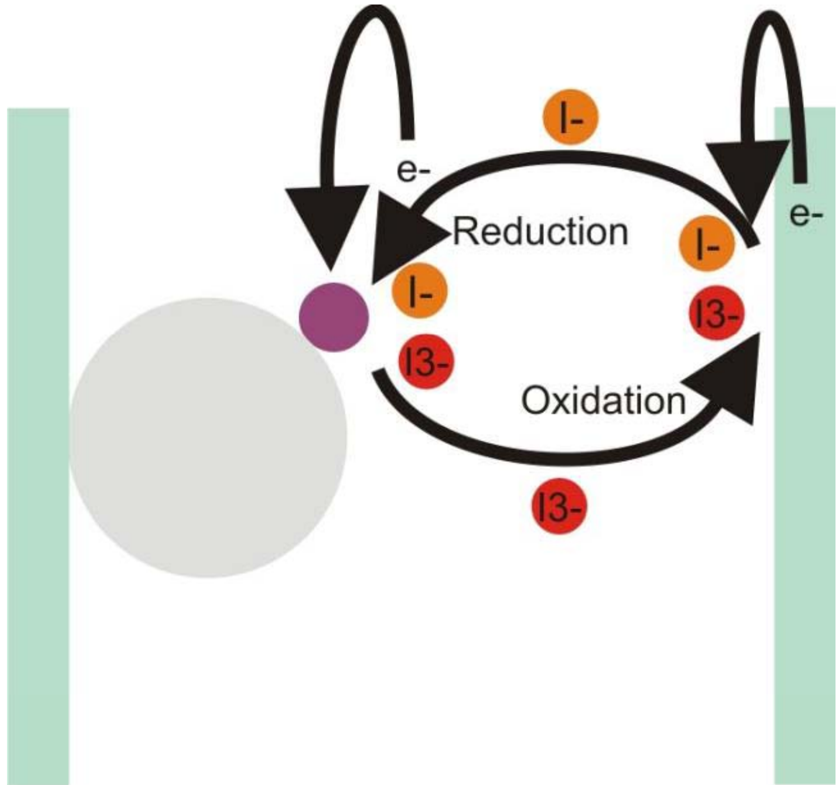
$2S^+ +2\ e^- \rightarrow 2S^0$ $\qquad$ $3I^- +2e- \rightarrow I3^-$

Bring them together:

$2S^+ +2\ e^- \rightarrow 2S^0$ $\qquad$ $3I^- -2e- \rightarrow I3^-$

$2S^+ +2\ e^- + 3I^- -2e- \rightarrow 2S^0 + I3^-$

$2S^+ + 3I^- \rightarrow 2S^0 + I3^-$

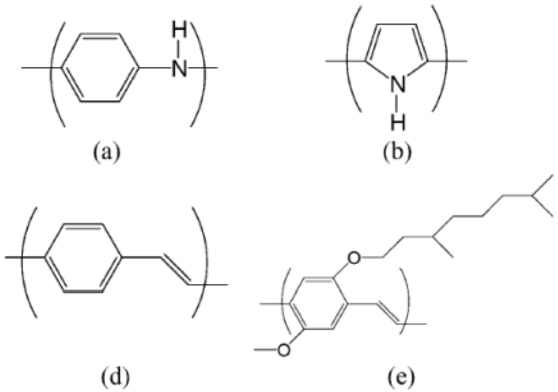


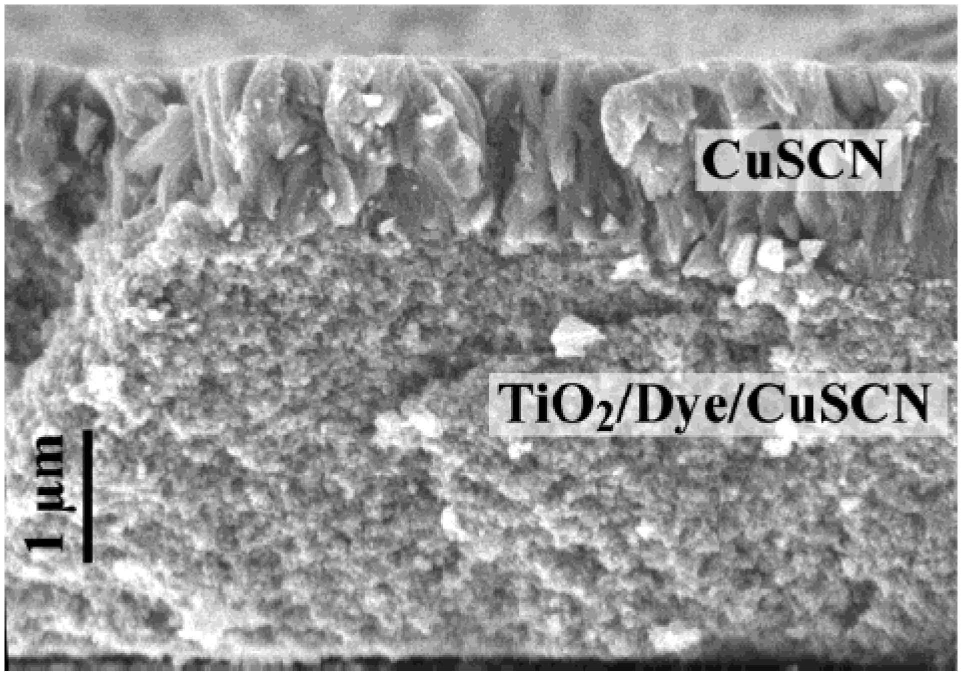
The ionic species are either dissolved in an organic solvent, or in an ionic liquid state (imagine salt, being melted)

