Introduction to the Theory of Luminescence: Basic Principles

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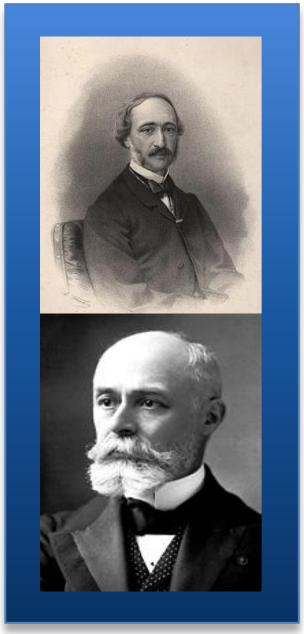
TL & OSL: History

Thermoluminescence, TL

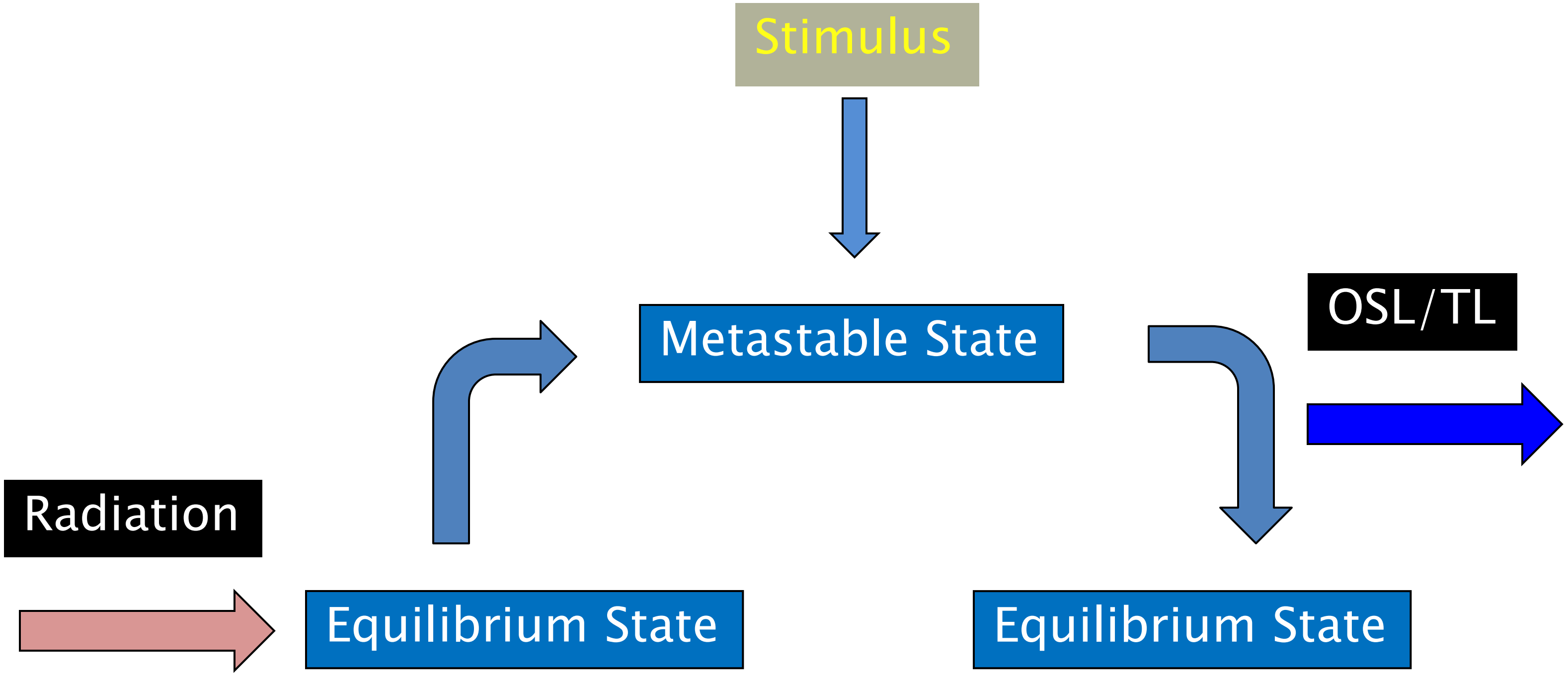
Robert Boyle, 1664
Weidemann & Schmidt, 1895
– first use of the word: "*Thermoluminescence*"

Optically Stimulated Luminescence, OSL



Edmund & Henri Bequerel, 1843, 1853
Antonov-Romanovski et al., Schulman et al.,
Albrecht and Mandeville, 1953, 1956
Fowler, 1963 – first use of the phrase:
"*Optically Stimulated Luminescence*"
Huntley et al., 1985

TL & OSL: A Conceptual Framework



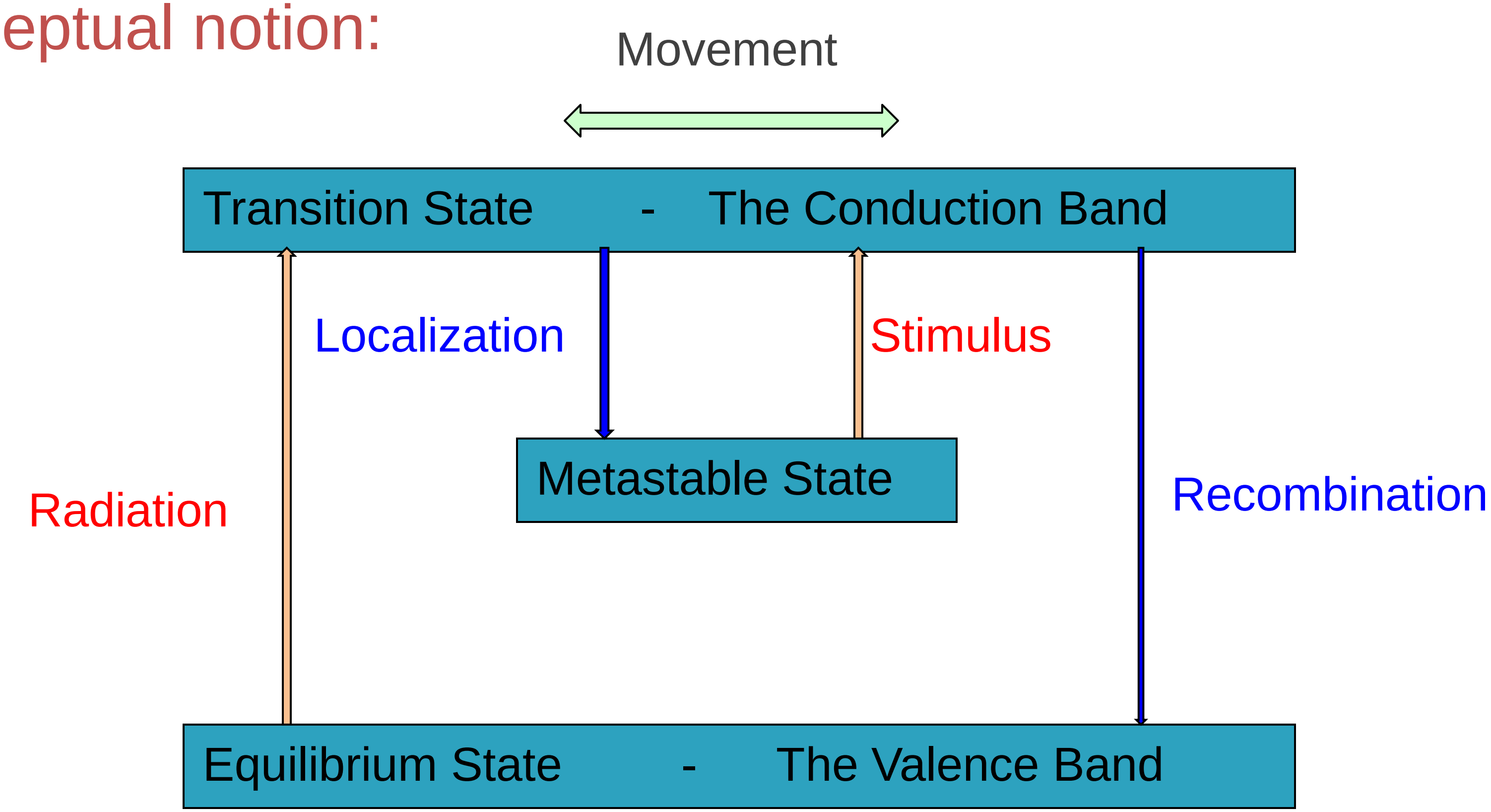
Conceptual notion:

Metastable State

Equilibrium State

Equilibrium State

Conceptual notion:



Changes of state involve transitions of electrons from one atomic or molecular configuration to another – at a different atomic or molecular site.

