Thermoluminescence Dosimetry

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Luminescence

- Thermoluminescence is a particular area of a general area termed Luminescence.
- The time between irradiation and emission is the distinguishing parameter.
- Times < 10^{-8} seconds are termed fluorescence. Times longer are luminescence. If the luminescence is stored and read out later, it is *x*luminescence where *x* is the method of read out.

2 Major Types of Luminescence

- Thermoluminescence is the emission of light by heat
- Optically Stimulated Luminescence (OSL) - the subject of the next lecture is when the light is emitted after light (Optical methods) is used to cause energy level transitions.

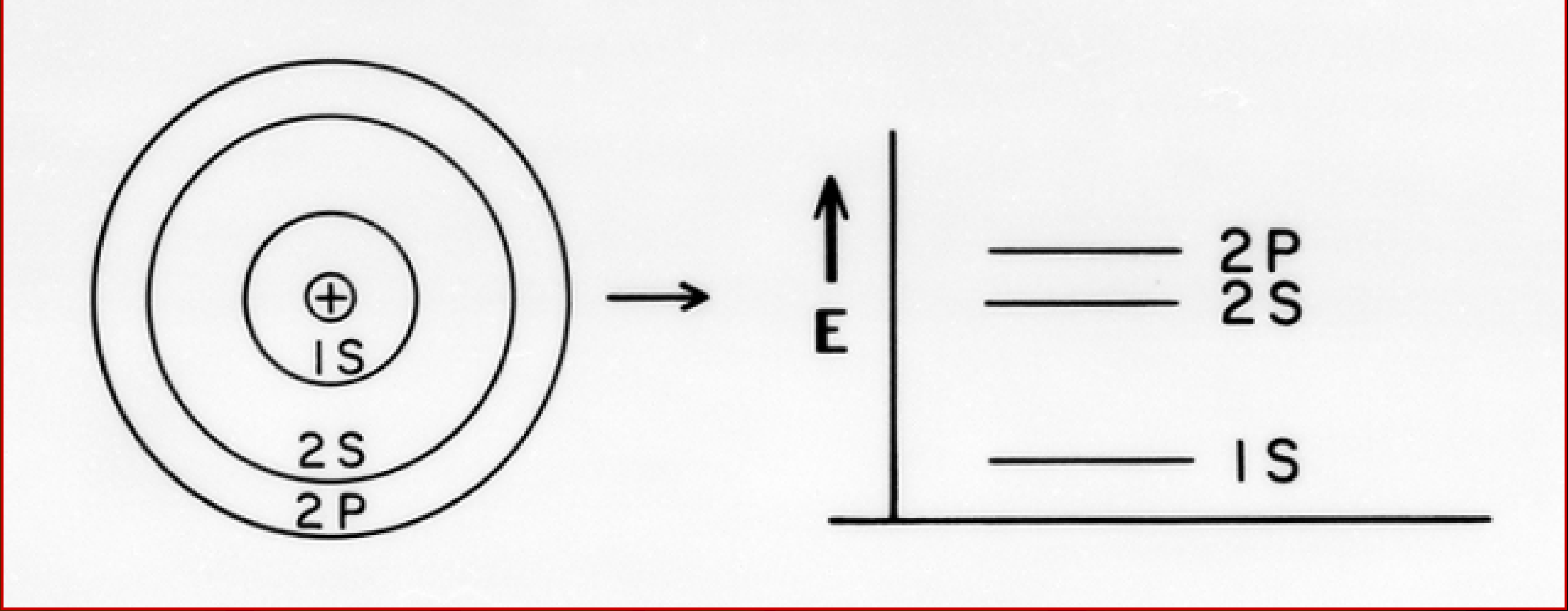
Thermoluminescence

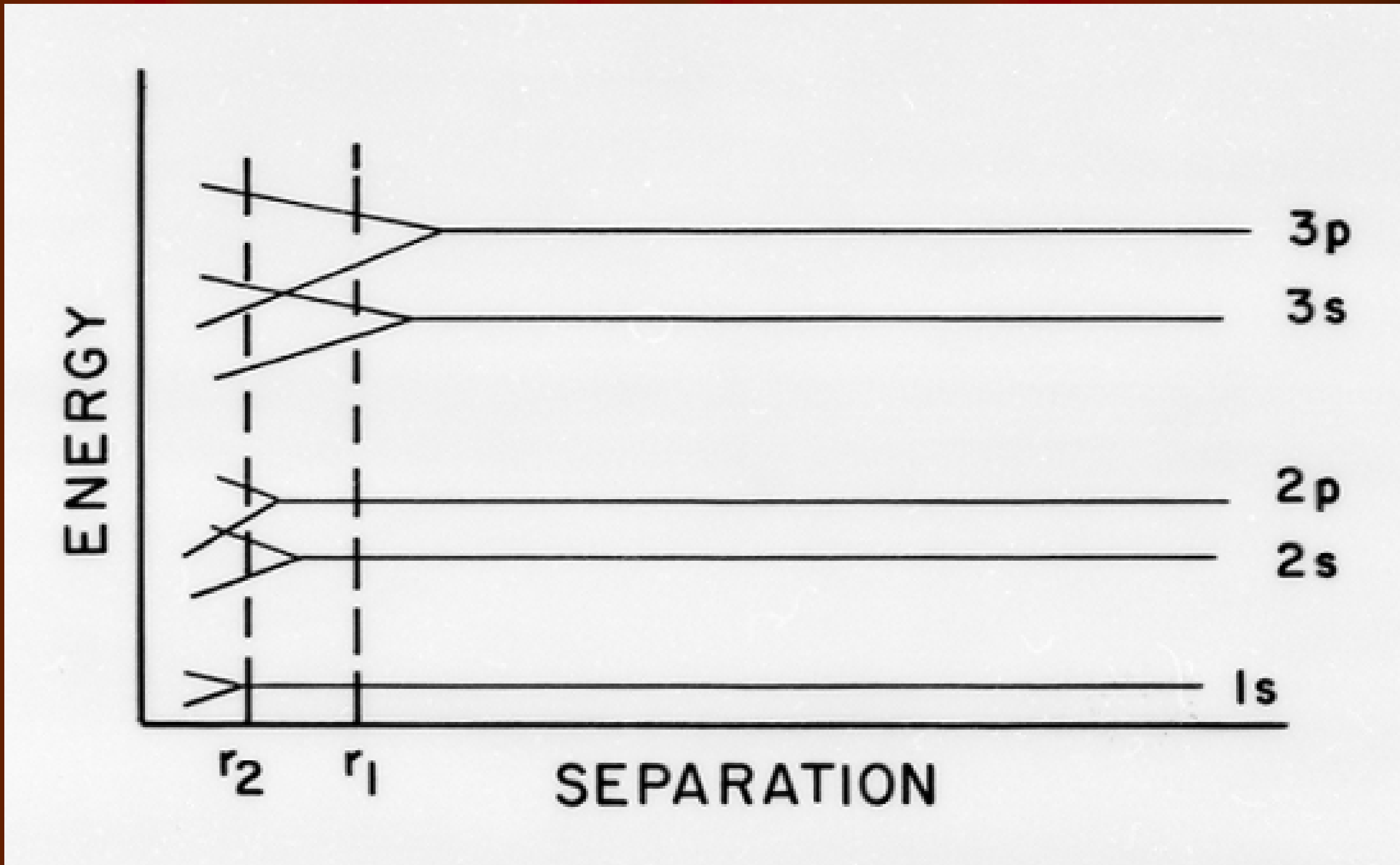
- The basic process is the storage of energy from radiation in “traps”
- Release of this energy by the application of heat. Electrons flowing from the traps to where they recombine with holes (positively charged)
- Recombination produces light with a wavelength characteristic of center.