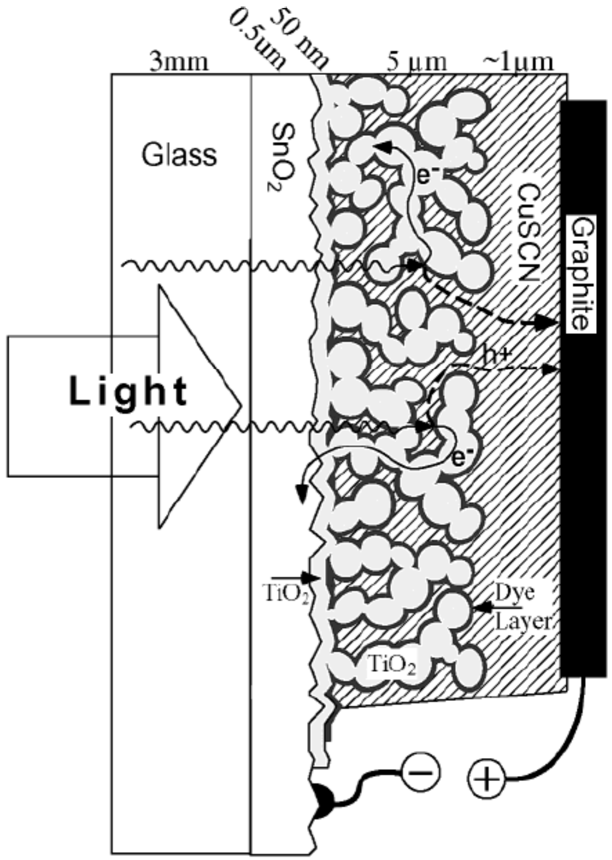
Solid state DSCs can come in two flavours