Conceptual notion:

Transition State - The Conduction Band

Equilibrium: empty

Non-Equilibrium: *not* empty

Fermi Level

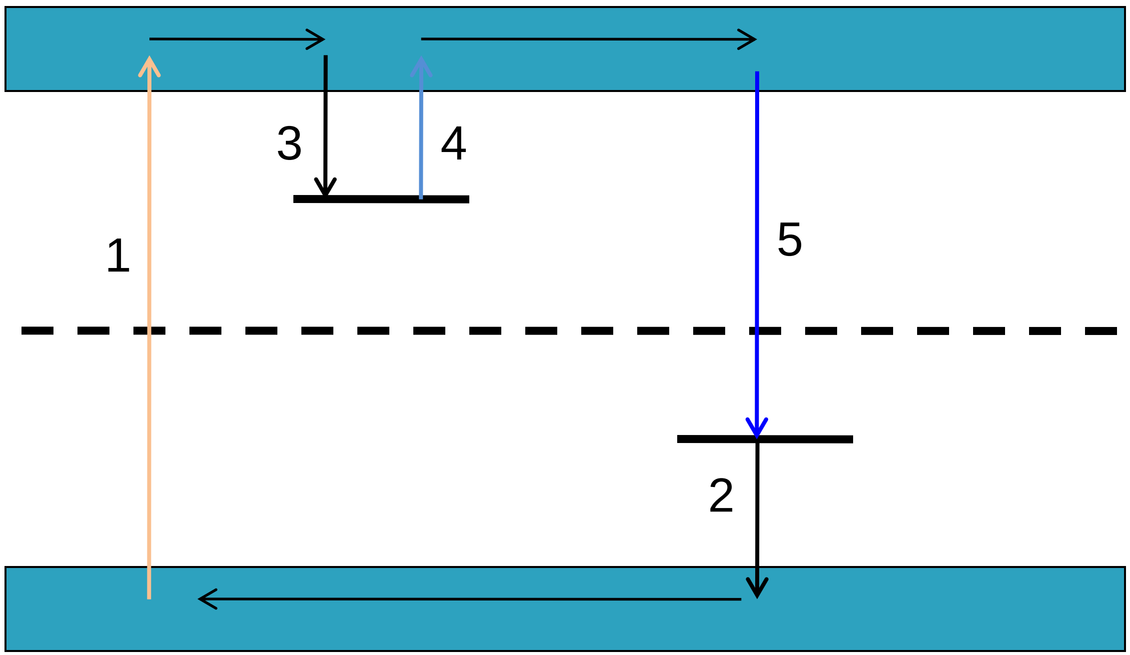
Metastable State

full

not full

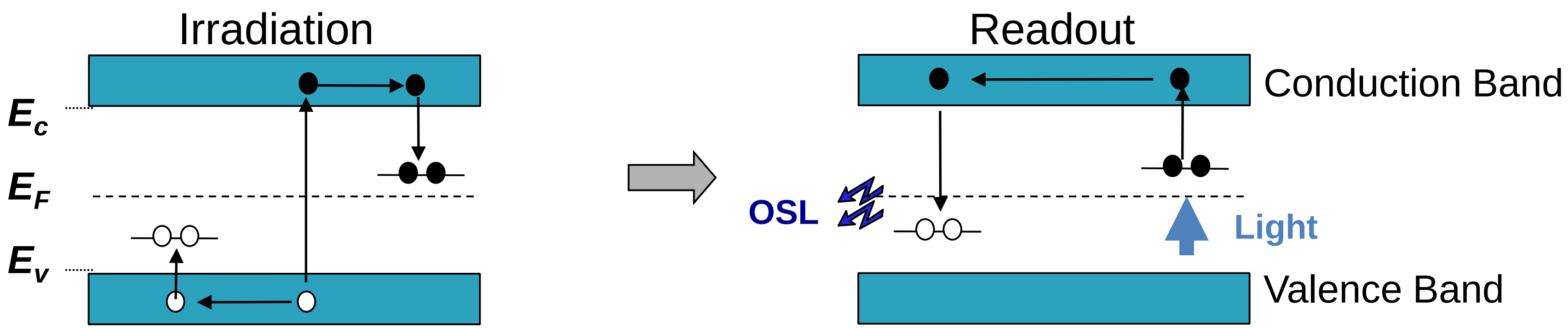
Equilibrium State - The Valence Band

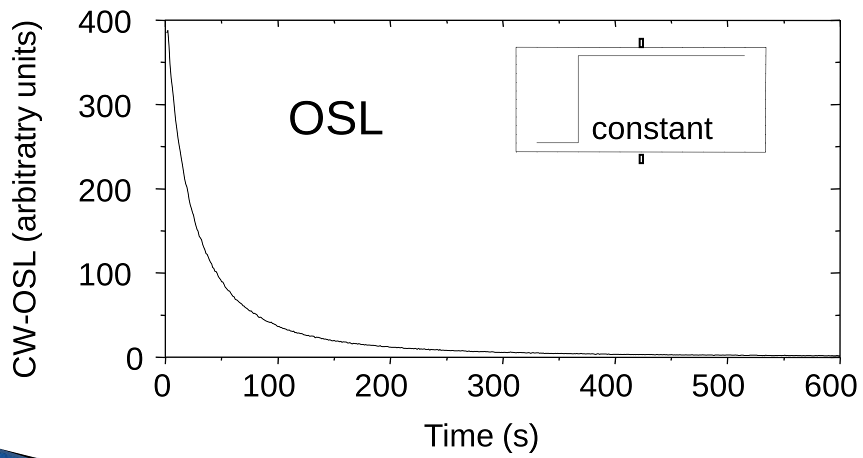
What do we mean by the Metastable state?

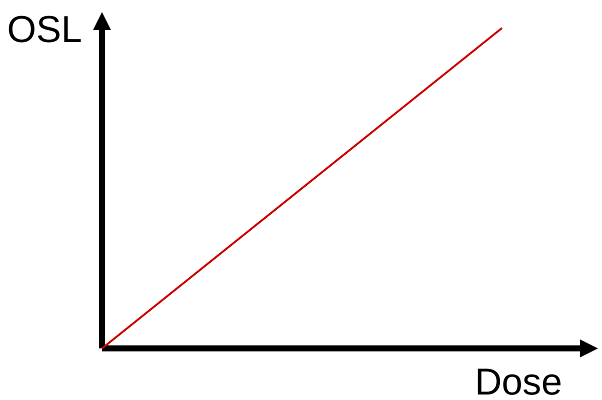


1 – excitation by radiation
2 & 3 –Localization (trapping)
4 – stimulation (by light (OSL) or by heat (TL))
5 – recombination (producing luminescence - OSL or TL)

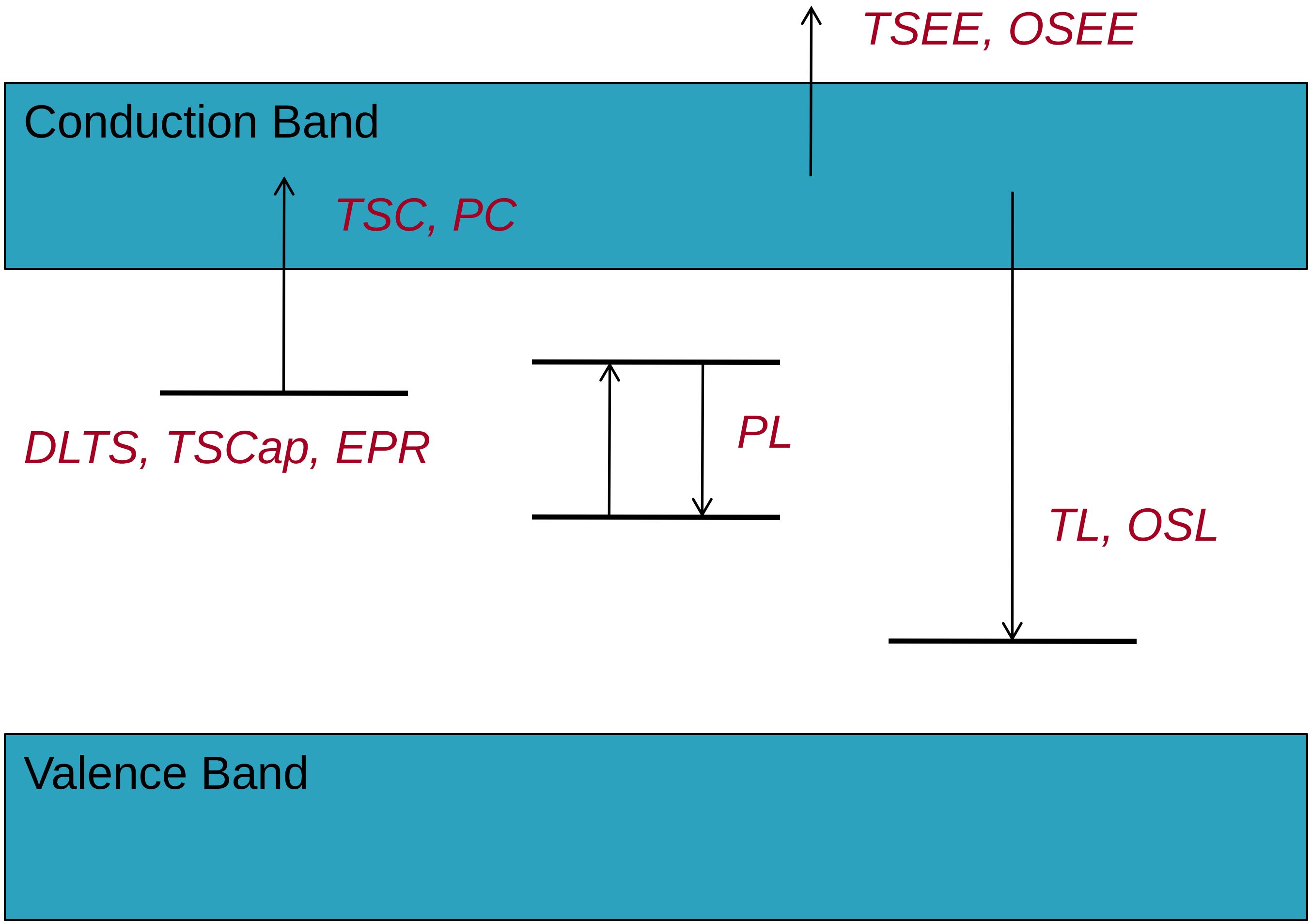
E.g. OSL – Total OSL output proportional to the dose absorbed



