Thermoluminescent Dosimeters

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Introduction

Introduction

1. General

When scintillators (e.g., NaI, ZnS) absorb energy imparted by ionizing radiation, they immediately release some of this energy as light. For each particle of radiation interacting with the scintillator, a flash of light (scintillation) is produced. The greater the energy absorbed by the material, the brighter the flash.

When thermoluminescent materials (e.g., LiF) absorb energy, much of this energy is trapped rather than released immediately. The material must be heated for this trapped energy to be released as light.

Introduction

1. General

The total amount of light emitted during the heating process reflects the absorbed dose (i.e., the radiation energy absorbed).

The emitted light can’t be used to determine the energy deposited by individual particles of radiation. It reflects the total energy deposited by all the radiation interactions in the TL material.

Introduction

2. Thermoluminescent Materials

- crystalline solids (chips, rods, pellets, powders)
- non-conductors (valence band is full)
- thermoluminescence is a fairly common phenomenon
- most thermoluminescent materials (e.g., NaCl) are not suitable as TL dosimeters
- TL materials suitable for dosimetry: LiF
  $Li_2B_4O_7$
  CaF_2
  $CaSO_4$
  Al_2O_3

Introduction

2. Thermoluminescent Materials

Four LiF chips sandwiched between two sheets of Teflon and mounted on an aluminum card/holder with barcode.

Bulb dosimeter. TL materials affixed with a spiral wire to a heating element and encased in glass bulbs.

Band Structure and Traps

Band Structure and Traps

1. General

All materials contain impurities and defects.

When impurities are added intentionally to a TL material, the latter is said to be "doped."

The added impurities are referred to as activators. The identity of the activator might appear in parentheses after the formula for the TL material, e.g., LiF(Mg), or following a colon, e.g., LiF:Mg.

Electrons located at these impurities may possess energies that electrons in other parts of the solid cannot, i.e., they may possess energies in the band gap.

Band Structure and Traps

2. Electron and Hole Traps

Two types of impurities:	electron traps
	hole traps

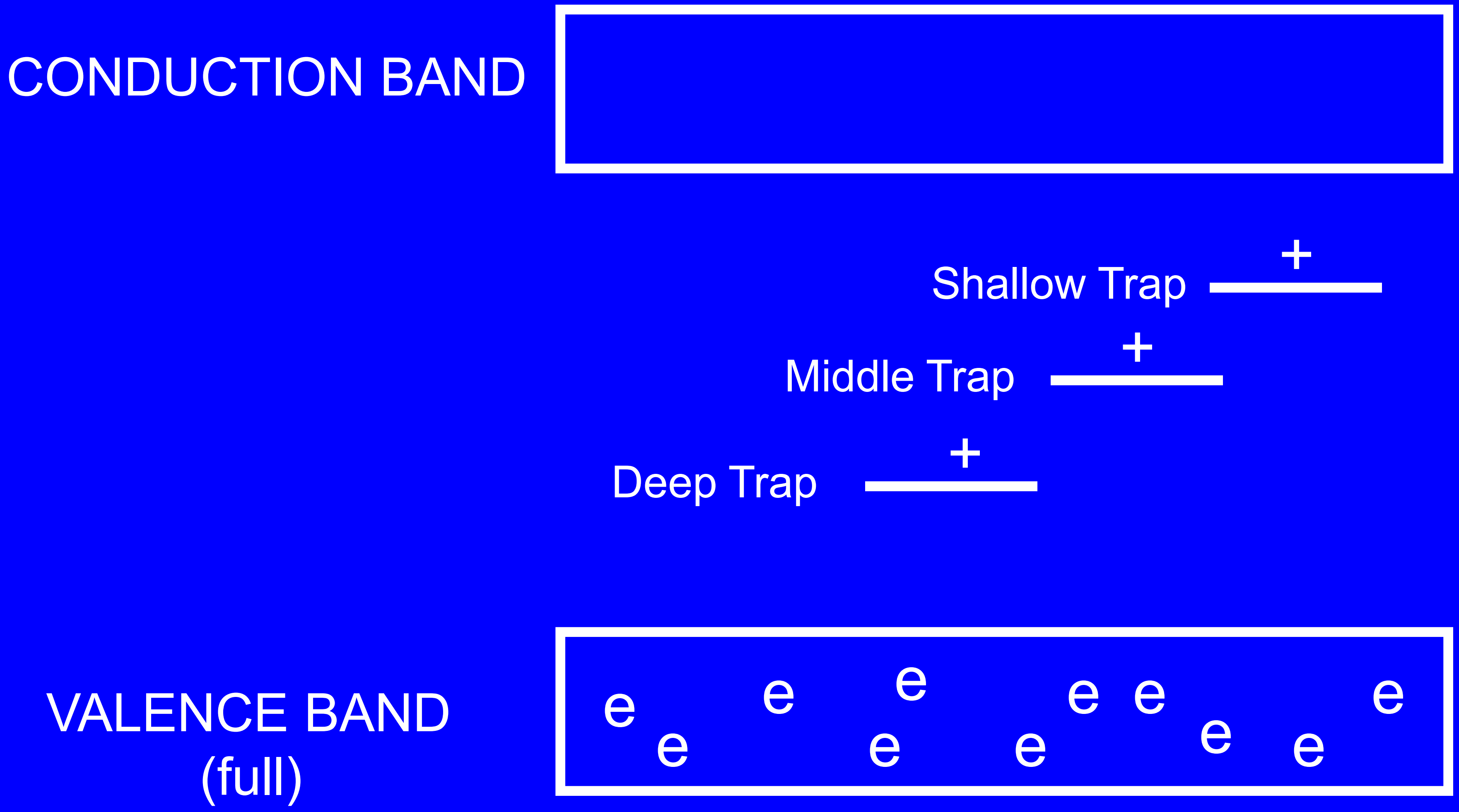
Electron traps are impurities with insufficient electrons to complete covalent bonds with the surrounding atoms.

Until filled by an electron, there is a hole at the electron trap. In the following figures, the hole is symbolized with a + sign.

TL materials have a specific number of traps, e.g., LiF is said to have 11 or 12 traps. The idea is that the material has a specific number of different types of impurities. Electrons at these impurities possess energies at different levels (depths) in the band gap.

Band Structure and Traps

3. Electron Traps



CONDUCTION BAND

Shallow Trap

Middle Trap

Deep Trap

VALENCE BAND
(full)

Band Structure and Traps

3. Electron Traps

The main electron trap of LiF (the trap that accumulates the most electrons) is believed to be produced by a magnesium trimer.

Magnesium is a natural impurity in LiF and is ordinarily found at a concentration of 175 ppm.

Band Structure and Traps

4. Hole Traps

Hole traps are impurities with more unpaired electrons than needed to form covalent bonds with the surrounding atoms.

In the case of LiF, the main hole trap is believed to be a $Ti(OH)_n$ complex. Like magnesium, titanium is an natural impurity in LiF. The titanium concentration is believed to be on the order of 10 ppm.

The extra electrons at such impurities are more loosely bound than those forming covalent bonds. Their energies are also higher, just above those in the valence band.