p-type organic hole conductors

- There is a great variaty of p-type hole conductors

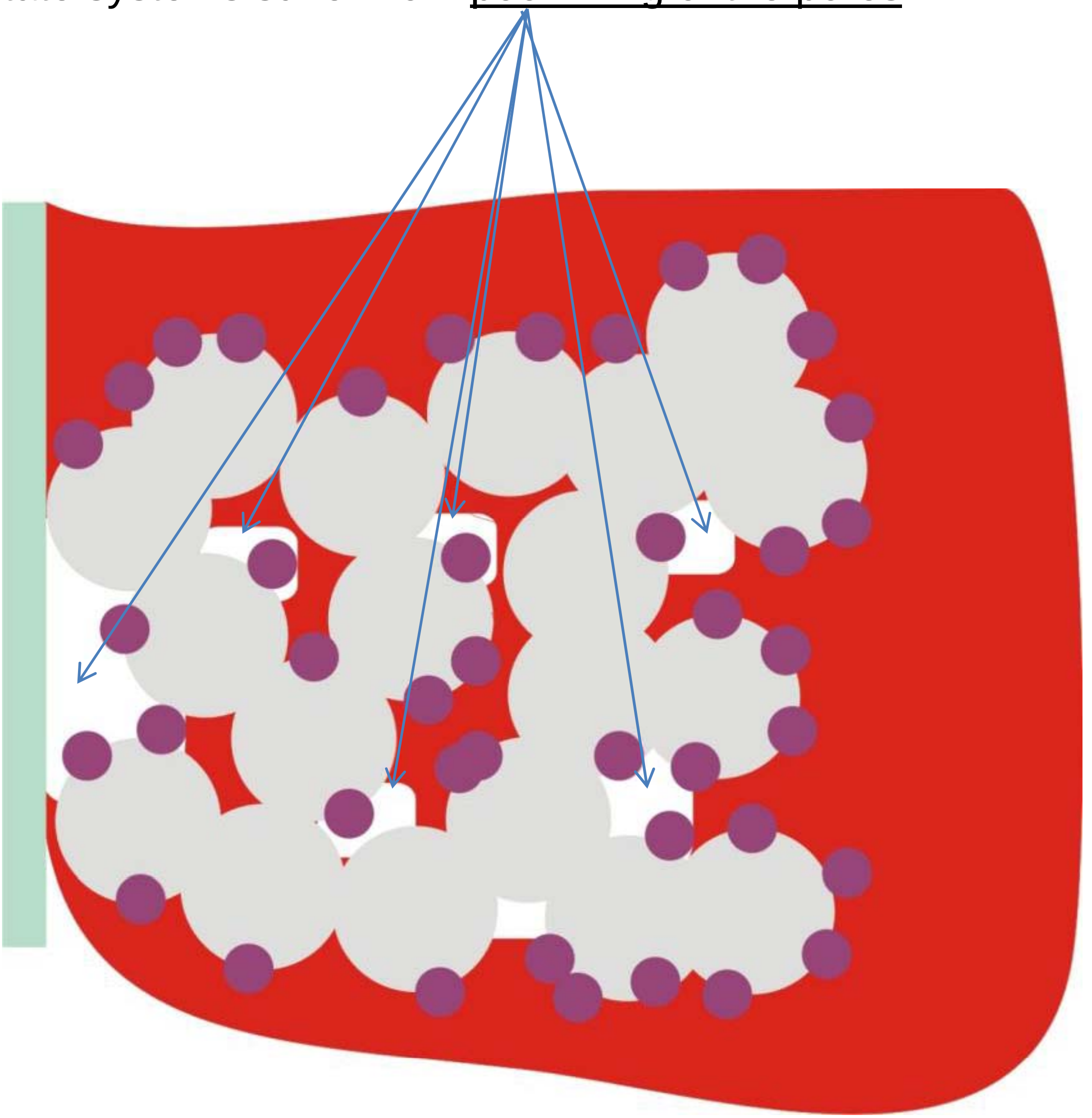






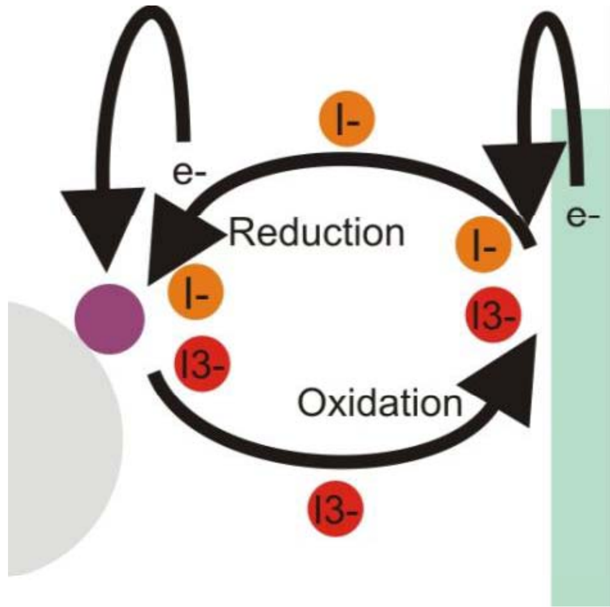
p-type solid state semiconductors – mainly CuSCN

These solid state systems suffer from poor filling of the pores



How the circuit is complete depends on what the dye regenerating material is:

For the liquid cells employing the I-/I3- redox couple a catalyst is required to reduce the I3- ion at the electrode – the best is platinum (expensive) but only a few nm are required. High surface area graphite also works



For the polymer cells or solid state cells, only an ohmic contact is required, be it either gold, graphite or any other conducting medium with the correct work function