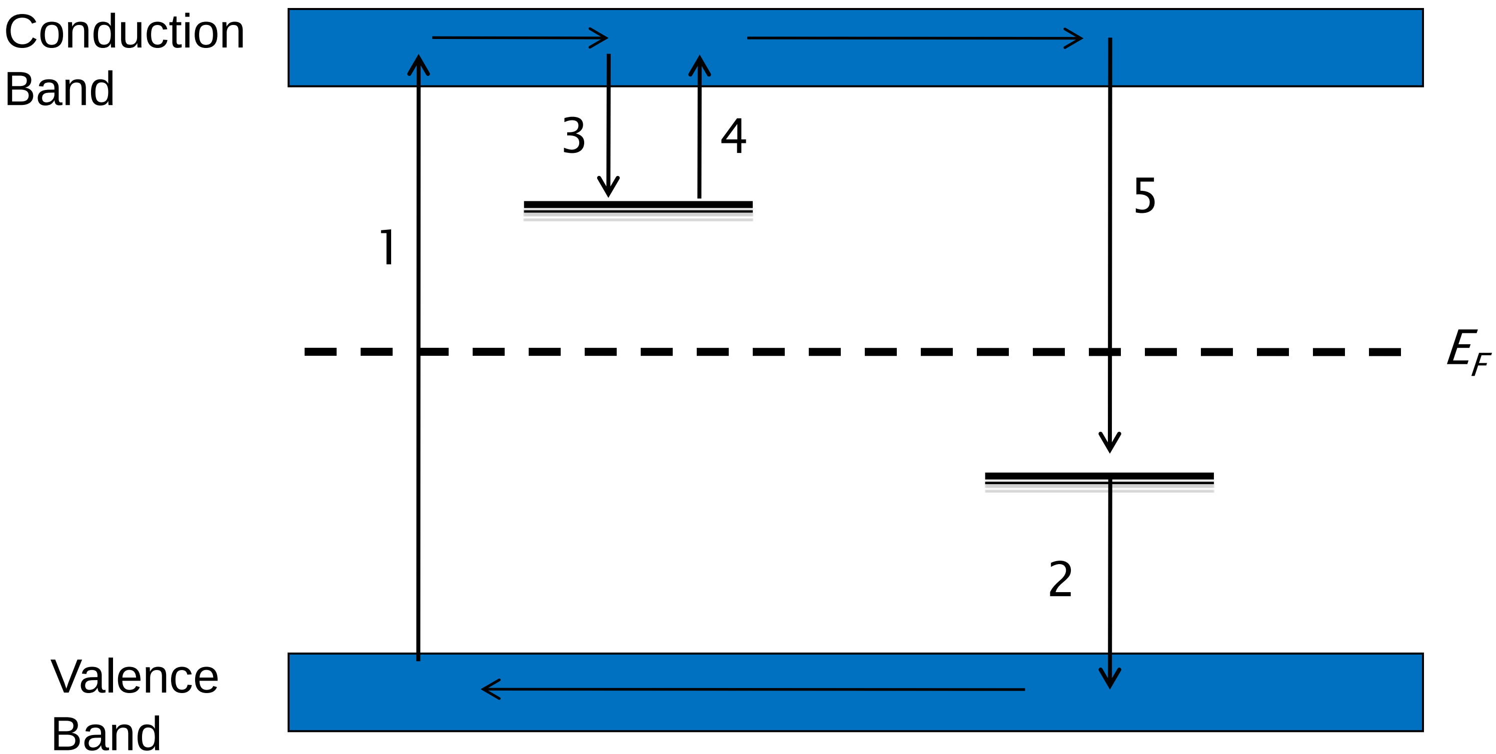




OSL and related phenomena:

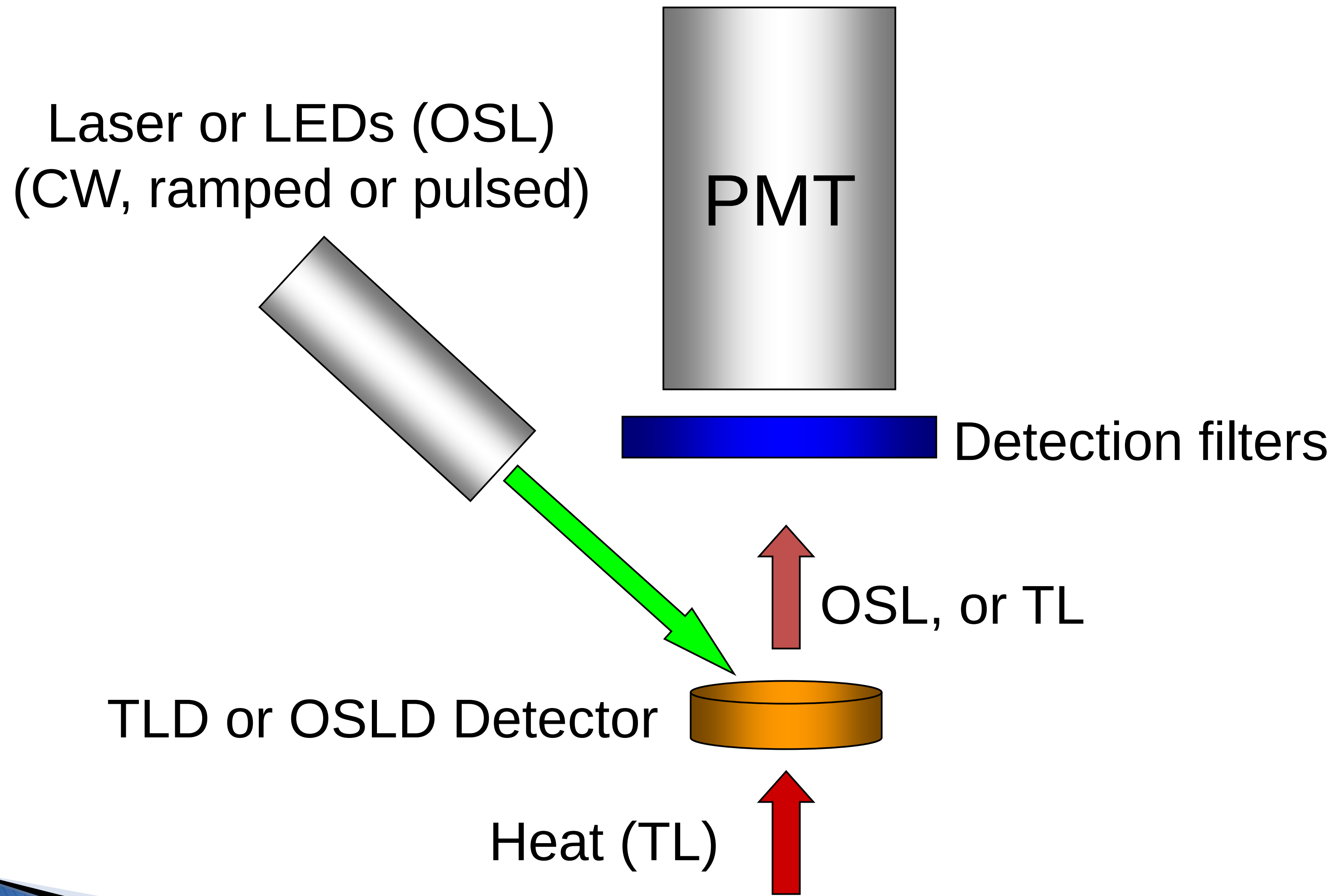


TL & OSL: A Conceptual Framework

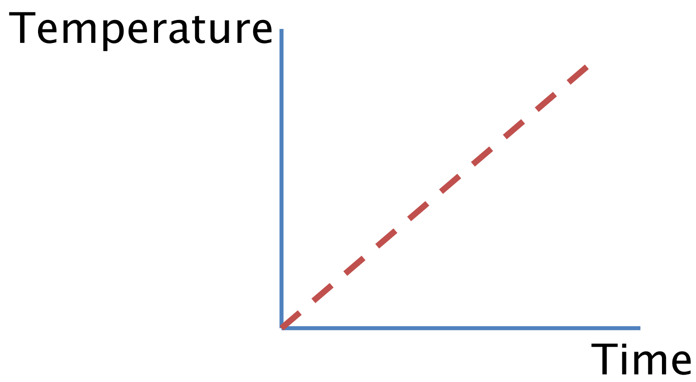


1 – excitation by radiation
2 & 3 –Localization (trapping)
4 – stimulation (by light (OSL) or by heat (TL))
5 – recombination (producing luminescence – OSL or TL)

Schematic of Equipment

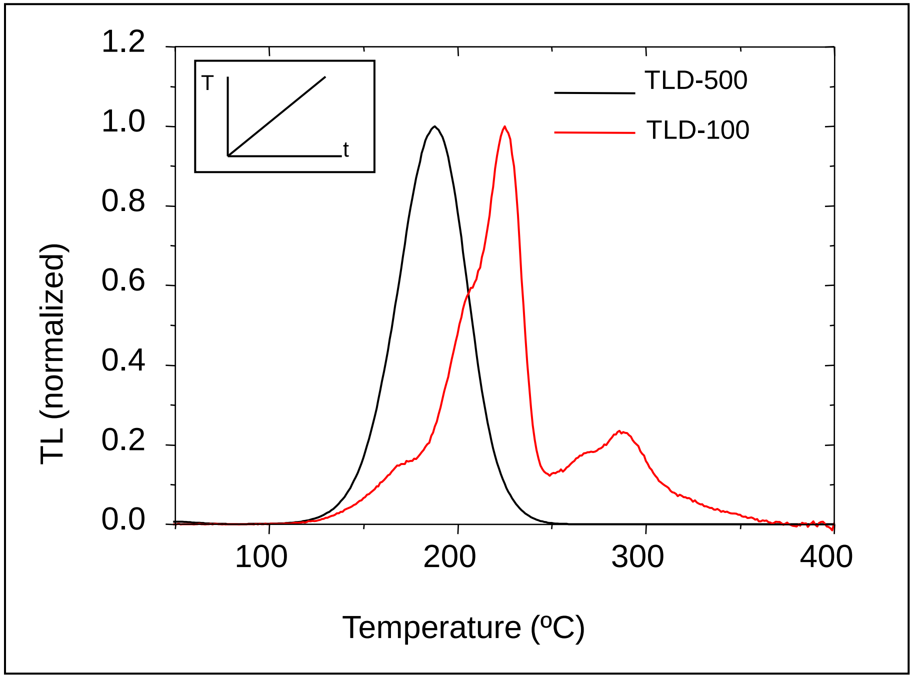


Thermoluminescence



Usually, linear temperature ramp

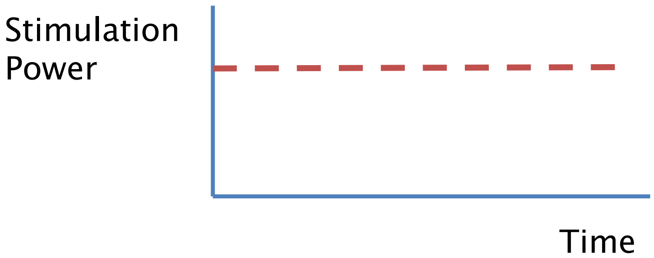
"Glow Curves"
[LiF:Mg,Ti and Al_2O_3:C]