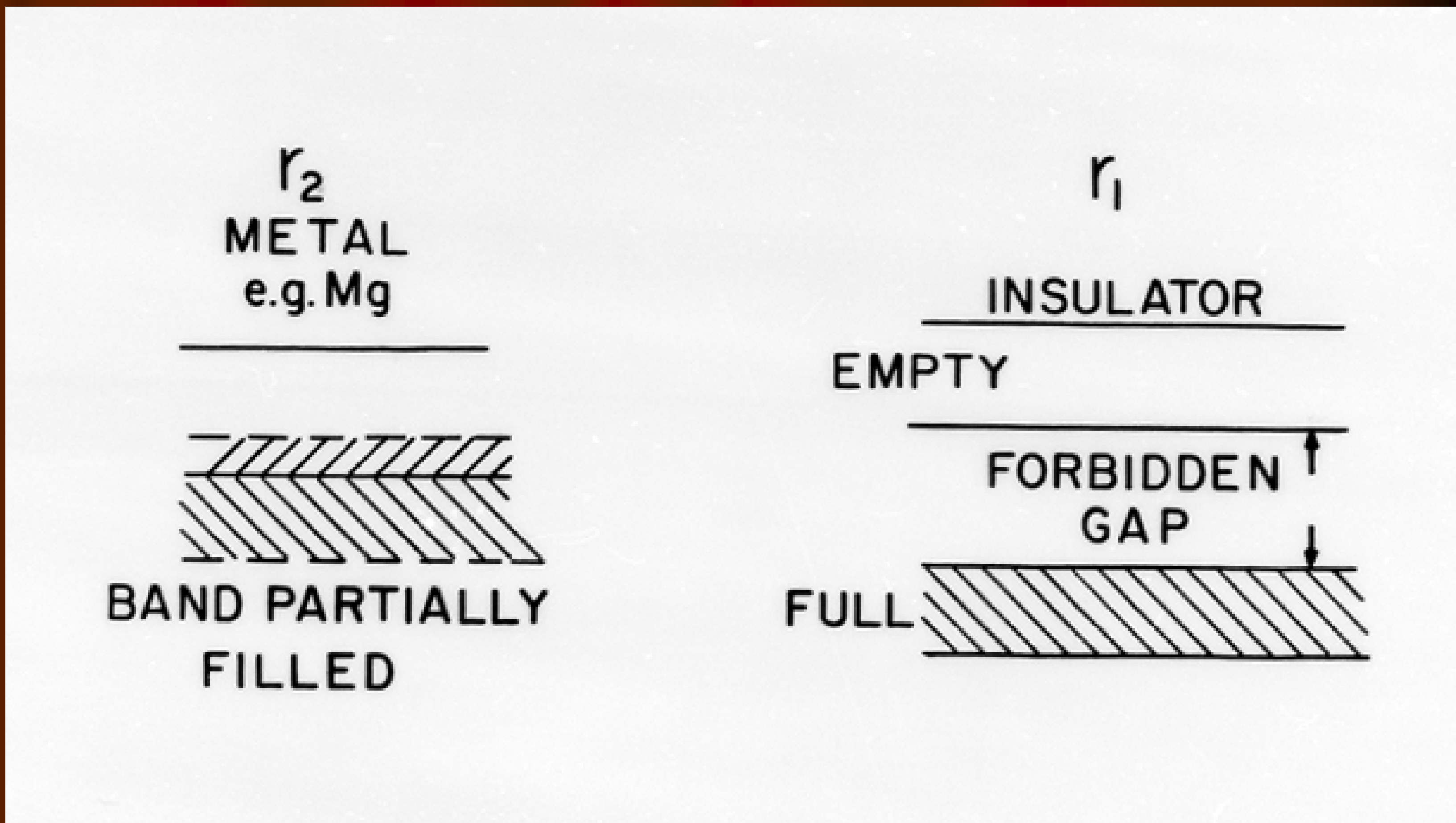
TL basis from Solid State Physics

- Uses the band theory of solids
- The forbidden energy gap is important
- The amount of impurities are important.
- A simple minded approach can explain this process.