Band Structure and Traps

4. Hole Traps

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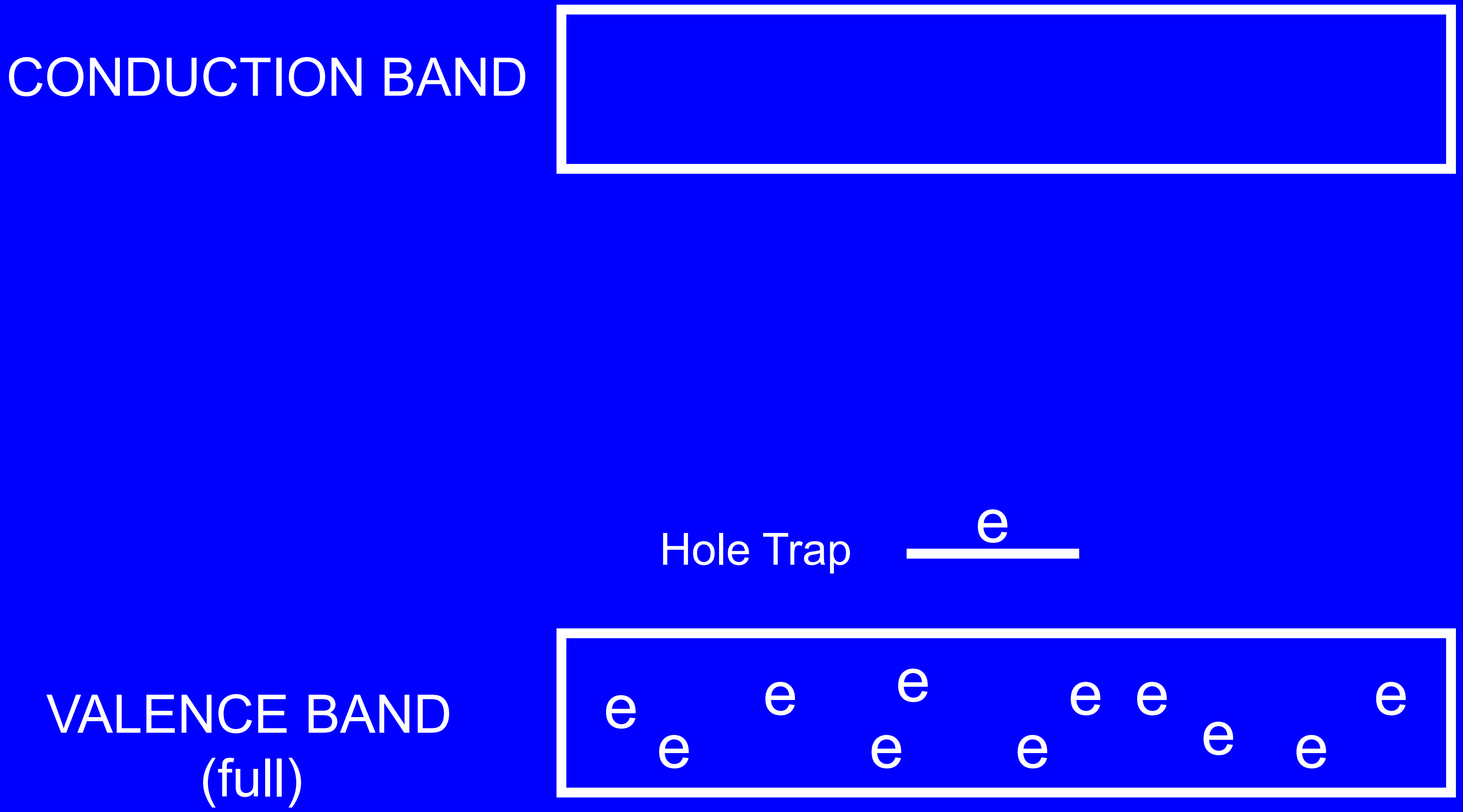
Band Structure and Traps

4. Hole Traps



CONDUCTION BAND

Hole Trap

e

VALENCE BAND
(full)

e e e e e e e e e e e e

Band Structure and Traps

5. Energy Absorption and Trapping

When radiation interacts with a TL material, energy is transferred to electrons. Some of these electrons absorb sufficient energy to be promoted from the valence band to the conduction band.

Once in the conduction band, the electrons are mobile and some will move to the electron traps.

At an electron trap (now filled), the electrons possess more energy than they did before the radiation interaction.

Band Structure and Traps

5. Energy Absorption and Trapping

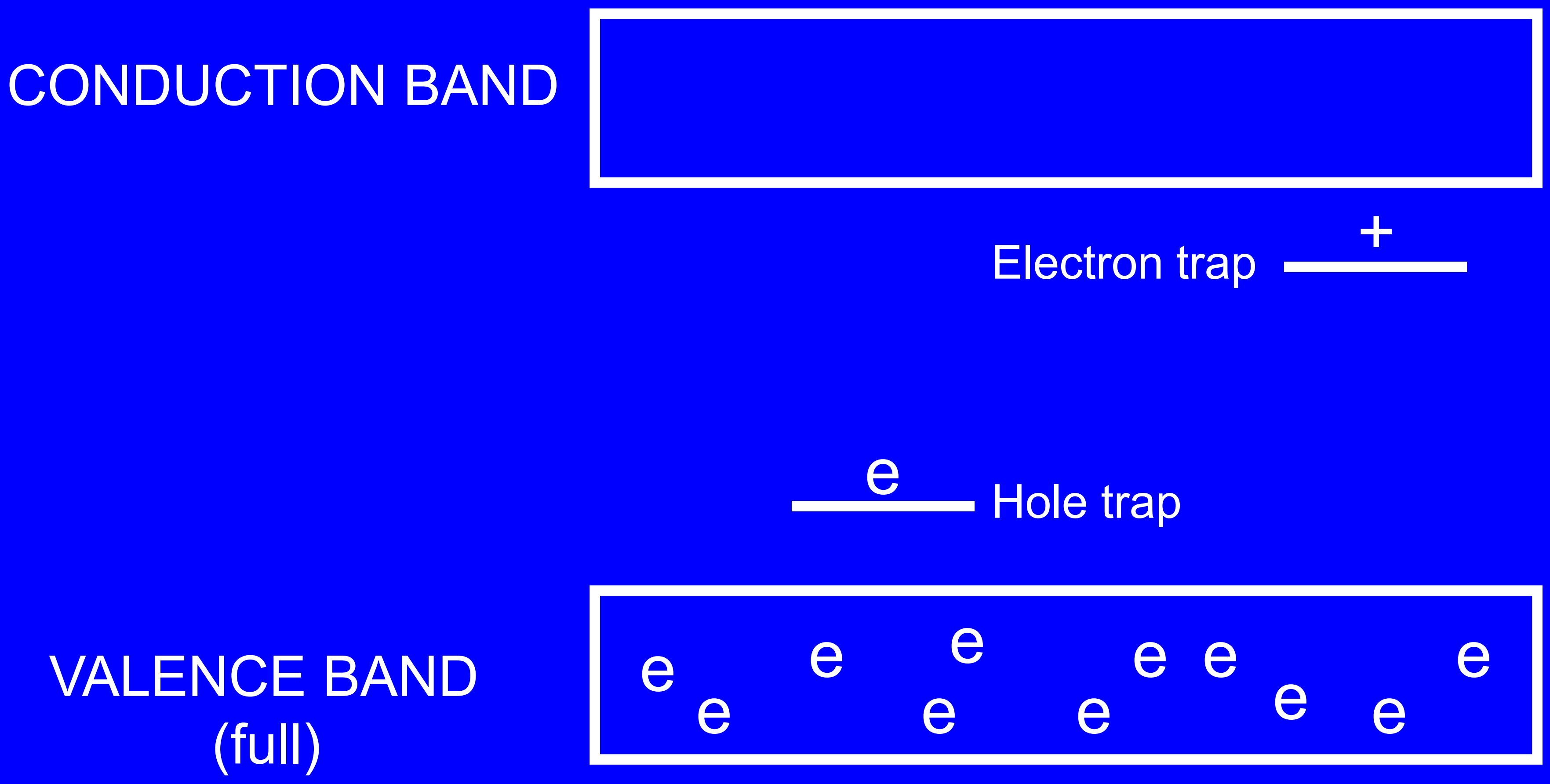
Electrons at the empty hole traps fall to fill the holes created in the valence band.

In effect, the holes have moved from the valence band to the hole traps. the latter are now filled. This leaves the hole trap filled.

Some of the electron traps and hole traps are now filled. This represents trapped energy.

Band Structure and Traps

Electron in the valence band absorbs radiation energy.