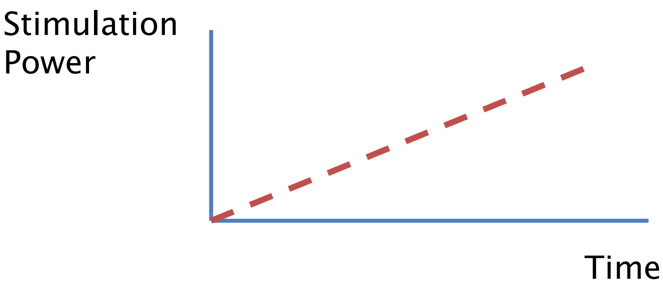


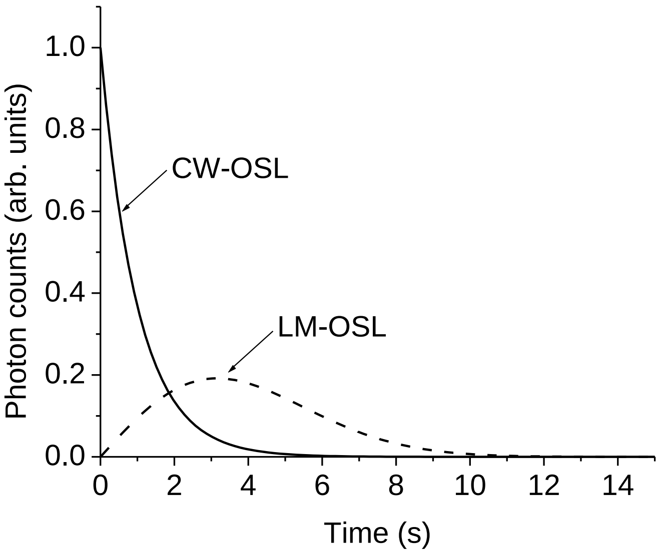
Optically Stimulated Luminescence

Modulate the stimulation intensity. Either:

<u>Constant</u> – **CW-OSL** or <u>Linear increase</u> – **LM-OSL**

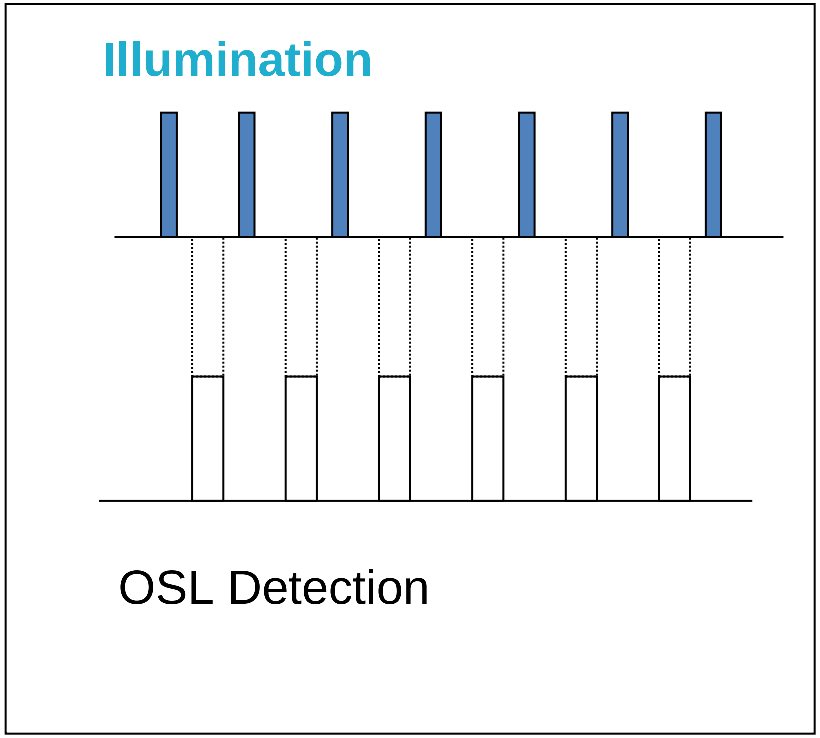


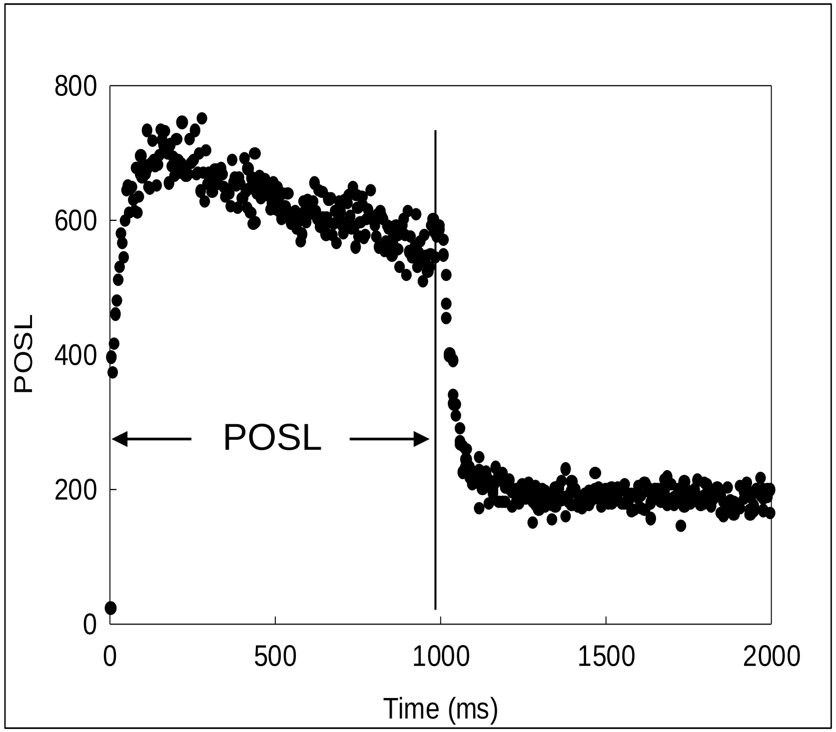




Optically Stimulated Luminescence

……or <u>Pulsed</u> – **POSL**





Mathematical Descriptions

Main assumption: *First-Order Kinetics*

$$I(t) \propto \left|\frac{dn}{dt}\right| = n_0 p$$

I = TL/OSL intensity
n, n_o = charge in traps
p = probability/unit time of charge being released
E = trap depth (eV)
s = frequency factor (s^{-1})
T = temperature (K)
β = heating rate (K/s)
k = Boltzmann's constant

Thermoluminescence

$$p = s\exp\left(-\frac{E}{kT}\right)$$

$$\boxed{I_{TL}(T) = n_0 s \exp\left(-\frac{E}{kT}\right)\exp\left[-\frac{s}{\beta}\int_{T_0}^{T}\exp\left(-\frac{E}{kT}\right)dT\right]}$$