Bohr Atom Levels




ENERGY
3p
3s
2p
2s
1s
r2
r1
SEPARATION



r_2
METAL
e.g. Mg
BAND PARTIALLY
FILLED
r_1
INSULATOR
EMPTY
FORBIDDEN
GAP
FULL

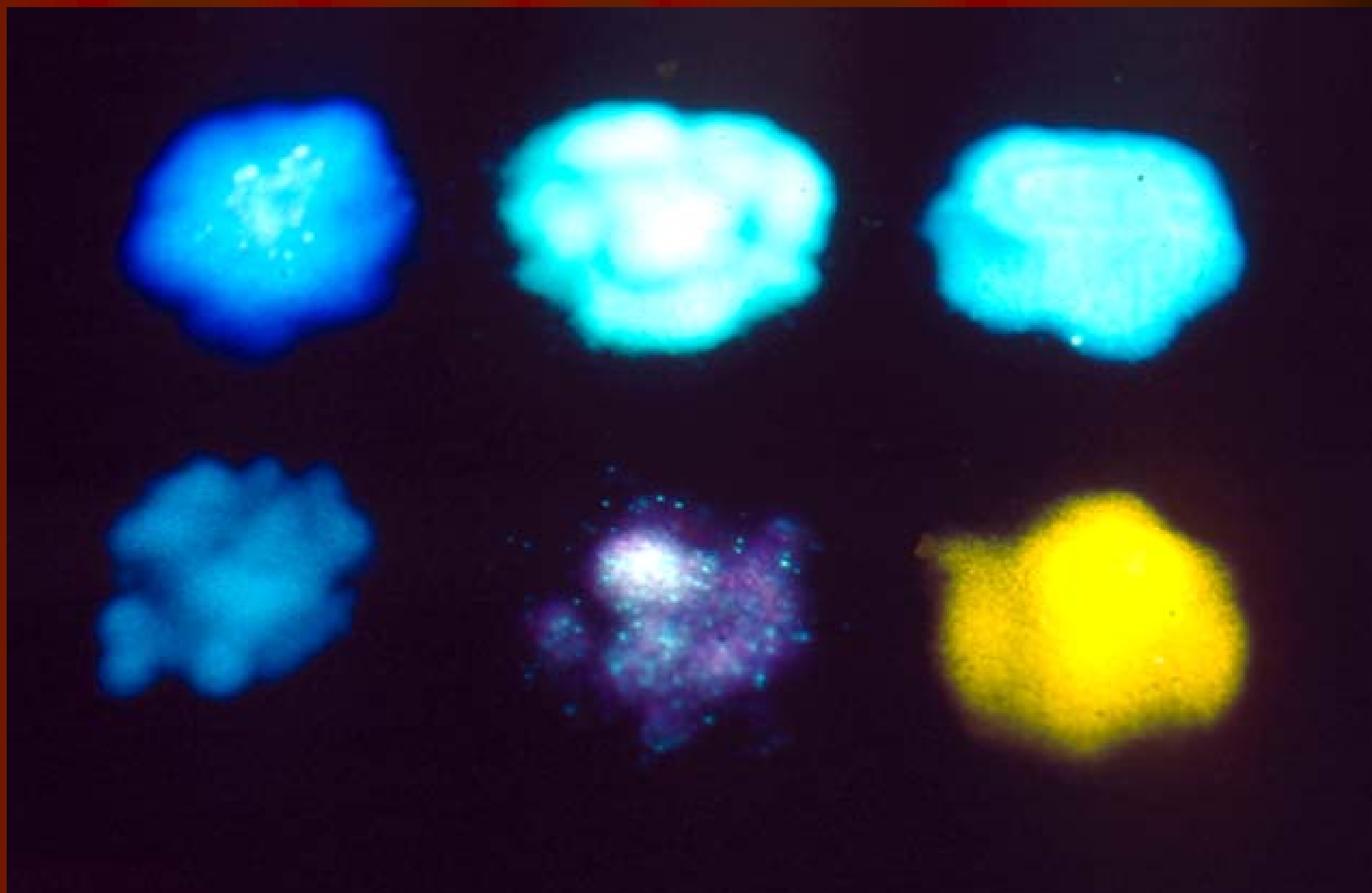
Thermoluminescence Dosimeters

- Store energy by electrons in trapping levels
- Material is an insulator (semiconductor too small a band gap (and too pure))
- Electrons released after heating and recombine with holes in Recombination centers (impurities)
- The light emitted is detected by photomultiplier tube in the reader.
- Traps affected by heating