CONDUCTION BAND

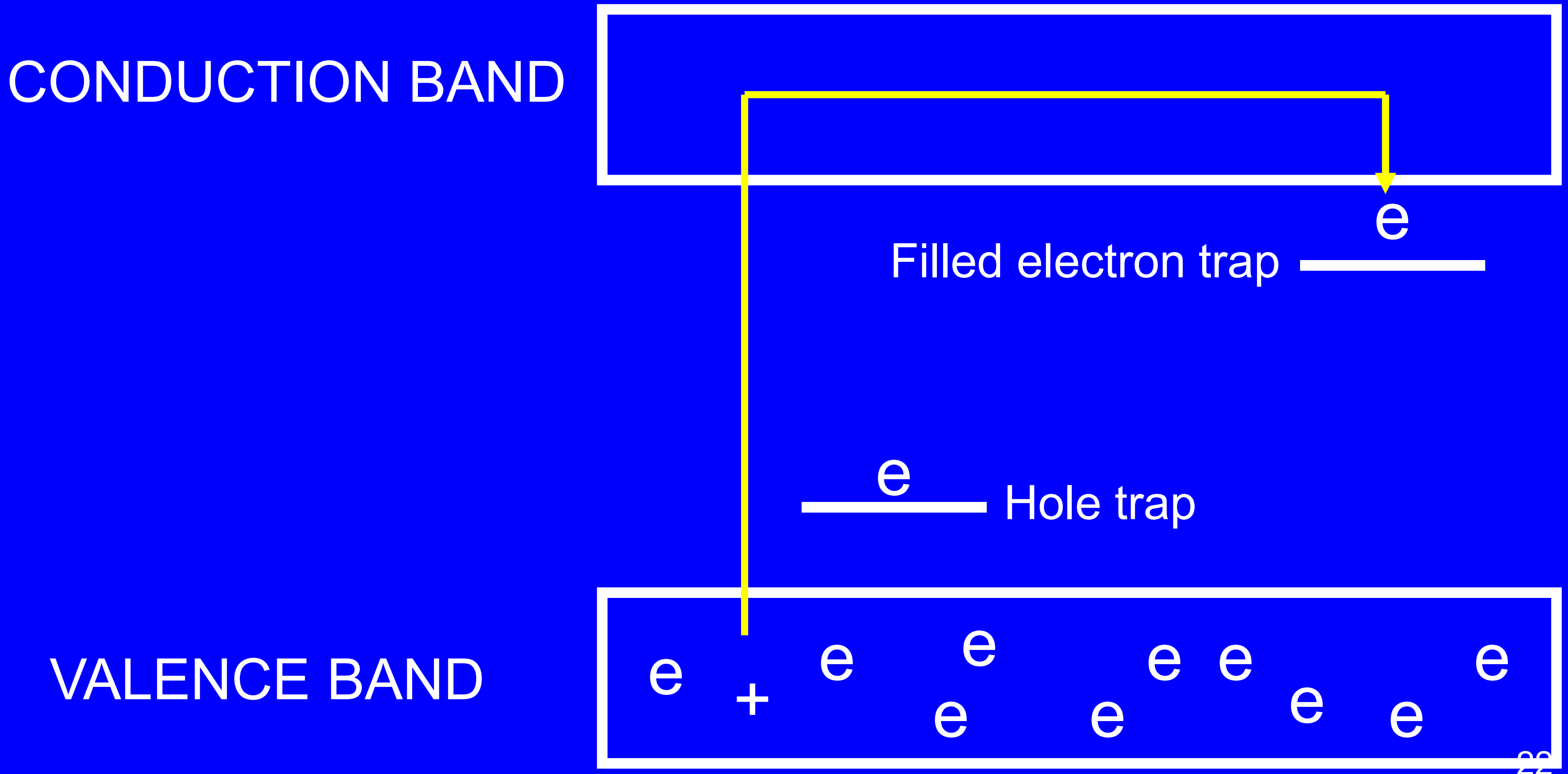
Electron trap

Hole trap

VALENCE BAND
(full)

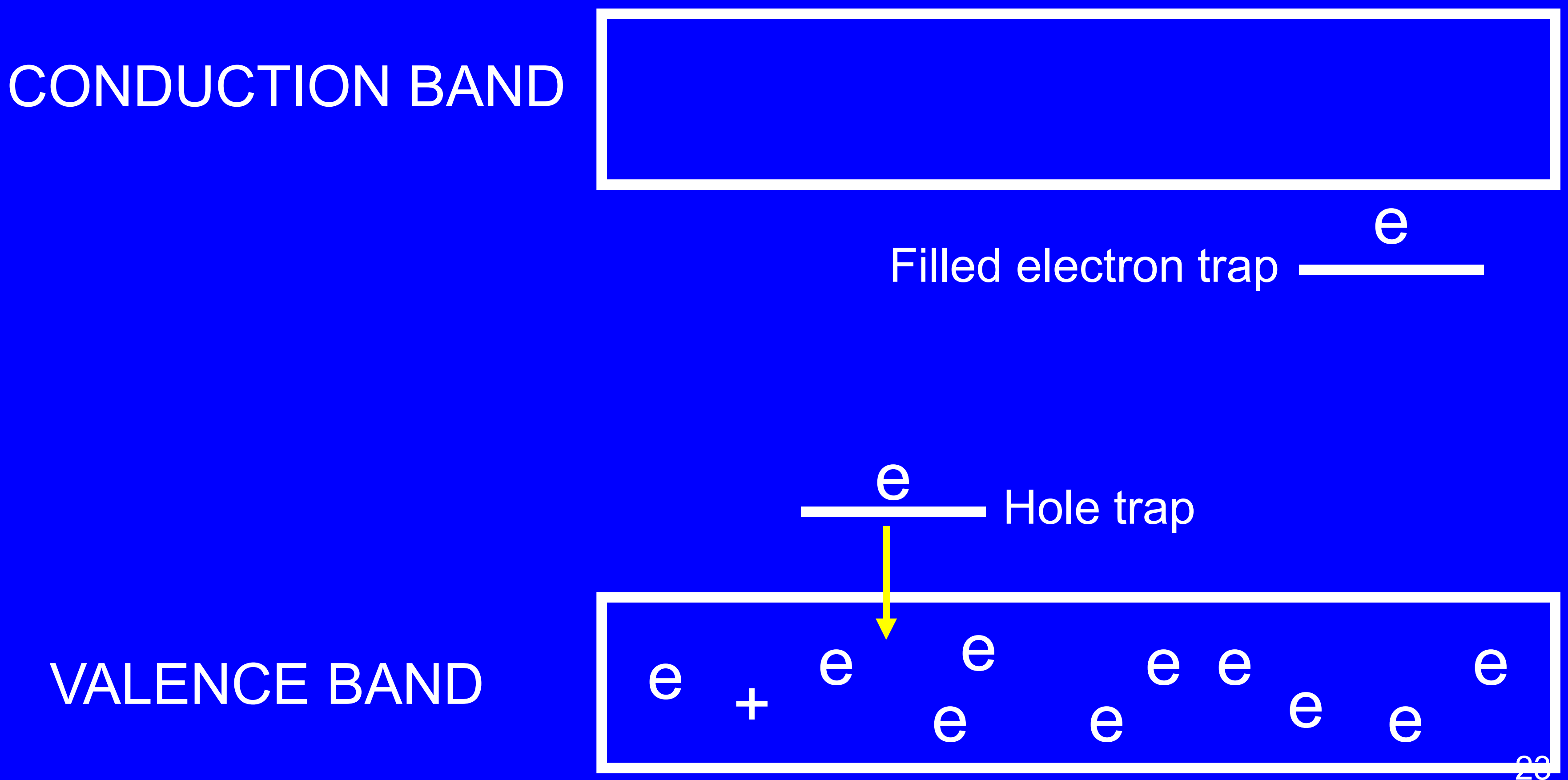
Band Structure and Traps

The electron is promoted to the conduction band. It then moves to a positively charged electron trap.



Band Structure and Traps

Extra electron at hole trap falls to fill hole in the valence band.