Mathematical Descriptions

Optically Stimulated Luminescence

$$p = \Phi\sigma\left(E_o\right)$$

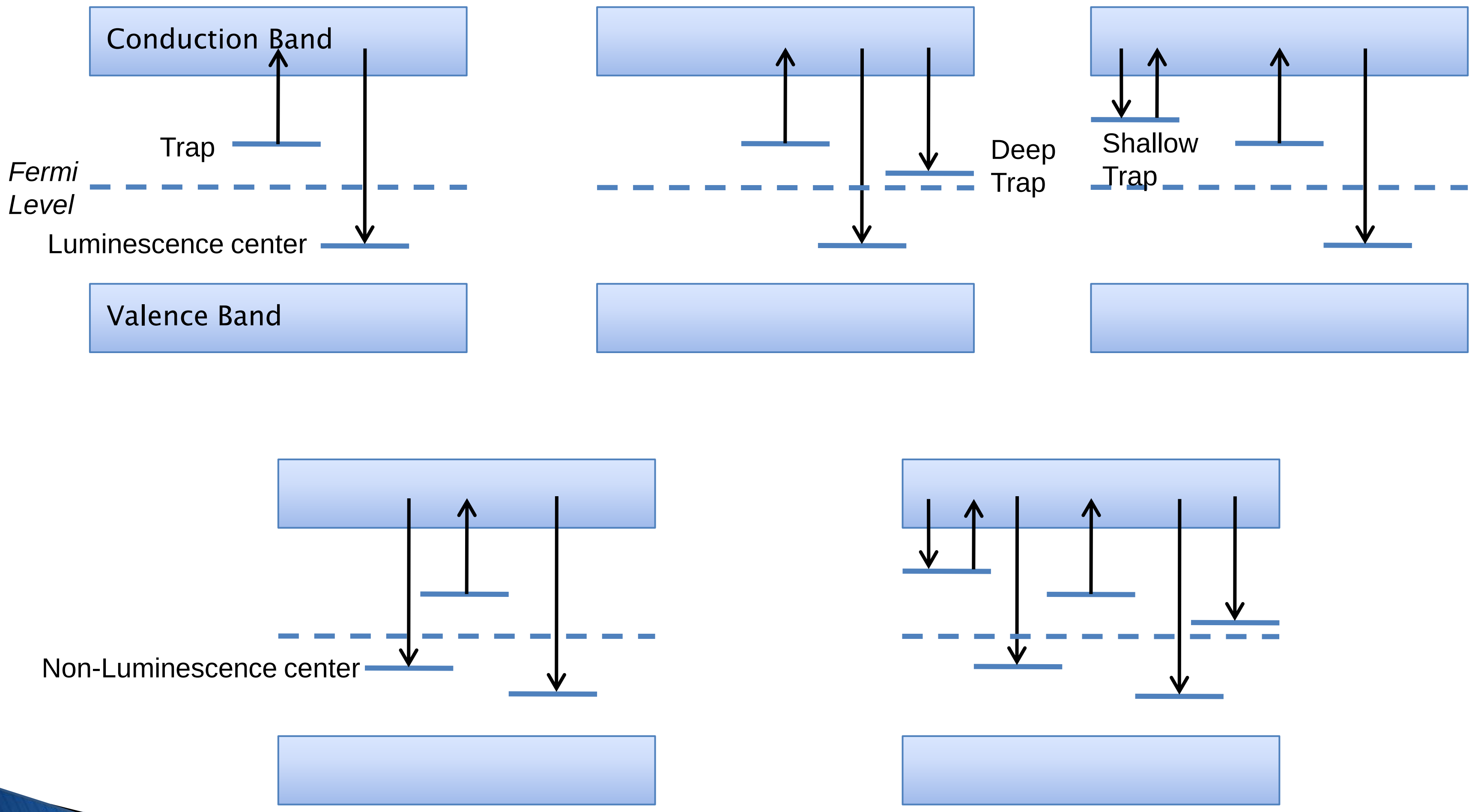
CW-OSL: Φ = constant

LM-OSL: Φ ramped; $\Phi\left(t\right) = \beta_\phi t$

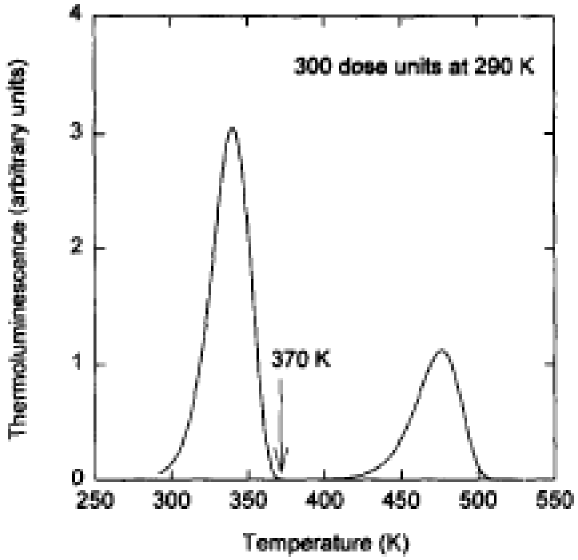
I = TL/OSL intensity
n, n_o = charge in traps
p = probability/unit time of charge being released
E_o = optical trap depth (eV)
Φ = stimulation intensity
σ = photoionization cross-section (m^2)
τ_d = CW-OSL decay constant

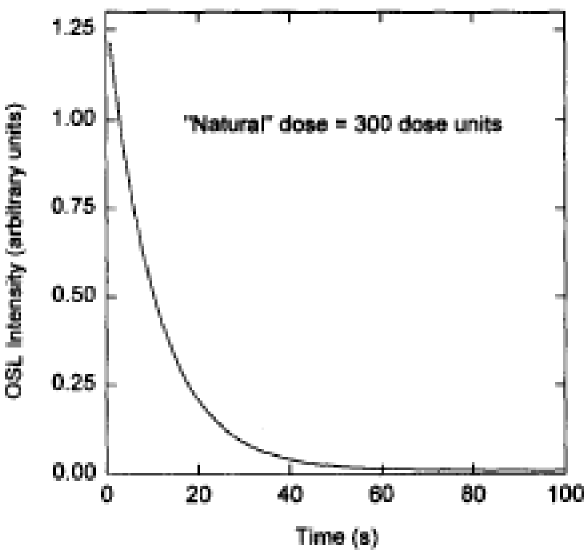
$$\boxed{I_{CW-OSL}\left(t\right) = n_0 p \exp\left(-tp\right) = I_0 \exp\left(-\frac{t}{\tau_d}\right)}$$

Example Models

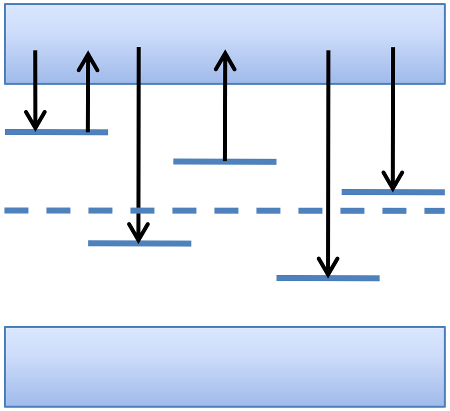


Simulated TL & OSL

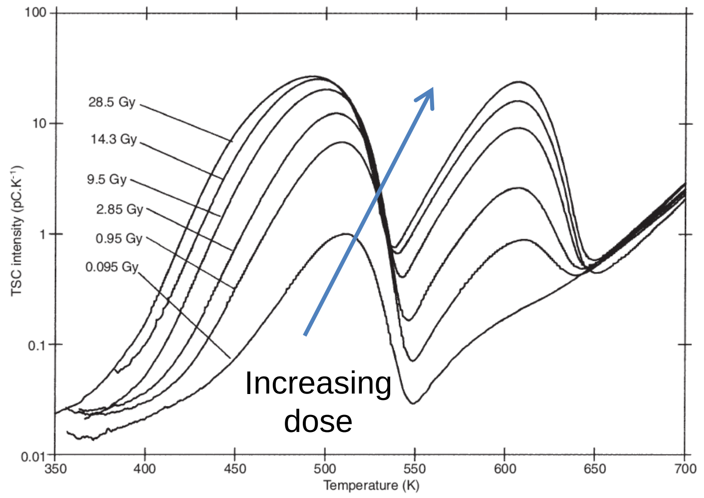


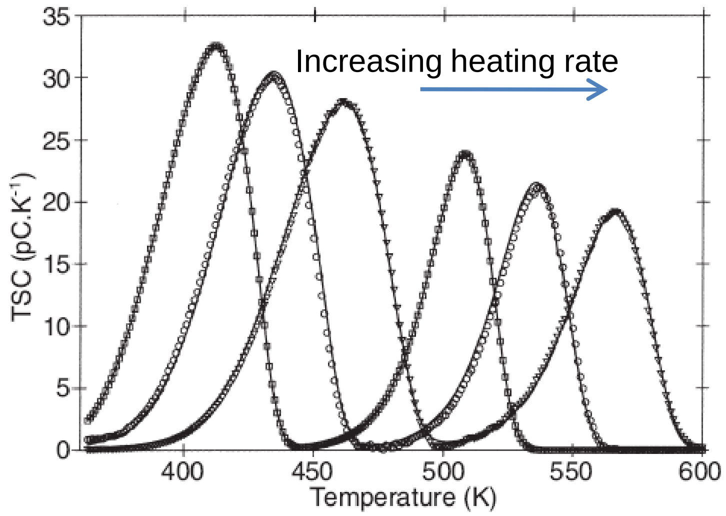


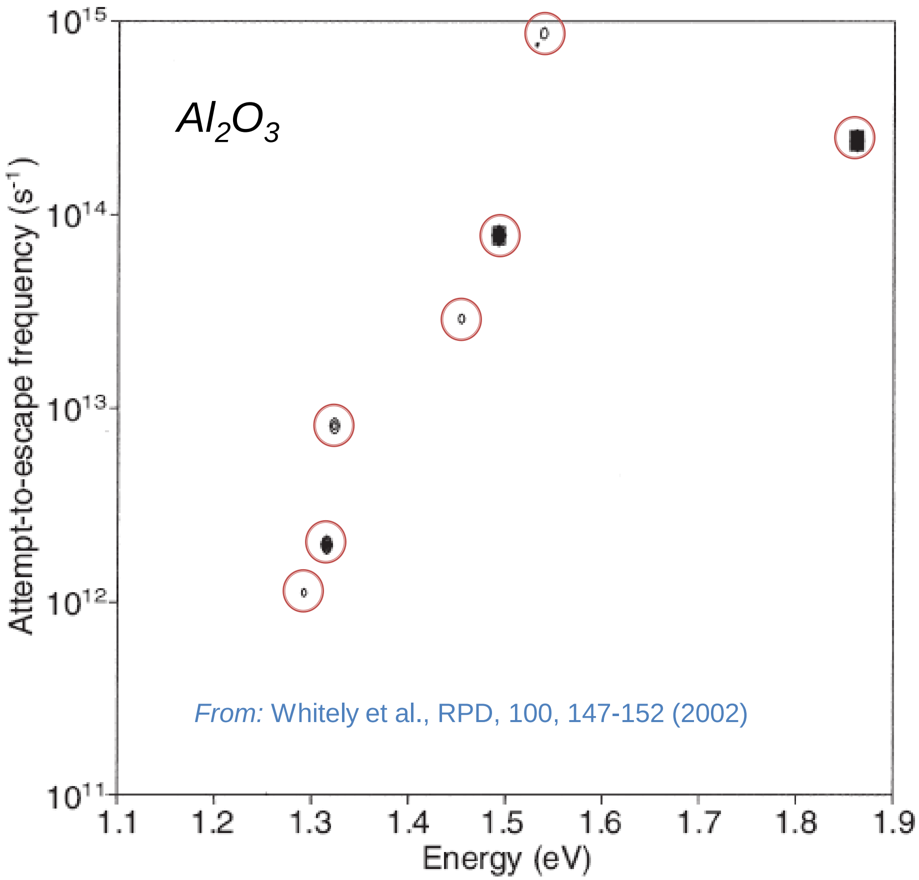
Simulated "Quartz-like" TL and OSL Curves using band diagram shown