TLD

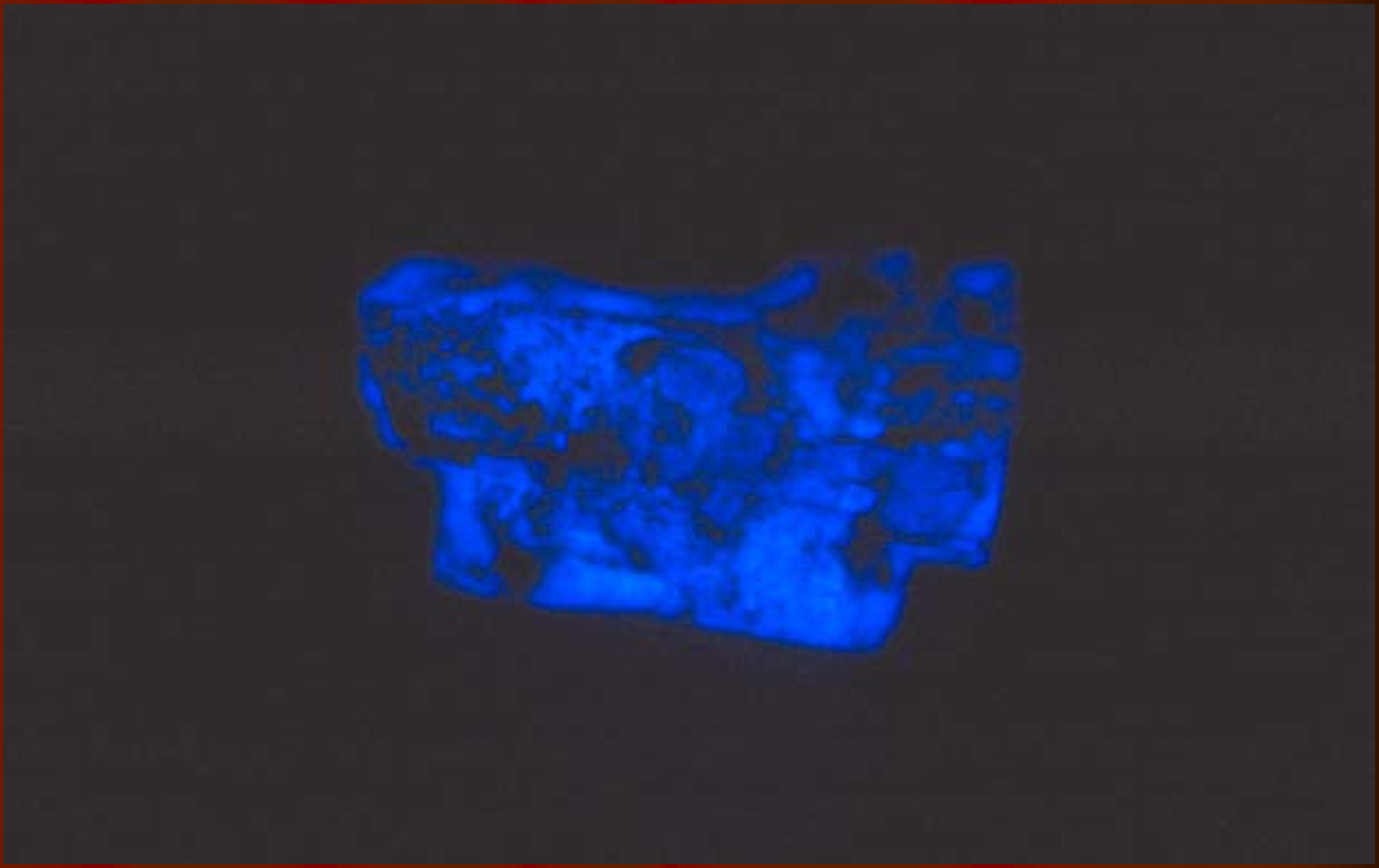
Light emitted

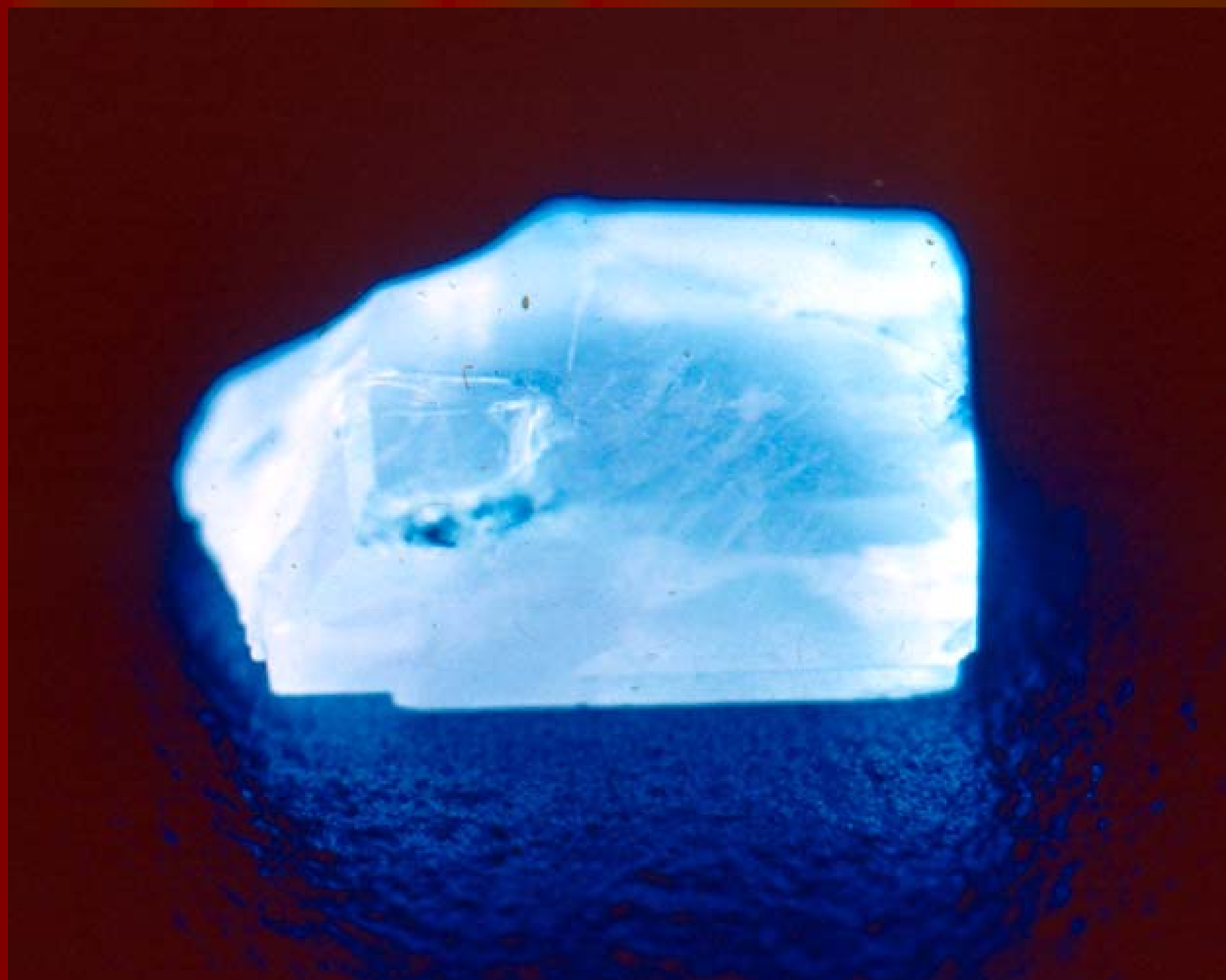
- Different colors (wavelengths) caused by the recombination center energy transitions.
- For example, Ti emits in the blue/ ultraviolet
- Some have 2 impurities and the light can be combined: aluminum oxide emits red, white (combination) and blue