CONDUCTION BAND

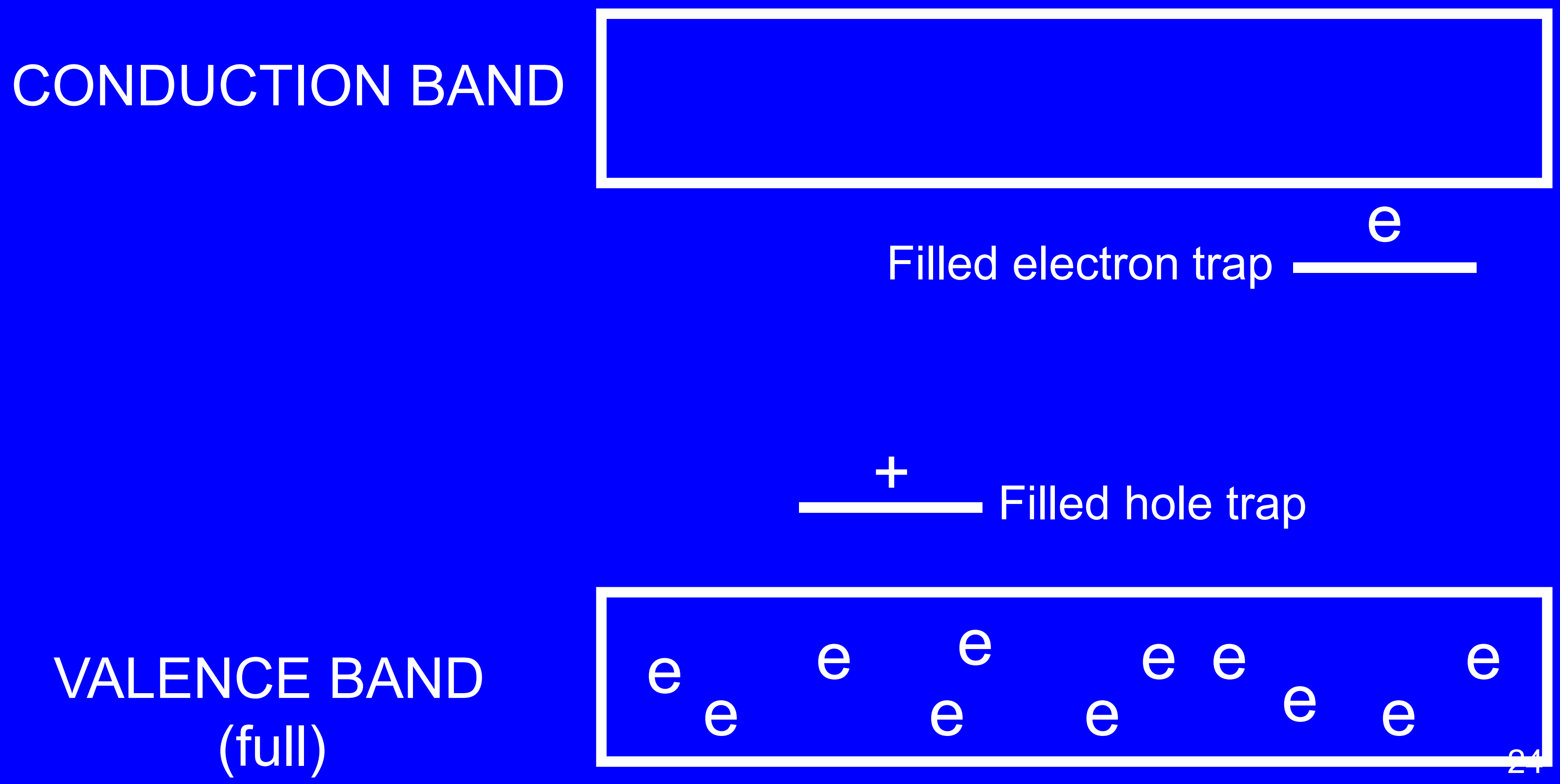
Filled electron trap

Hole trap

VALENCE BAND

Band Structure and Traps

Both the electron trap and the hole trap are now filled. This represents trapped energy. The net effect has been to raise an electron from the hole trap to the electron trap.



CONDUCTION BAND

Filled electron trap

Filled hole trap

VALENCE BAND
(full)

Heating, Recombination and Light Emission

Heating, Recombination and Light Emission

1. General

Upon heating, many of the trapped electrons and holes will recombine at what are known as recombination centers. This recombination results in the emission of light.

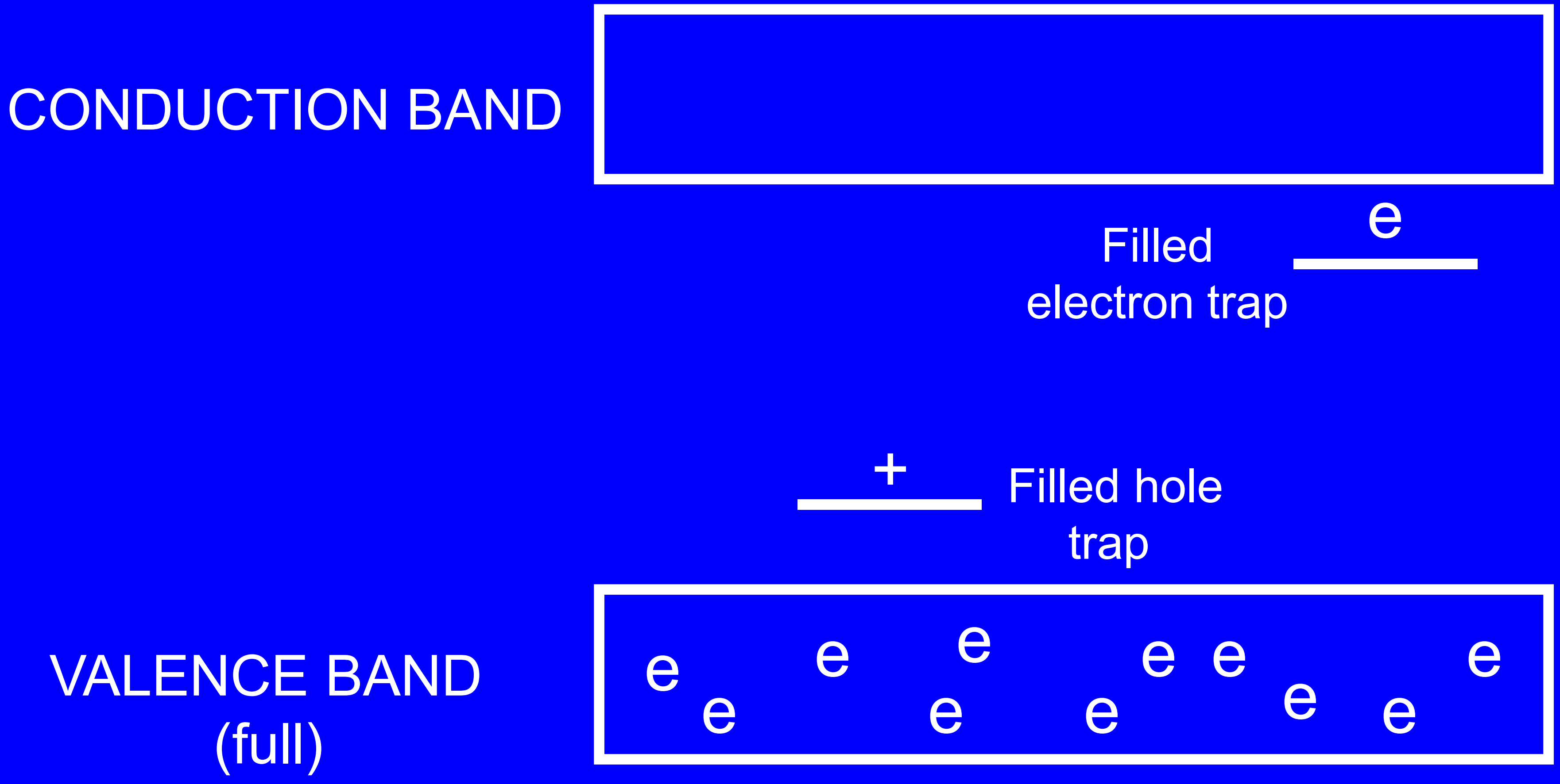
When heating promotes a trapped electron into the conduction band, the electron moves to a filled hole trap. In this case, the hole trap is the recombination center.

The recombination involves the electron falling from the conduction band to a lower energy at the filled hole trap. In most cases this results in the emission of a photon whose wavelength is on the order of 300-600 nm.

Heating, Recombination and Light Emission

2. Hole Trap as the Recombination Center

Post exposure. The electron trap and the hole trap are filled.