Real materials:multiple traps/centers



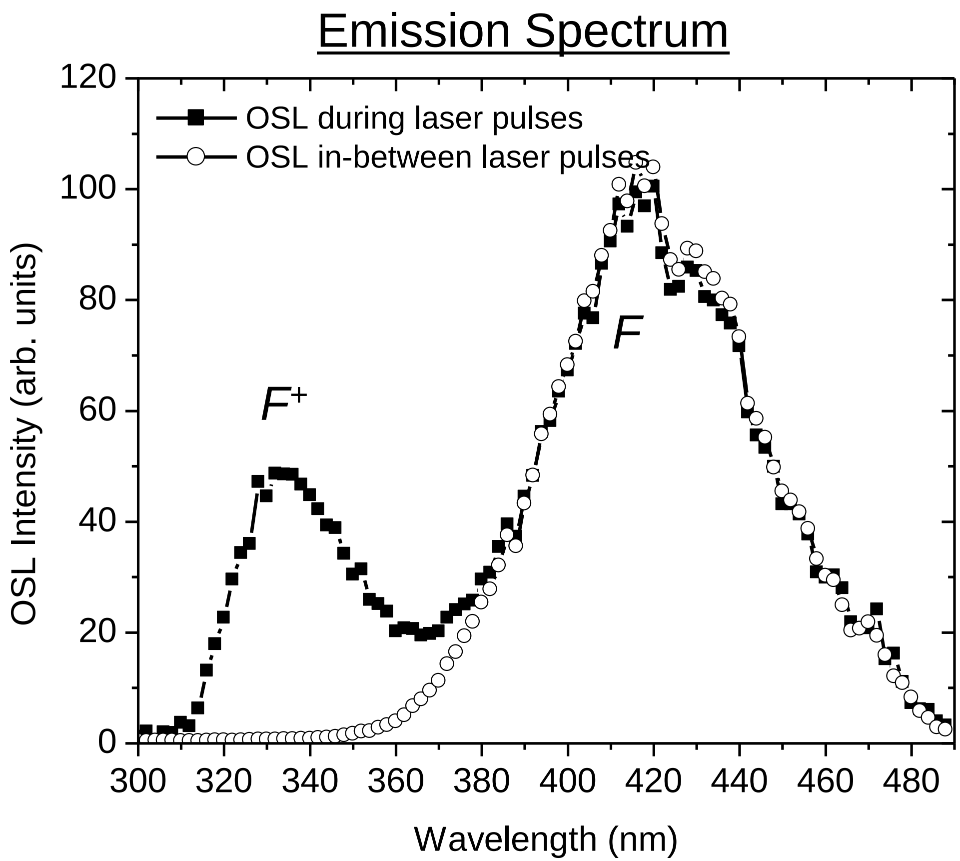




$$I_{TSC}(T,\beta)=\int\int g[E,s]I_{RW}(T,\beta)dEds$$

$$I_{RW}(T,\beta)=s\exp\left\{-\frac{E}{kT}\right\}\int_{T_o}^{T}\left(-\frac{s}{\beta}\right)\exp\left\{-\frac{E}{k\theta}\right\}d\theta$$

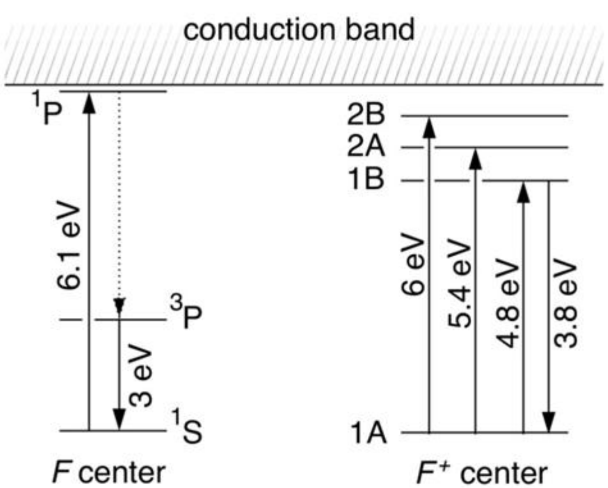
Emission and Excitation Spectra



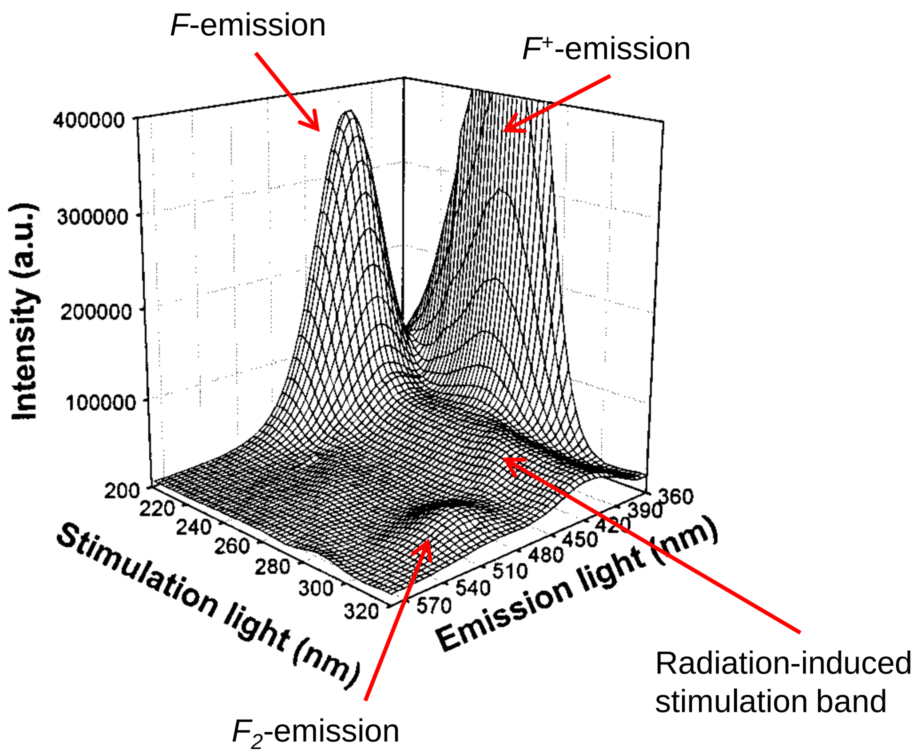
From: Yukihara and McKeever.
J. Appl. Phys. 100, 083512 (2006)

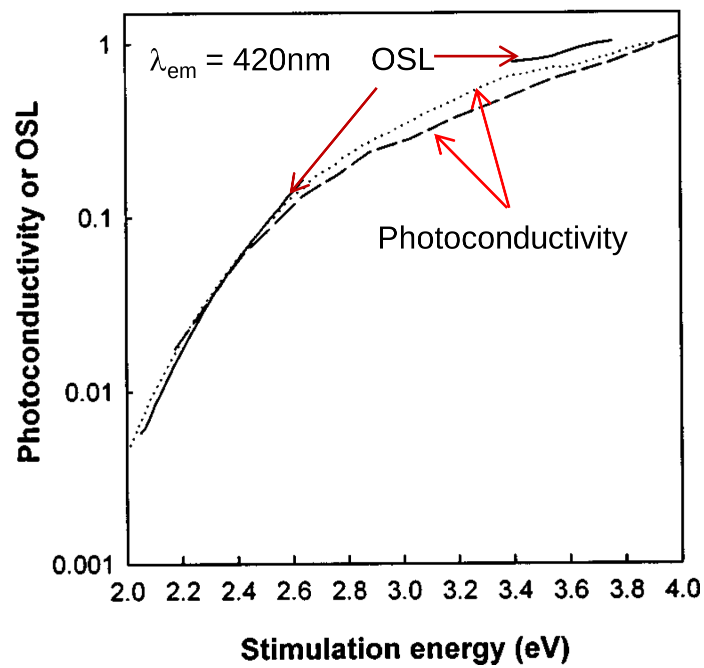
F-center emission
^3P-^1S; 420nm broad emission
τ=35 ms

F$^+$-center emission
1B-1A; 330 nm broad emission
τ<7ns



Emission and Excitation Spectra

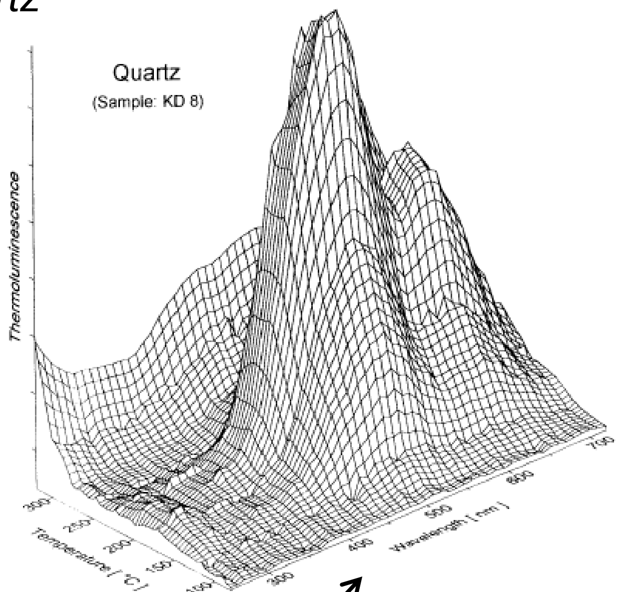


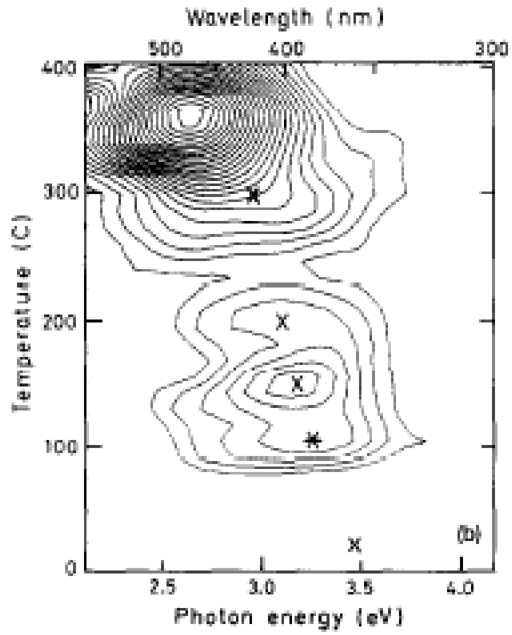


Data from: Whitely and McKeever.
J. Appl. Phys. 87, 249-256 (2000)