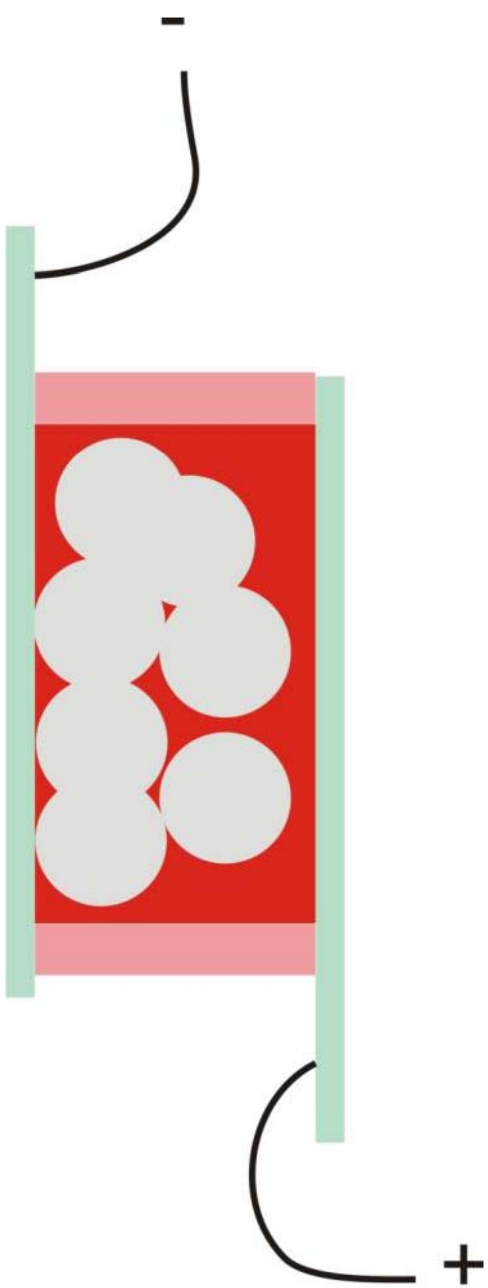
How to seal or encapsulate these solar cells?

These are highly photocatalytic systems and thus can react with almost any species.

Thus water and other impurities must be kept out!

And for the liquid systems, the liquid must be contained.

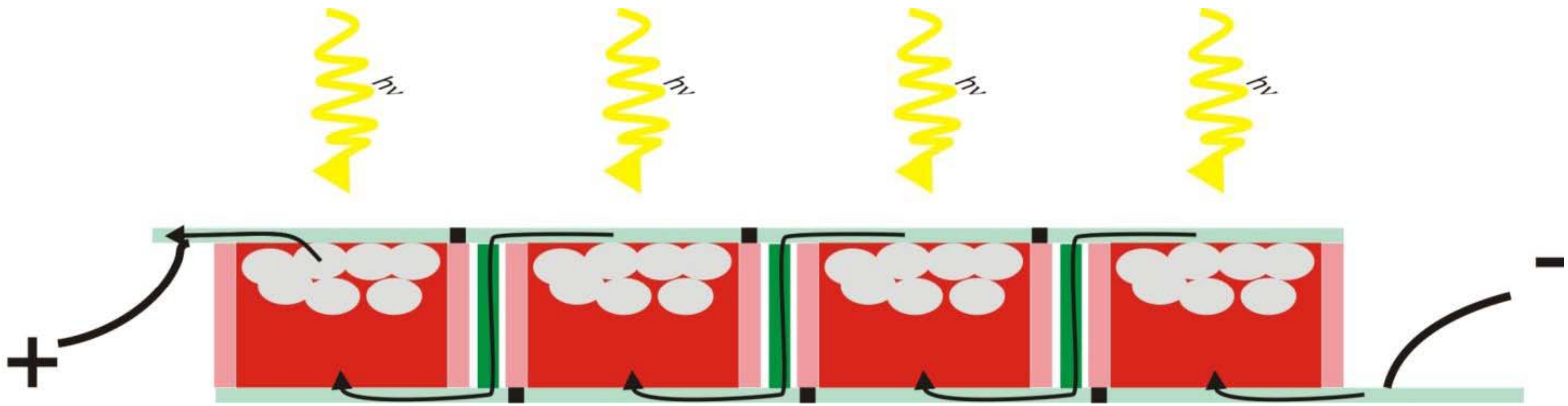
The liquid tend to be an organic solvent which are highly volatile and thus easily evaporate