Thermoluminescence

- As a general phenomena many materials show TL
- Some “gems” - e.g. smoky quartz can be turned clear by reading out the thermoluminescence.

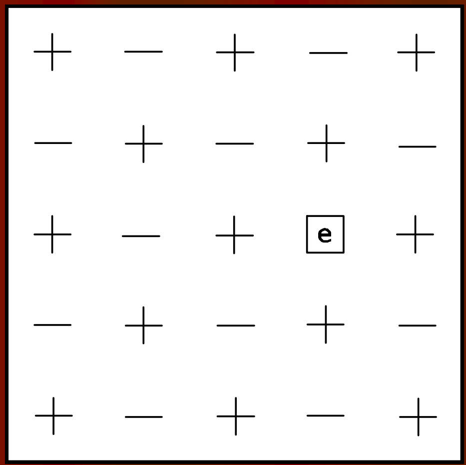


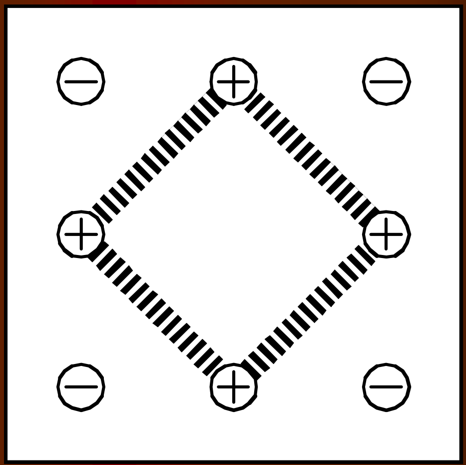


Causes

- Defect centers in the crystal lattice are responsible for the TL process
- Defects (impurities) are responsible for both the traps and for the recombination centers.
- The amount of impurities are important for “good” thermoluminescent response - Old TLD58

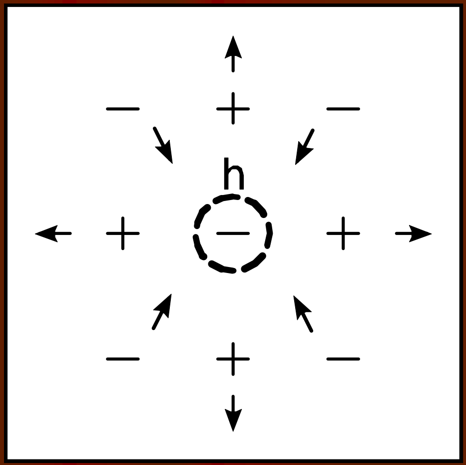
Color centers (traps)





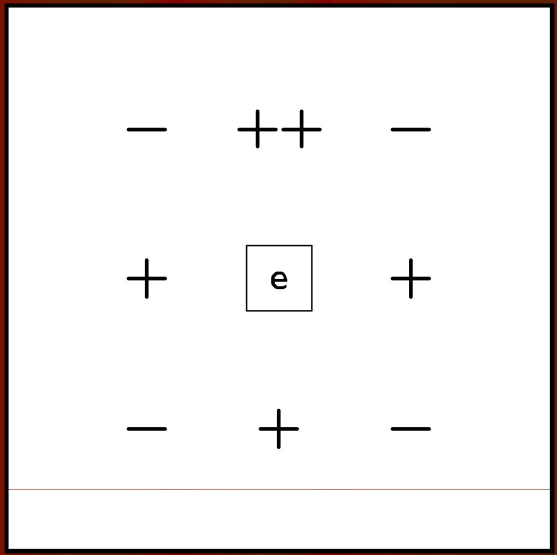
- Schematic of an F-center. (A) Diagram of a simple electron trap. The square represents an ion vacancy and *e* represents the electron filling the vacancy. (B) Diagram of an electron in a force field. The trapped electron is actually distributed among the surrounding positive cations (DeWerd and Stoebe 1972).