Emission and Excitation Spectra

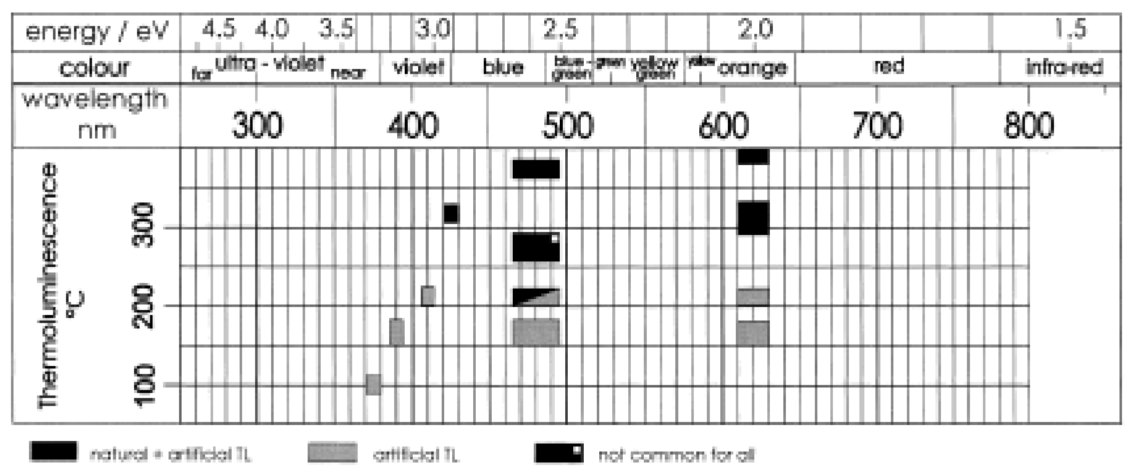
Quartz





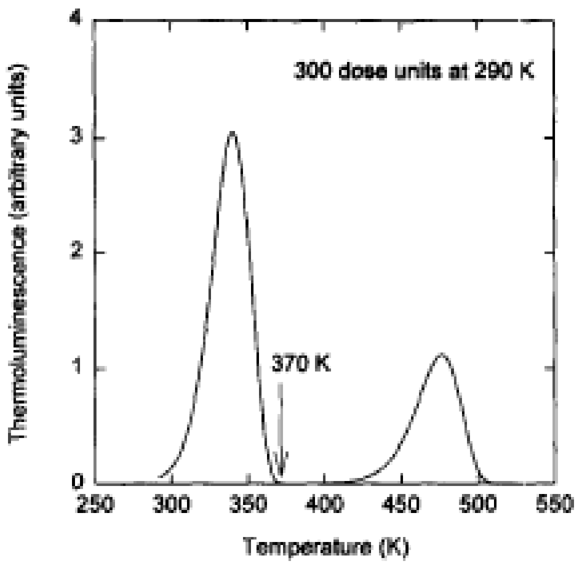
Data from: Franklin et al
J. Lumin. 63, 317-326 (1997)

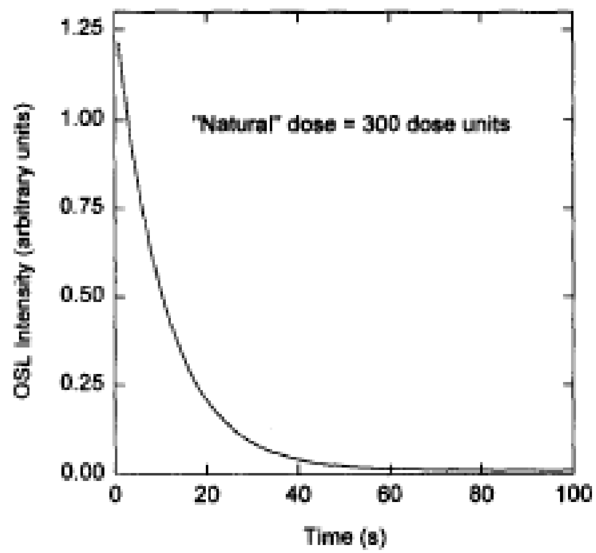
Data from: Krbetschek et al
Rad. Meas. 27, 695-748 (1997)



Curve Shapes

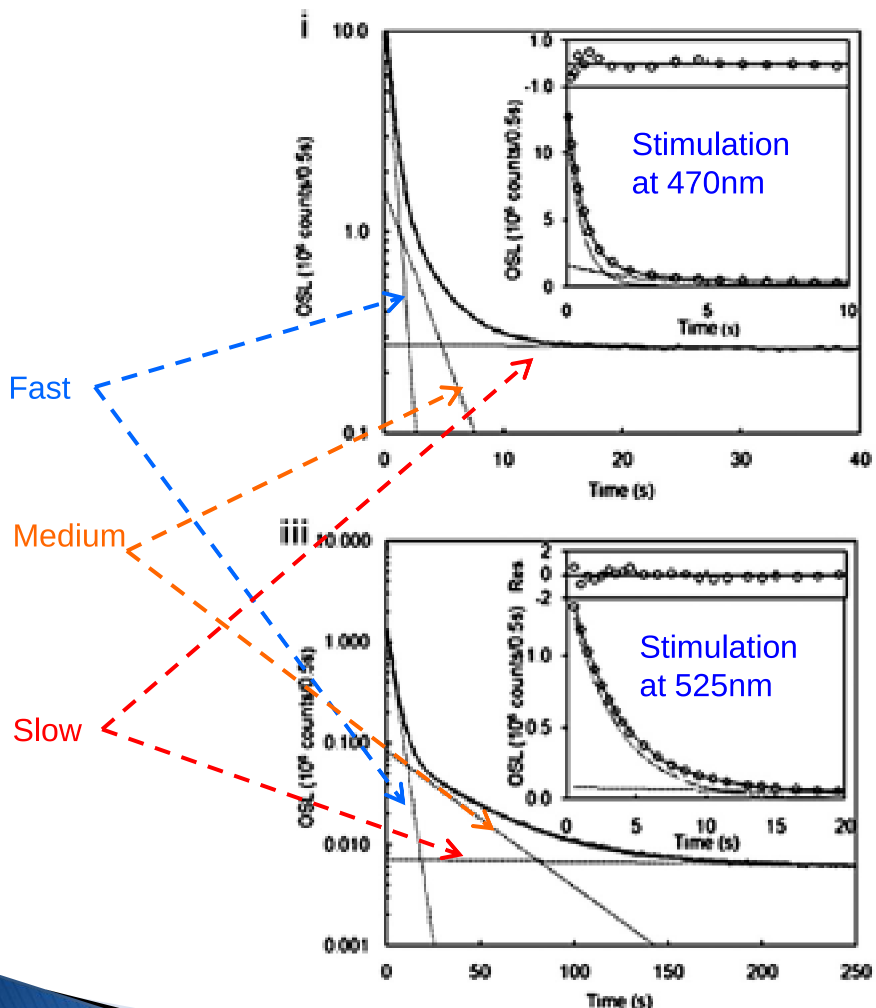
No re-trapping; no trap interactions…….First-Order kinetics