CONDUCTION BAND

Filled
electron trap

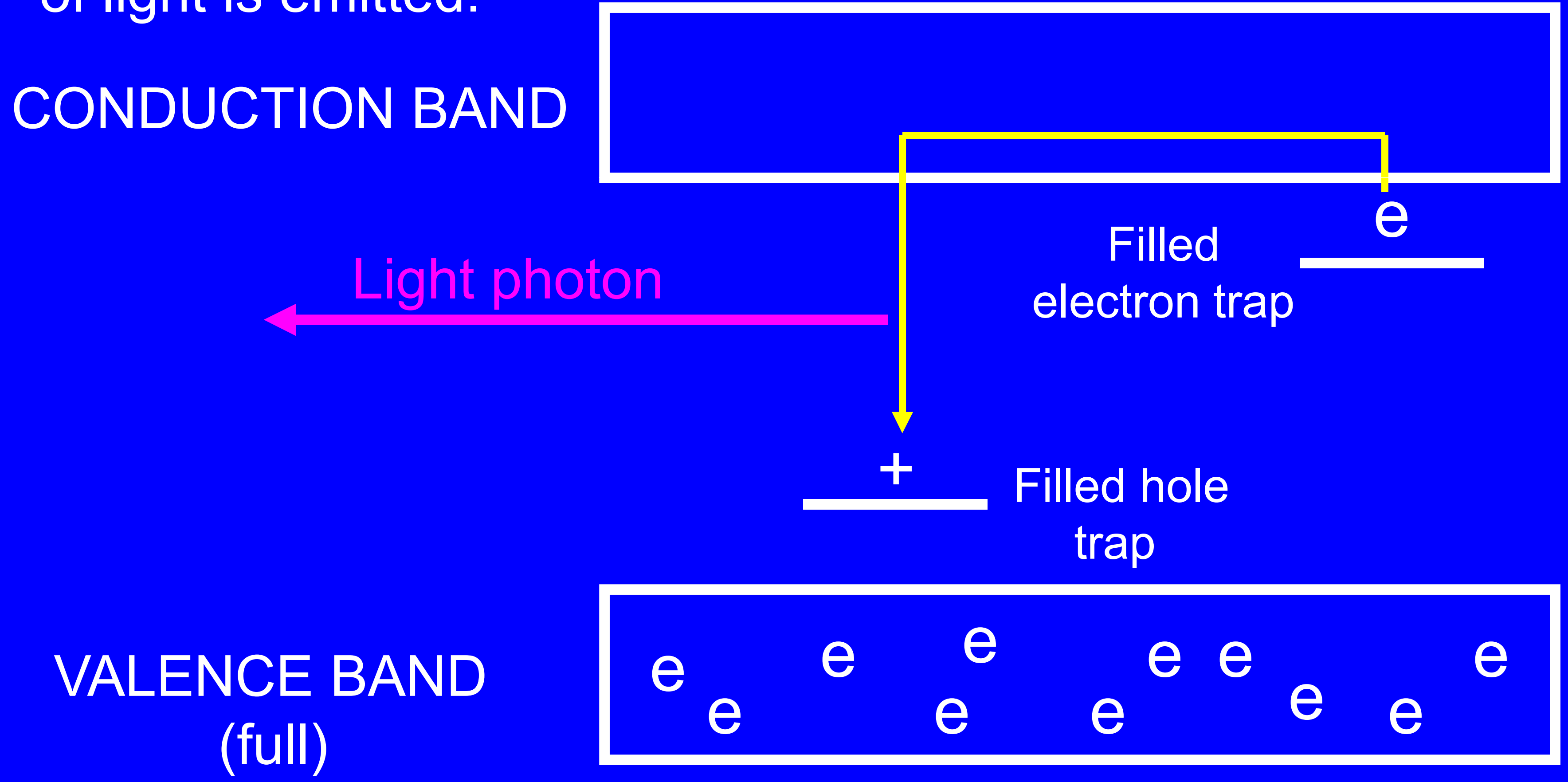
Filled hole
trap

VALENCE BAND
(full)

Heating, Recombination and Light Emission

2. Hole Trap as the Recombination Center

TL material is heated. Trapped electron promoted to the conduction band and moves to the filled hole trap. A photon of light is emitted.



CONDUCTION BAND

e

Filled electron trap

Light photon

+

Filled hole trap

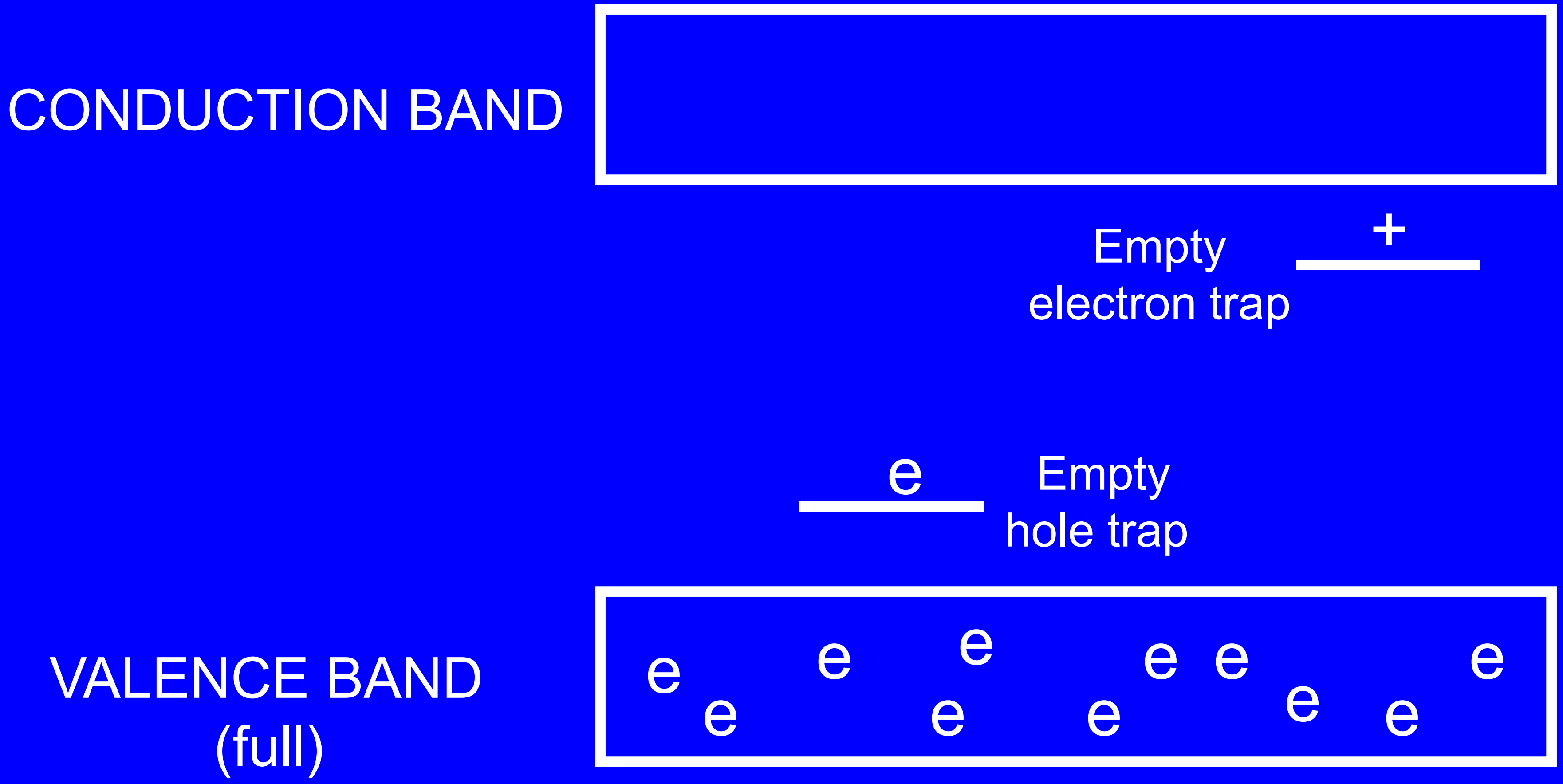
VALENCE BAND (full)

e e e e e e e e e e e e

Heating, Recombination and Light Emission

2. Hole Trap as the Recombination Center

The pre-exposure situation: electron and hole traps are empty. The electrons are in the lowest possible energy state.