Hole center



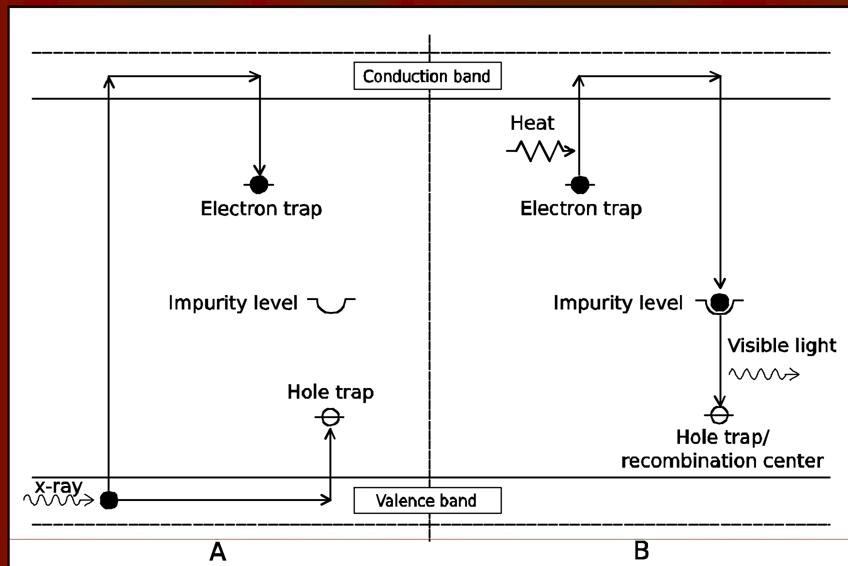
- Diagram of a V_k-center (simple hole trap). The hole is maintained at an anion position and causes redistribution of the surrounding ions (DeWerd and Stoebe 1972).

A Dipole center



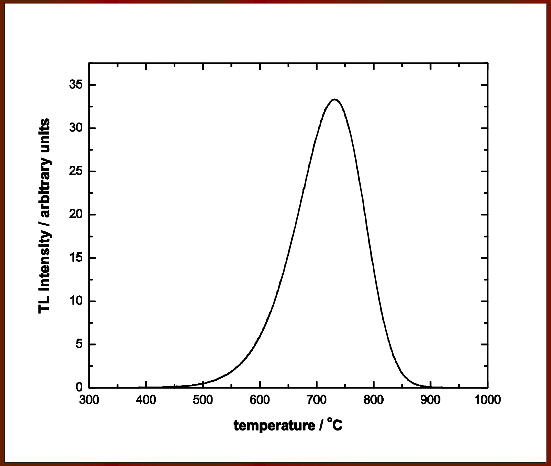
- Diagram of a Z-center, an impurity electron trap center (DeWerd and Stoebe 1972).

TL Process



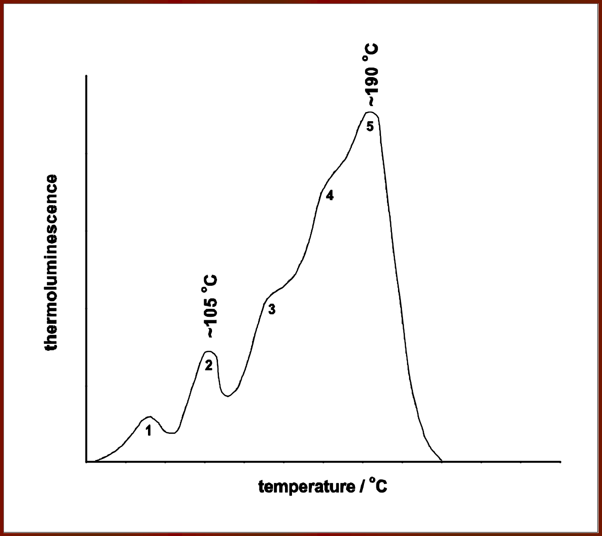
- (A) Energy-level diagram for thermoluminescent materials. In this diagram, the hole trap acts as the luminescence center. (B) Energy-level diagram showing the effect of impurities.

Glow Peak



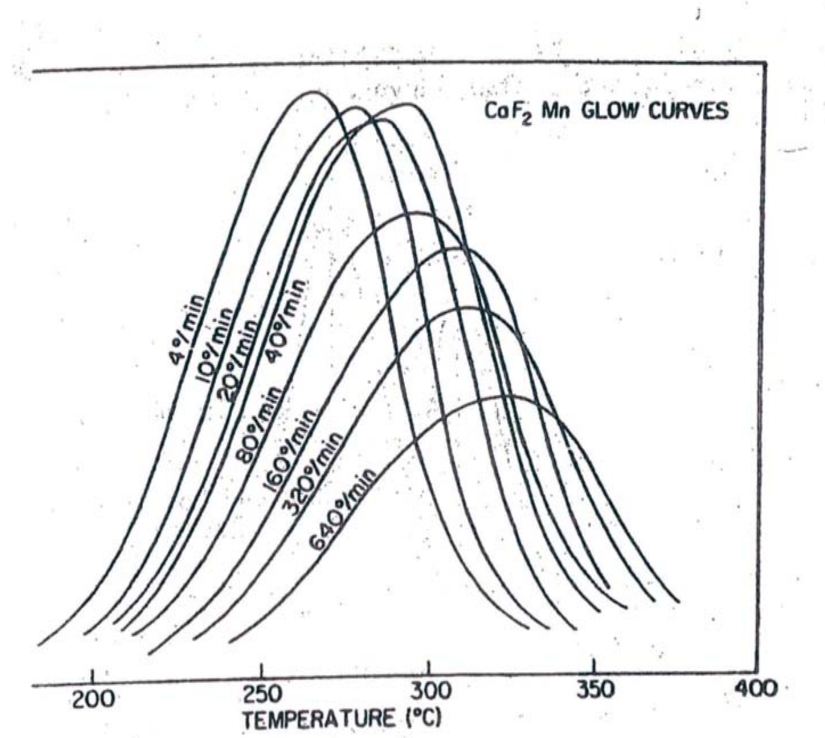
- Thermoluminescence glow peak that results from heating an irradiated TL phosphor. This hypothetical phosphor contains only one trap depth. The glow peak was calculated according to the work by Vejnovic *et al* (1998). Randall - Wilkins were the first to propose a theory to do this.