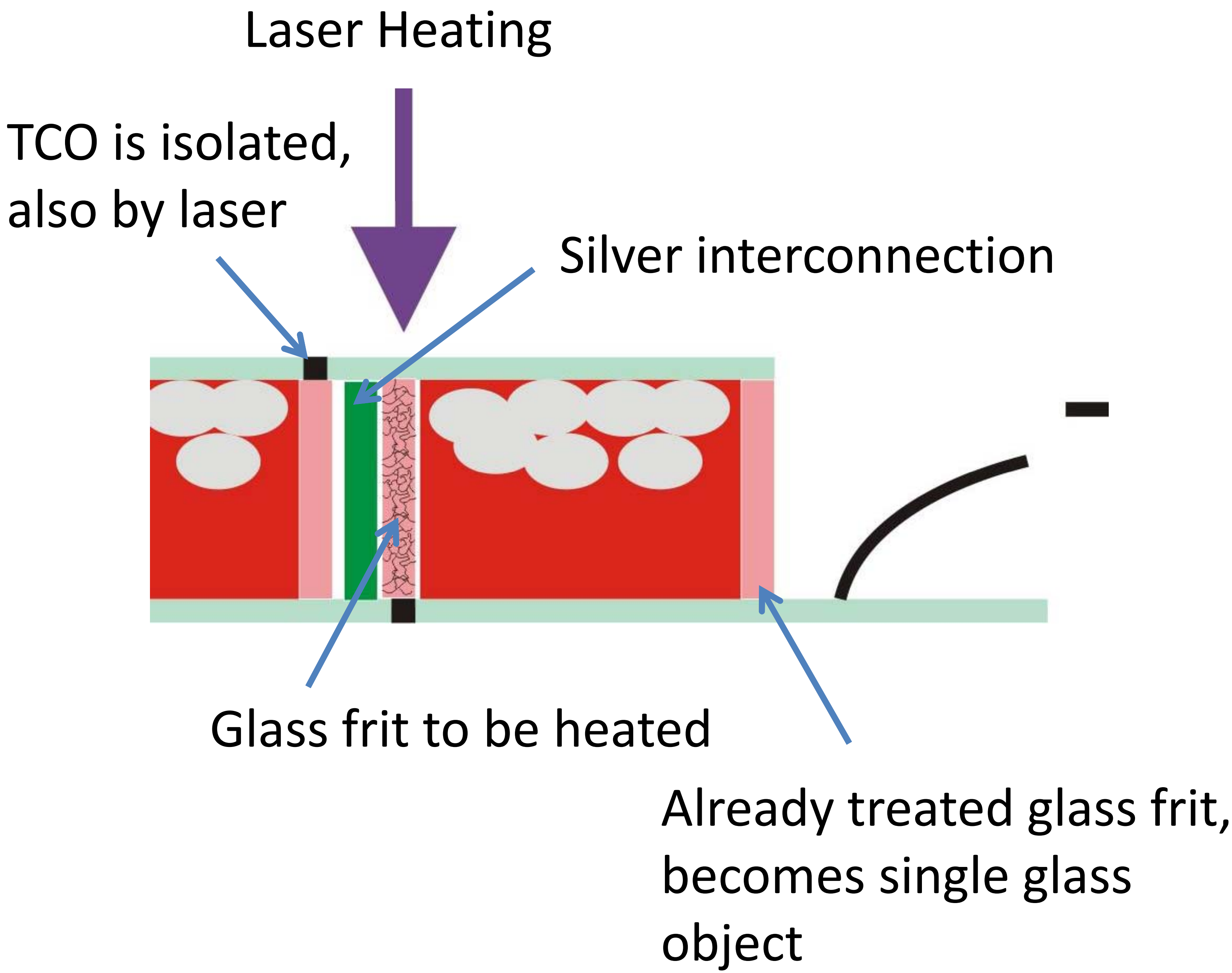
Use a polymer holtmelt - a polymer that when heated, softens and adheres to surfaces – these are stable and wildly available from commercial manufactures

This is useful for flexible DSCs

A more rugged solution for rigid DSCs – possibly for producing power
A company in Portugal is involved in applying this solution



This reduces series resistance, but also uses glass instead of a polymer for sealing


Laser Heating
TCO is isolated, also by laser
Silver interconnection
-
Glass frit to be heated
Already treated glass frit, becomes single glass object

These are not yet commercial at a large scale but implemented in consumer goods and recently a company is selling flexible roll-up DSC based solar charges phone charges in Africa

Efficiencies are low <5% for modules, 11% lab tests

However the potential provided by organic Chemistry is almost limitless, so research continues…

Also, a lot is still not understood about these types of systems, so they serve as a good catalyst for further research

Pros Extremely low cost, well below 1€/Wp
High efficiencies
BIPV with various different colours
Flexible for ease of transport
Maintain high efficiencies under diffuse light conditions (indoor, cloudy days)
Large potential for roll to roll processing

Cons Current low efficiencies
lack of breakthrough in novel dyes to expand the light absorption range
the more complicated a material is, the more susceptible it is to degradation
this leads to problems in encapsulation and stability
still much discord in the literature as to the understanding of these types of cells