CONDUCTION BAND

+

Empty
electron trap

e

Empty
hole trap

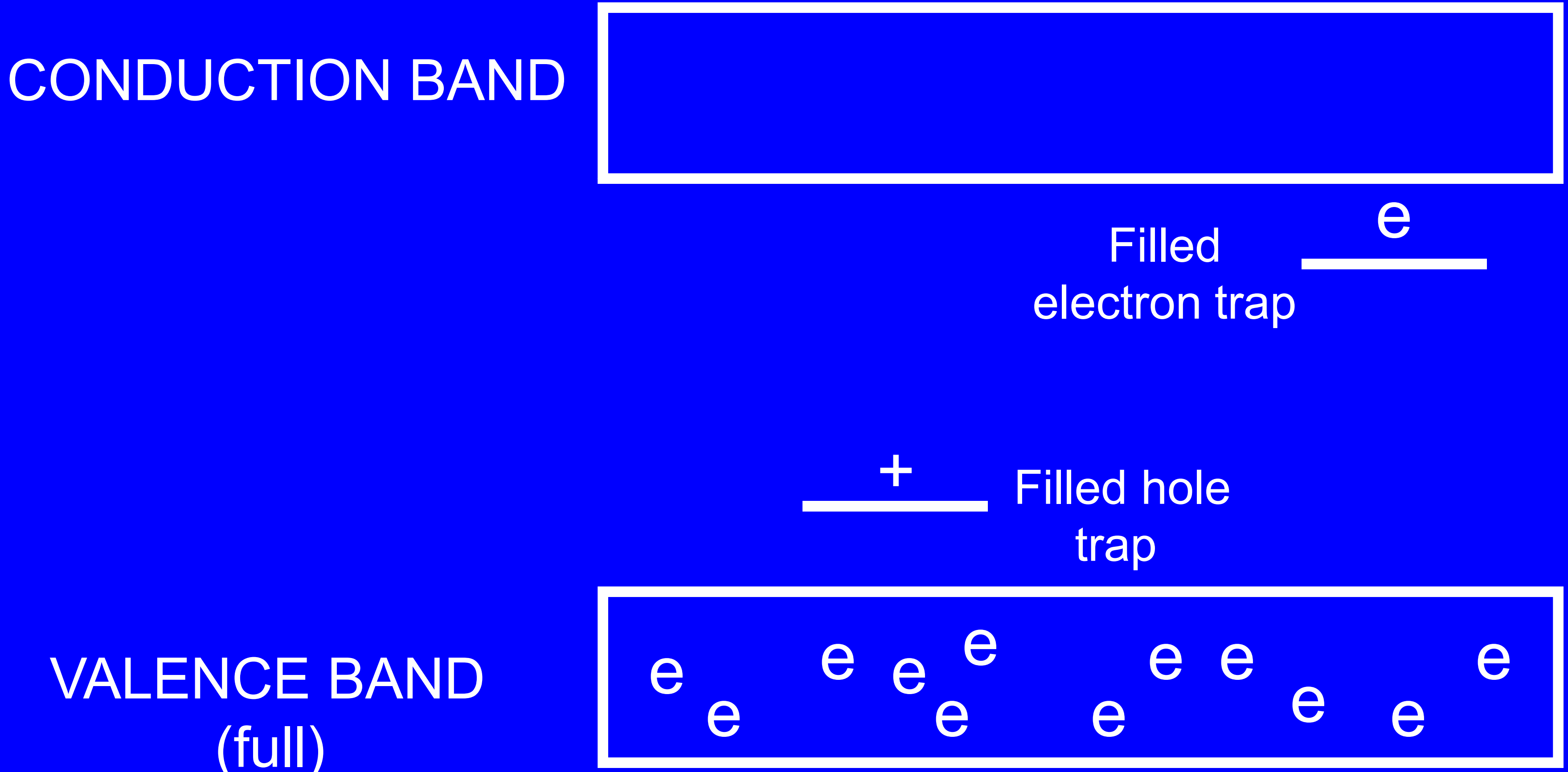
VALENCE BAND
(full)

e e e e e e e e e e e e

Heating, Recombination and Light Emission

3. Electron Trap as the Recombination Center

Another recombination mechanism: In the following figures, the electron trap serves as the recombination center.



CONDUCTION BAND

Filled
electron trap

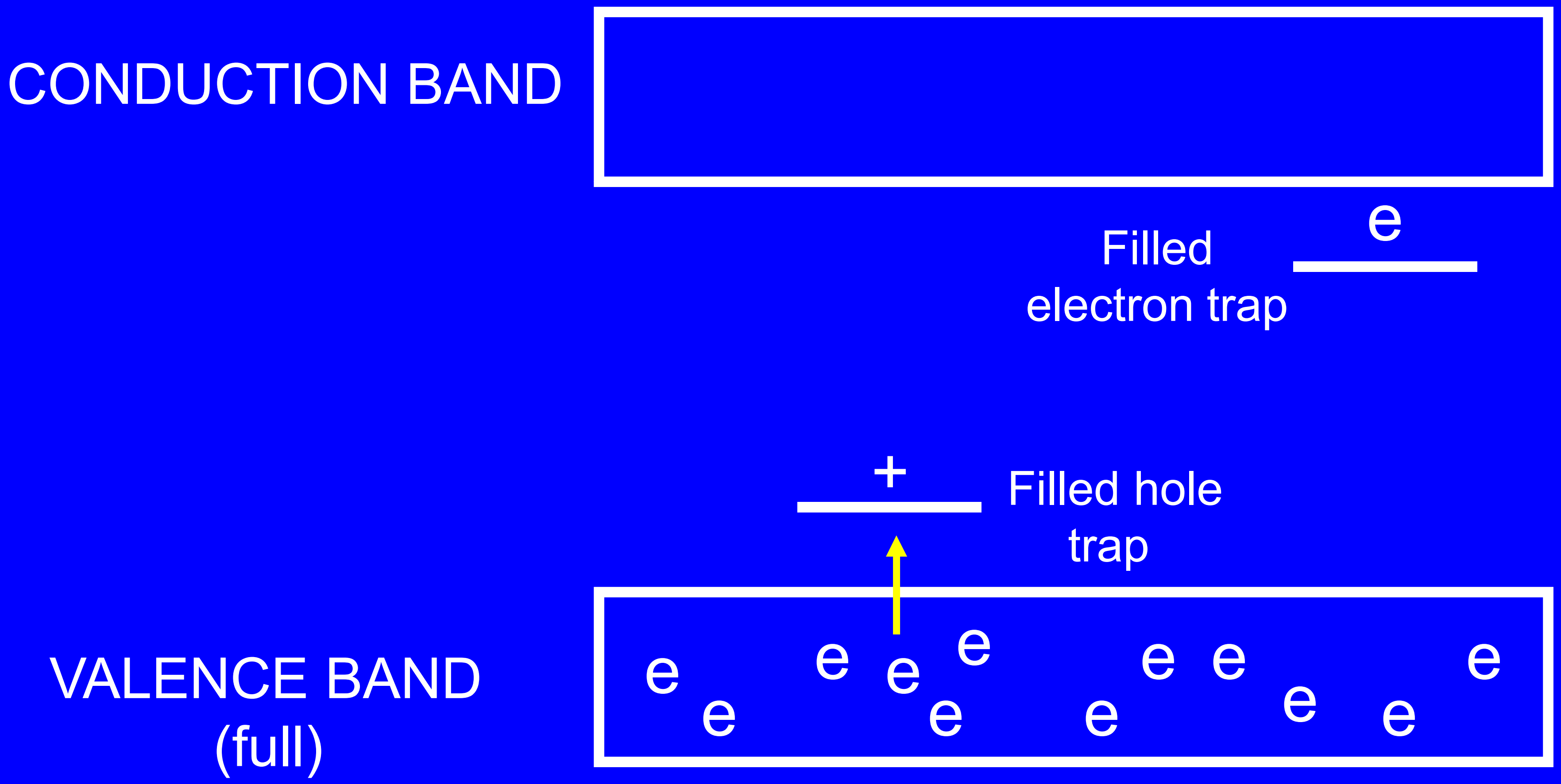
Filled hole
trap

VALENCE BAND
(full)

Heating, Recombination and Light Emission

3. Electron Trap as the Recombination Center

The TL material is heated. An electron in the valence band is promoted to the filled hole trap.