Multiple traps glow curve



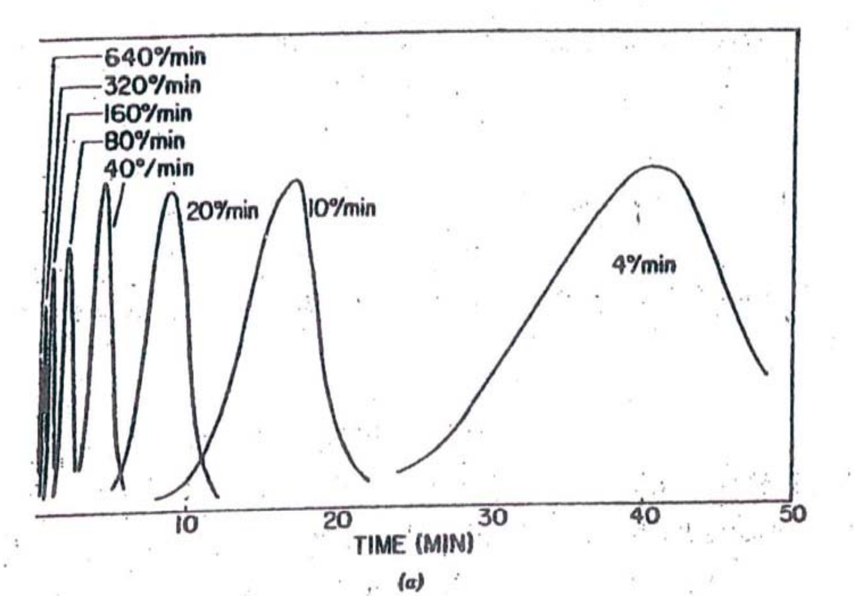
- Thermoluminescent glow curve for LiF:Mg,Ti. The individual glow peaks are numbered and correspond to different trap depths (DeWerd and Stoebe 1972).

Effect of Readout Temperature Rate on Glow Curve (Temperature of Readout)



(b)

Effect of Readout Temperature Rate on Glow Curve (Time of Readout)



Annealing effects

- Annealing is used to determine the traps of interest
- Low temperature traps fade away with time at room temperature.
- Basically want just the high temperature traps to remain (half life of 80 years)

Annealing Effects for LiF:Mg,Ti

- **400 C for 1 hour**
  - **Resets the trap structure and eliminates any electrons in residual traps.**
- 80 C for 24 hours
  - **Eliminates the traps that result in peak 2**
  - **Dimers become trimers (peak 5)**
- **100 C for 1 hour**
  - **Empties peak 2 traps - but has little effect on trap structure - does not remove traps.**

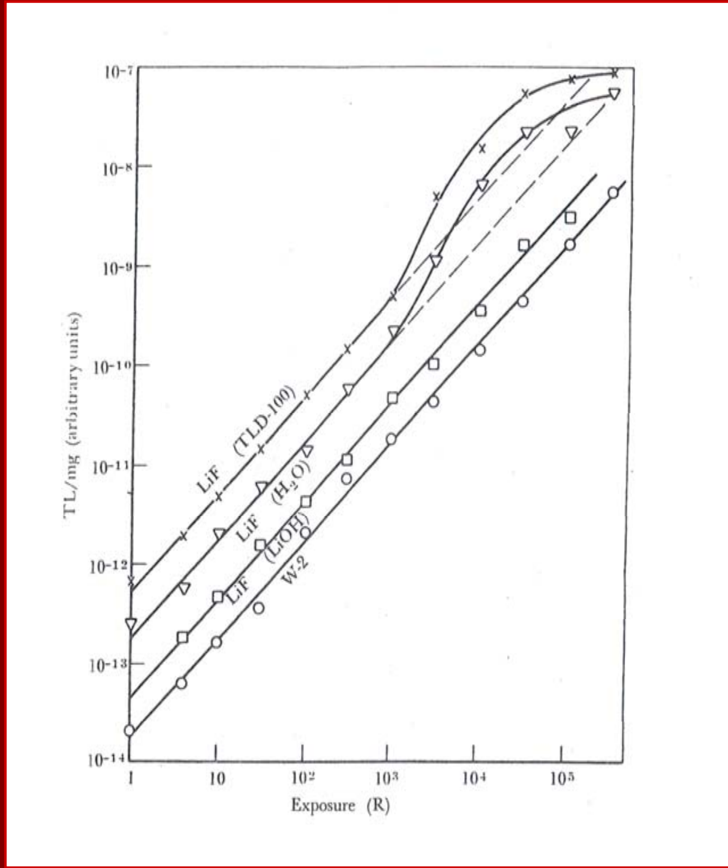
Cooling after annealing

- Cooling rate can have large effect on resulting TL
- Best cooling for greatest sensitivity is an aluminum plate at room temperature.
- Asbestos or slow cooling the worst. Electrons and trap structure changes.
- Good contact for cooling important

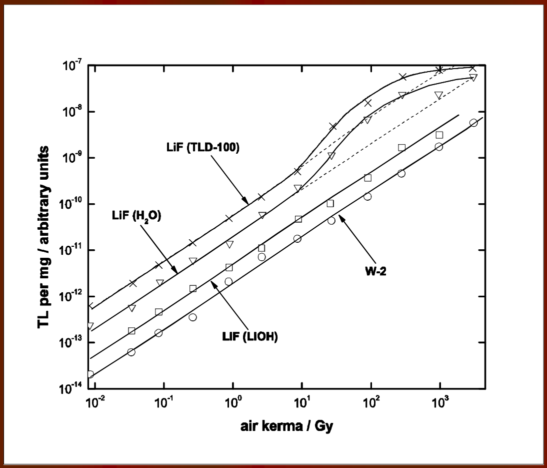
Parameters for LiF:Mg,Ti TLD

- TL Response with exposure or dose:
  - Linear up to the range 5 Gy to 10 Gy
  - Supralinear 10 Gy to 1.0 kGy
  - Damage after 1.0 kGy
- Supralinearity and damage
- TL sensitivity - light vs. exposure
- Annealing effects
- Energy Response