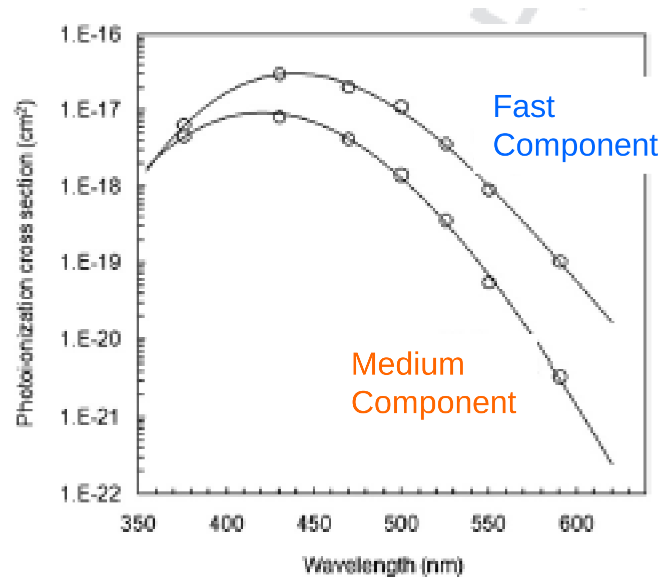




…….but reality can be more complex

Curve Shapes

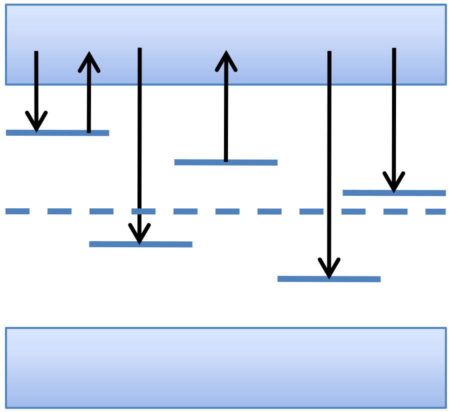


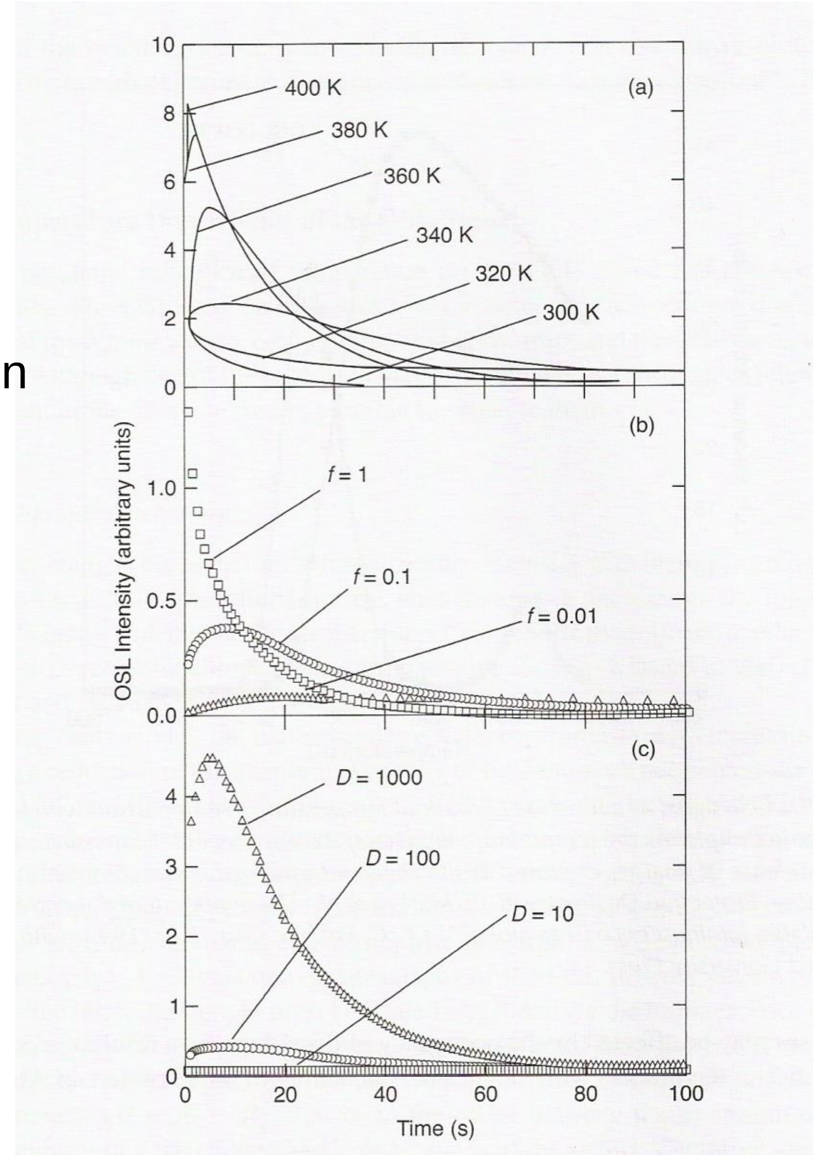


Data from: Bailey et al
Rad. Meas. (2011; in press)

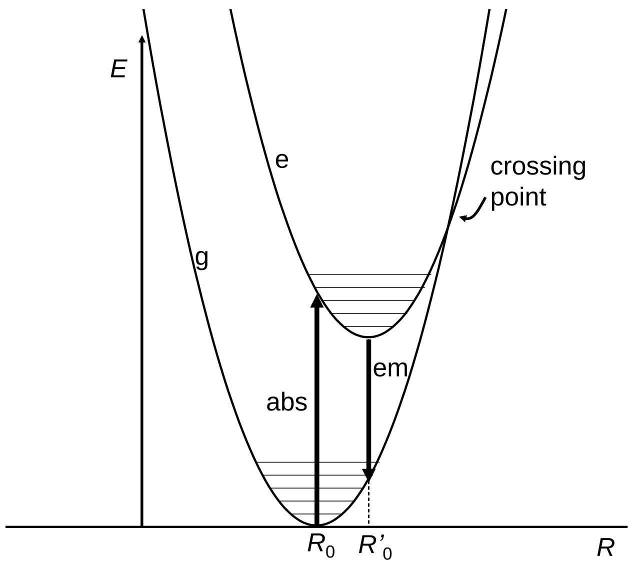
Curve Shapes

Possible OSL curve shapes using model shown, for a variety of conditions: Simulation

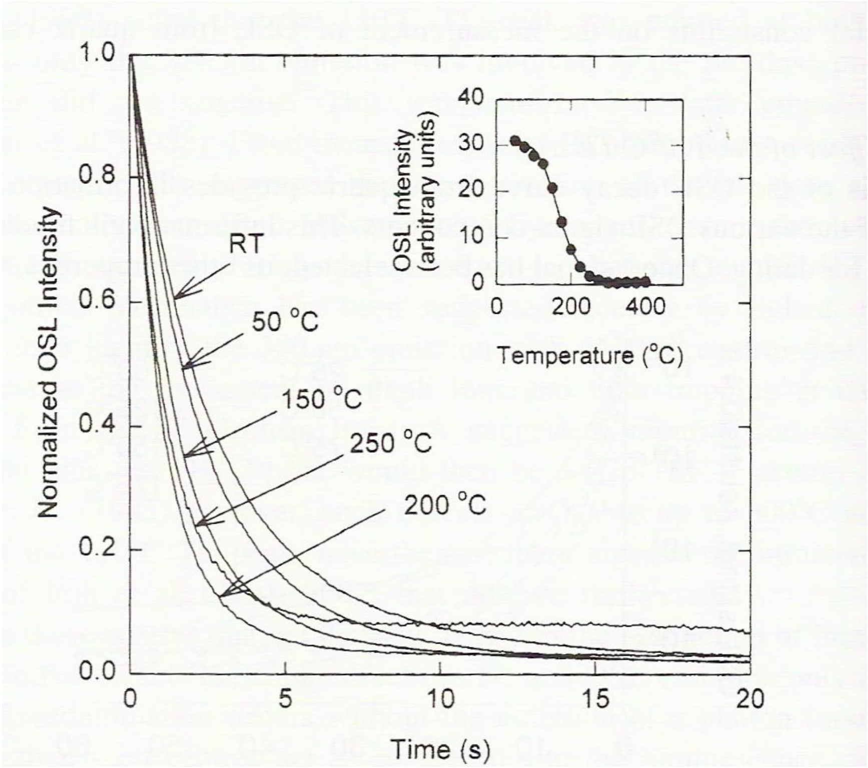




Thermal Quenching

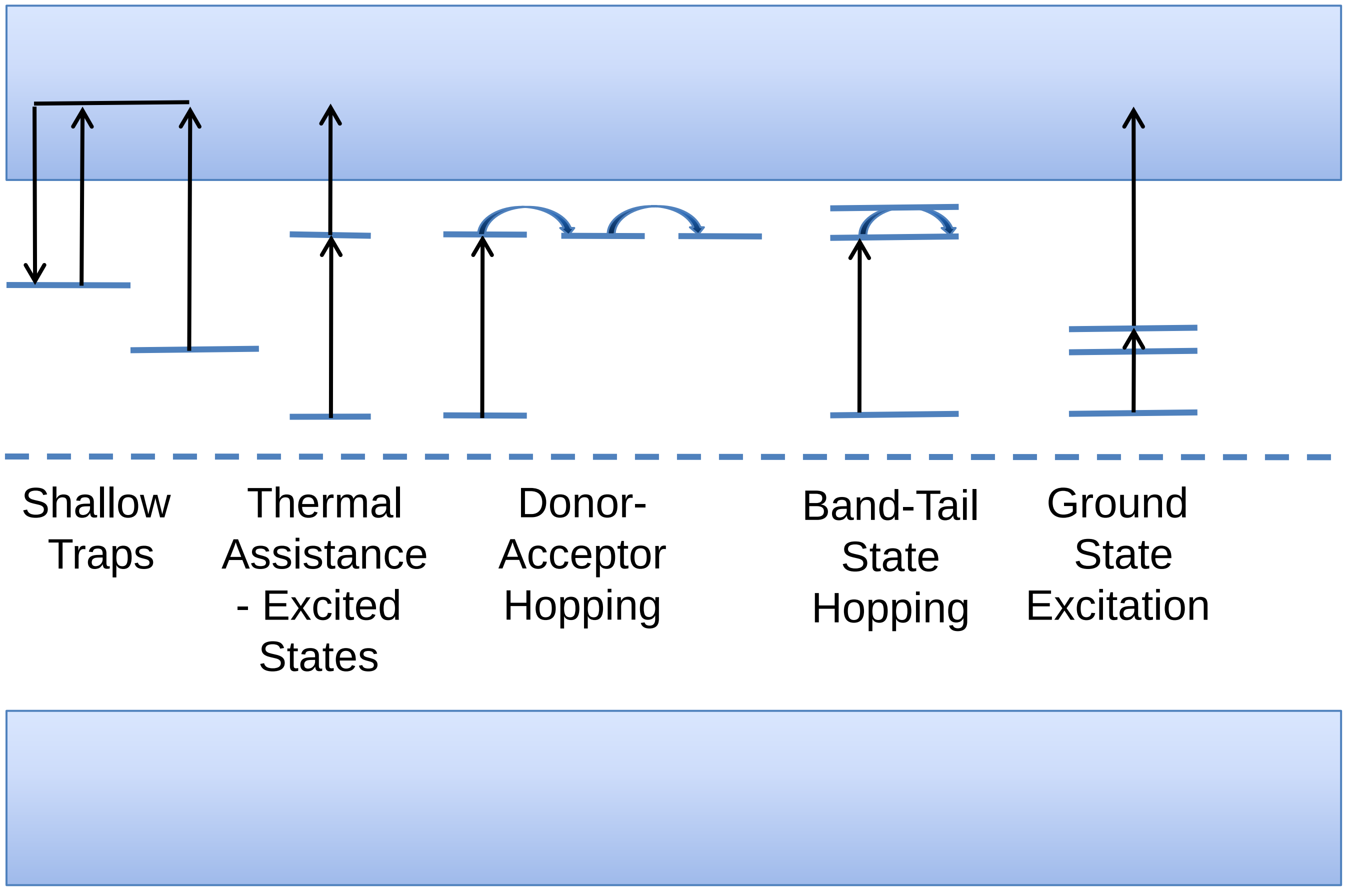


Configurational Coordinate Diagram



Data from: McKeever et al
Rad. Meas. 27, 161-170 (1997)

Temperature Dependencies



Thank You!