CONDUCTION BAND

e

Filled electron trap

+

Filled hole trap

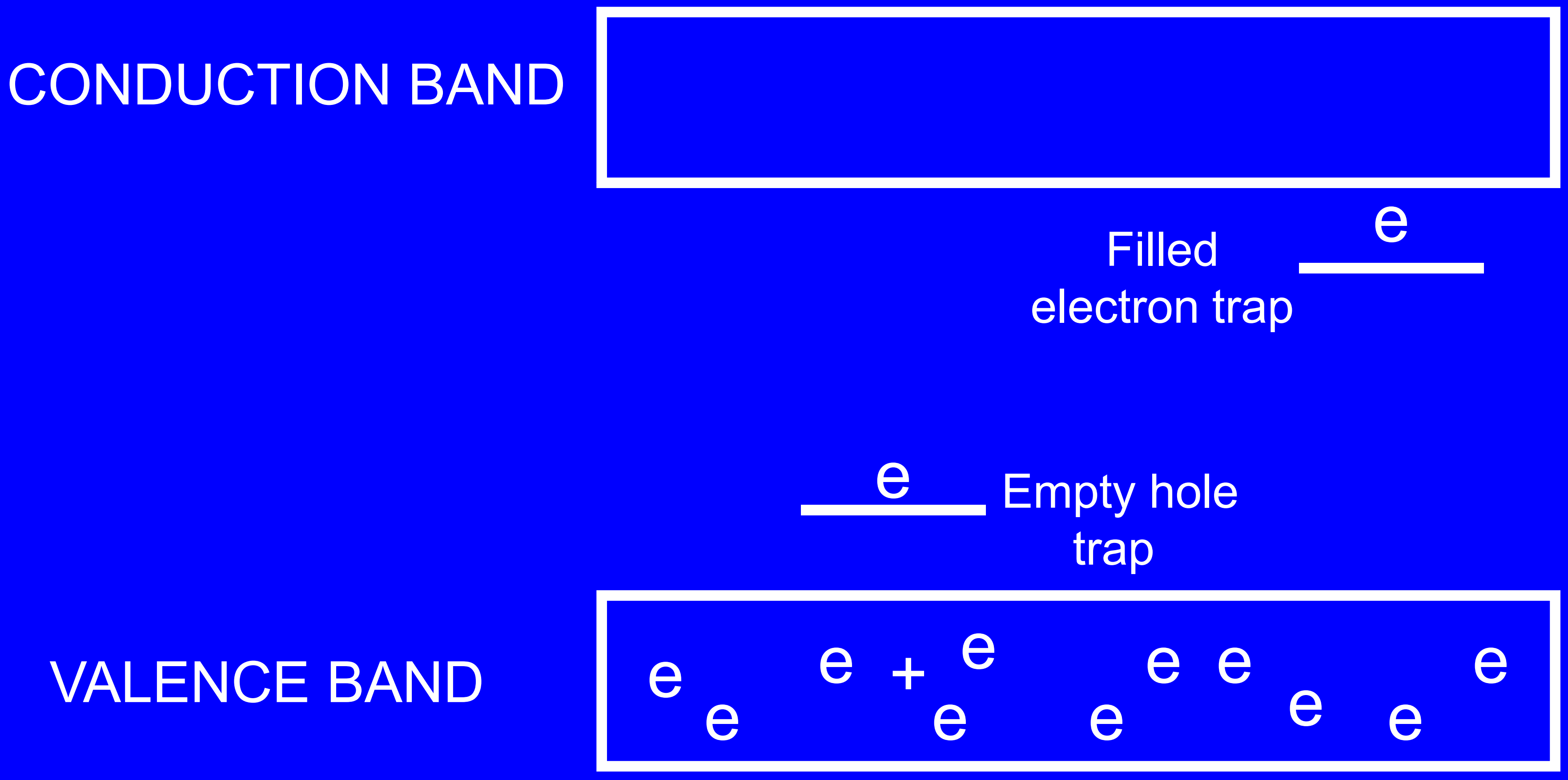
VALENCE BAND (full)

e e e e e e e e e e e e e

Heating, Recombination and Light Emission

3. Electron Trap as the Recombination Center

The hole trap is now empty and there is a hole (vacancy) in the valance band.



CONDUCTION BAND

e

Filled
electron trap

e

Empty hole
trap

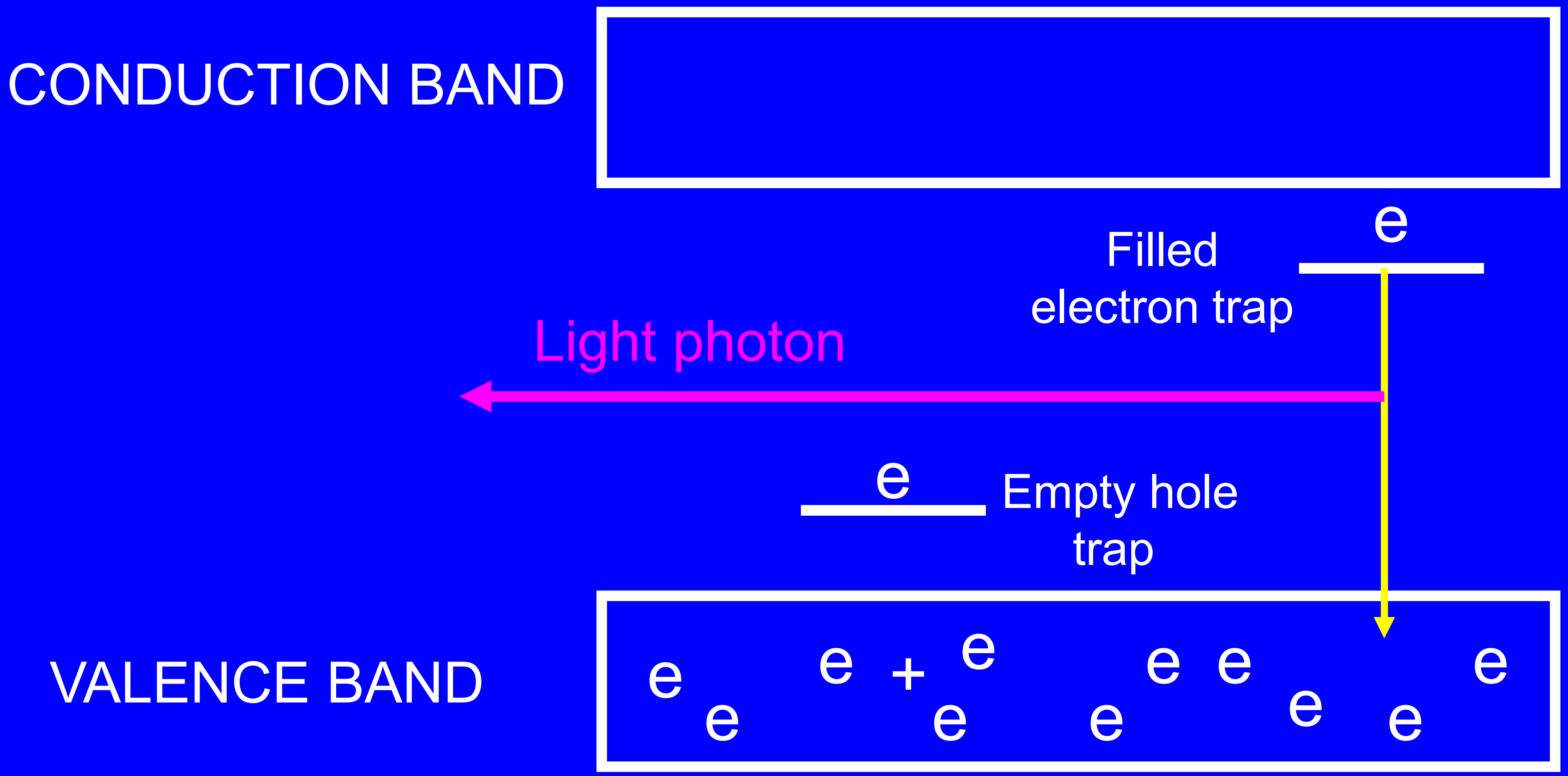
VALENCE BAND

e e e + e e e e e e e e e

Heating, Recombination and Light Emission

3. Electron Trap as the Recombination Center

The electron in the electron trap falls to fill the hole (vacancy) in the valence band.