Supralinearity and Sensitivity affected by Impurities



Importance of impurities

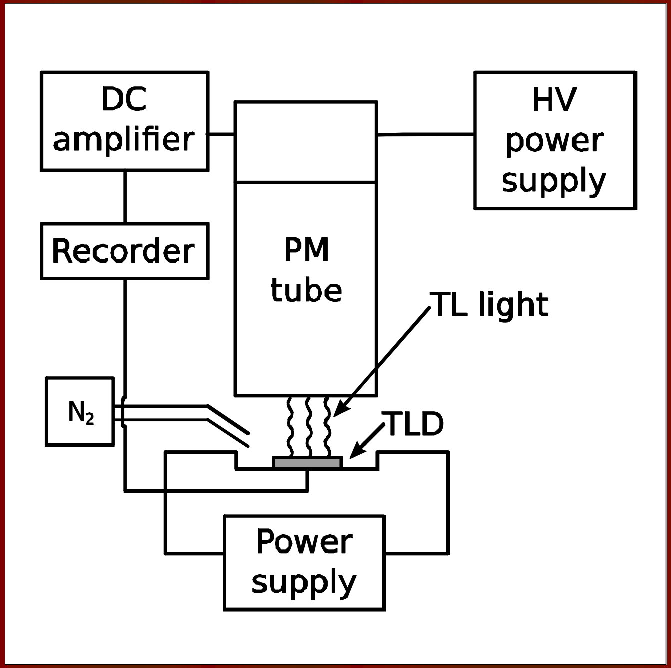


- Thermoluminescent output as a function of exposure for LiF:Mg,Ti with different levels of OH impurities. The concentrations of OH, Ti, and Mg in ppm for each phosphor are: TLD-100 (40, 12, 230), LiF (H_2O) (90, 10, 150), LiF (LiOH) (135, 10, 100), W-2 (200, 10, 100) (Stoebe and DeWerd 1985)

Readout

- TL Sample handling - Vacuum tweezers
- Stable high voltage on reader
- Dark current of PMT
- Infrared from heating pan - and its condition
- Hot gas used to eliminate pan
- Nitrogen flow for reduction of surface effects.

TL Reader

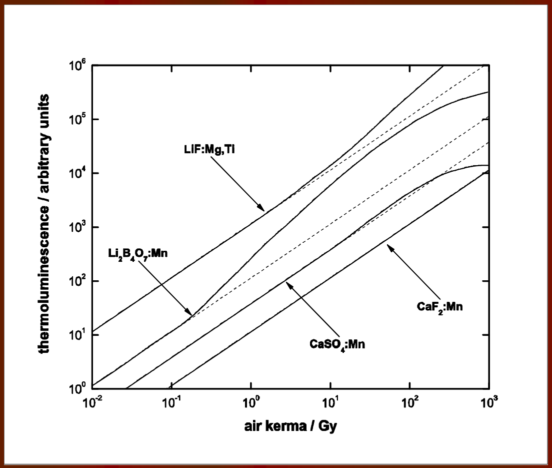


- Diagram of typical TLD reader components (adapted from Attix 1986).

Importance of PMT Match

- The wavelength sensitivity of the photomultiplier tube of the reader has a great effect on the TL sensitivity
  - LiF:Mg,Ti has a blue / ultraviolet emission and standard TL readers have a PMT optimized for this wavelength
  - $Li_2B_4O_7$:Mn has a yellow emission and needs a PMT responding to yellow for optimization. This PMT could have higher dark current.

Various TL Phosphors

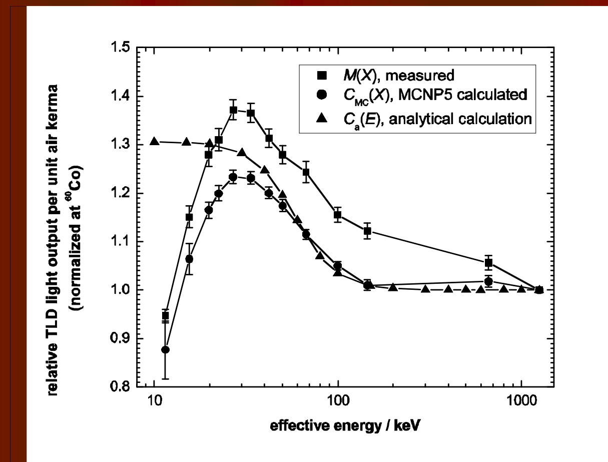


- **Thermoluminescent output as a function of exposure for different TL phosphors (adapted from Attix 1986).**

Energy Response

- There is an over response for lower energies compared to Cobalt 60
- Maximum over response is about 1.4 to 1.6 at about 100 kVp
- Decreasing at lower x-ray energies
- Energy of calibration point is important
- Linac energies may have an under response of 5% compared to cobalt.

Energy Response



- Measured TL output per unit air kerma as a function of photon energy normalized at the average ^{60}Co energy. All measurements were made in the linear region of the TLD output (Nunn *et al* 2008).

Advantages of TLD

- Advantages
  - Small size
  - Wide linear range
  - Reusable
- Disadvantages (Take Care!)
  - Slight instabilities in Sensitivity -be consistent
  - Susceptible to surface contamination - nitrogen gas
  - Structural damage - scratches -vacuum tweezers

Applications

- Radiation Therapy
  - External beam: Precision 2%, Energy correction to cobalt -5%
  - Brachytherapy: Precision 3%, energy correction, lower doses
- Diagnostic
  - Precision 5%, energy correction necessary
- Health Physics
  - Precision 10%, Mixture of energies

Conclusion

- TL points out the importance of knowing how the material and the instrumentation works.
- Must be aware of each TL parameter and how it is affected.
- Be consistent when you do something.