CONDUCTION BAND

e

Filled
electron trap

Light photon

e

Empty hole
trap

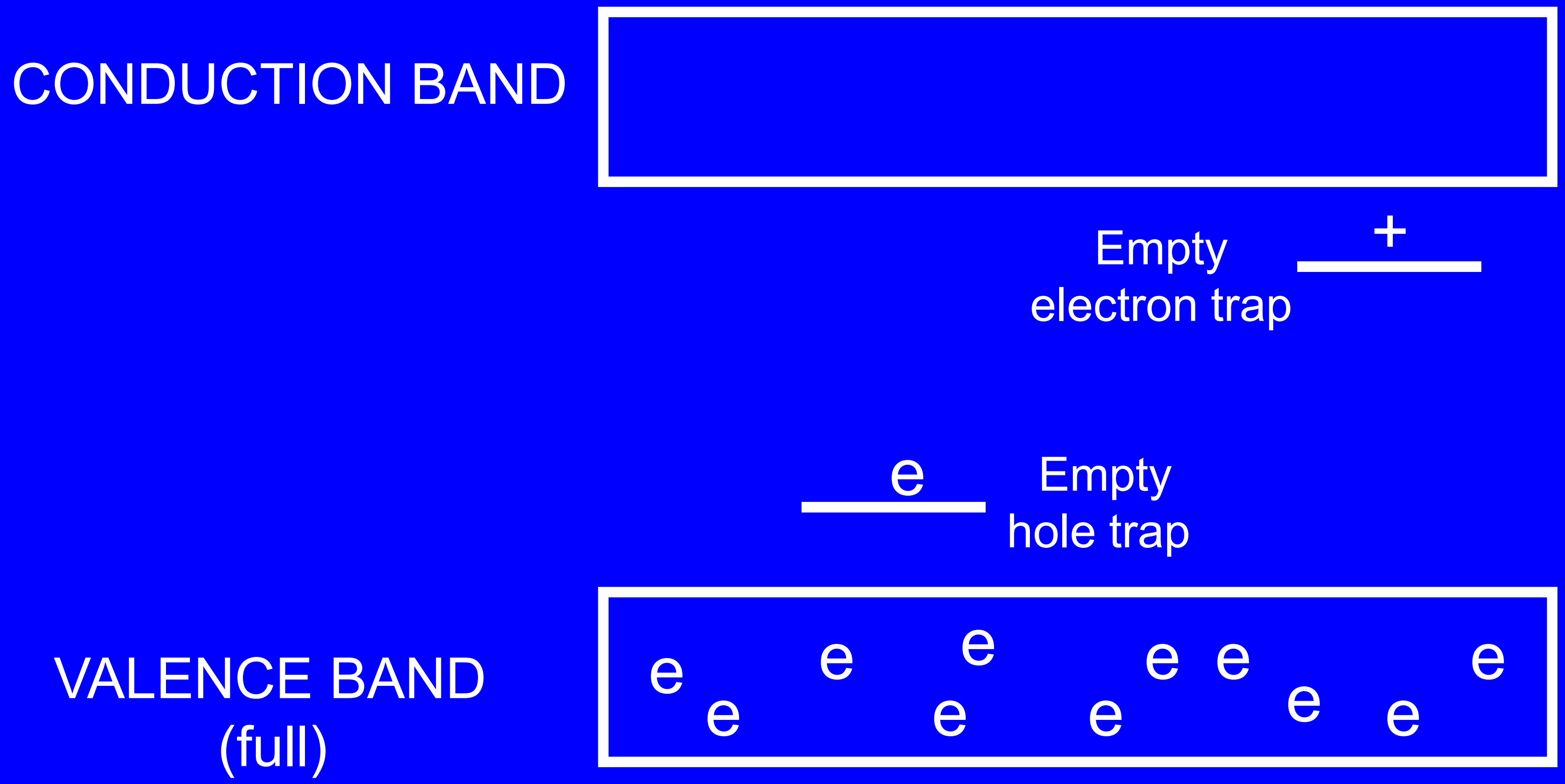
VALENCE BAND

e e e + e e e e e e e e e e

Heating, Recombination and Light Emission

3. Electron Trap as the Recombination Center

Pre-exposure situation: electron and hole traps are empty.



CONDUCTION BAND

Empty
electron trap

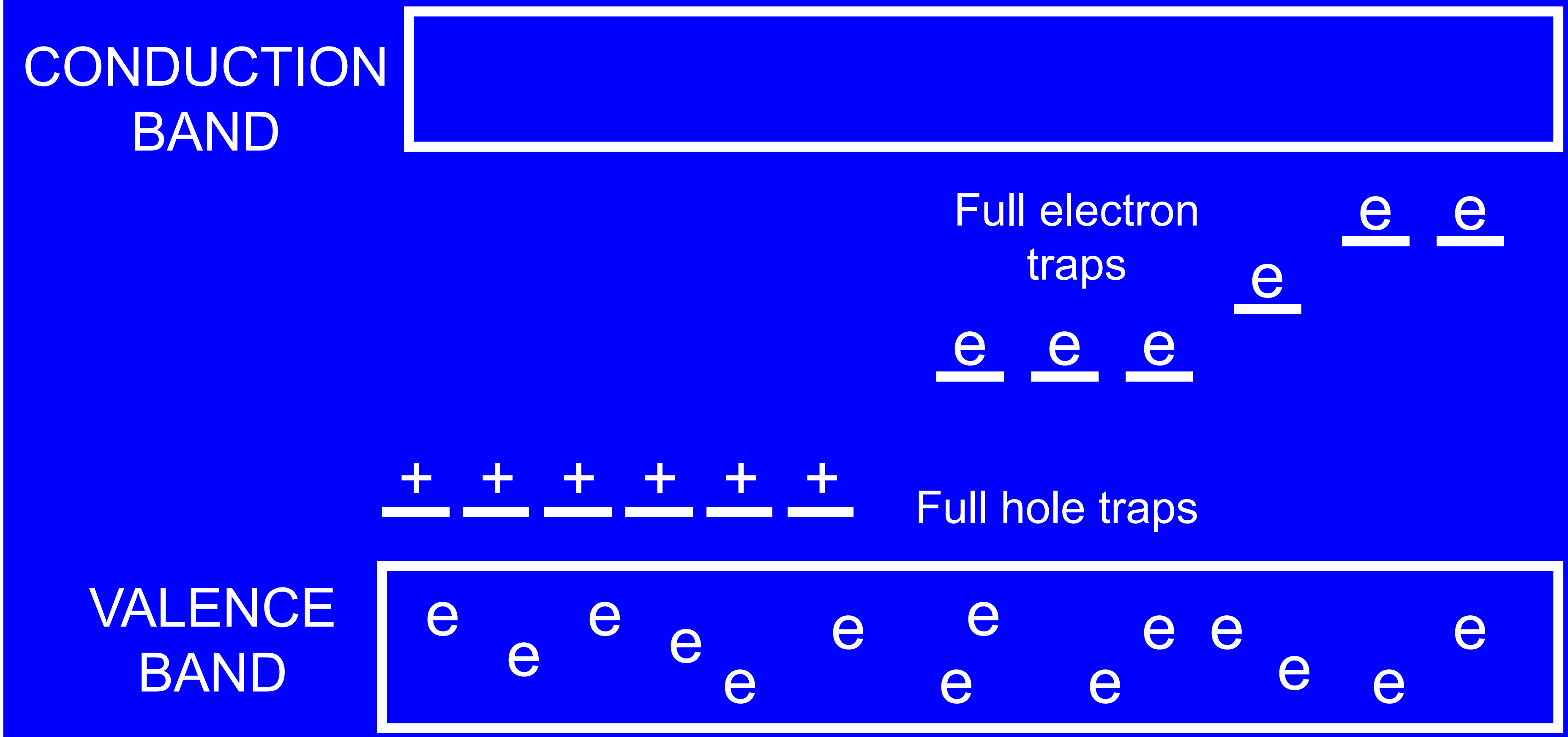
Empty
hole trap

VALENCE BAND
(full)

Heating, Recombination and Light Emission

4. Effect of Multiple Trap Depths

Post-exposure situation: electron and hole traps are full.
Three types of electron trap (three depths).



CONDUCTION BAND

Full electron traps

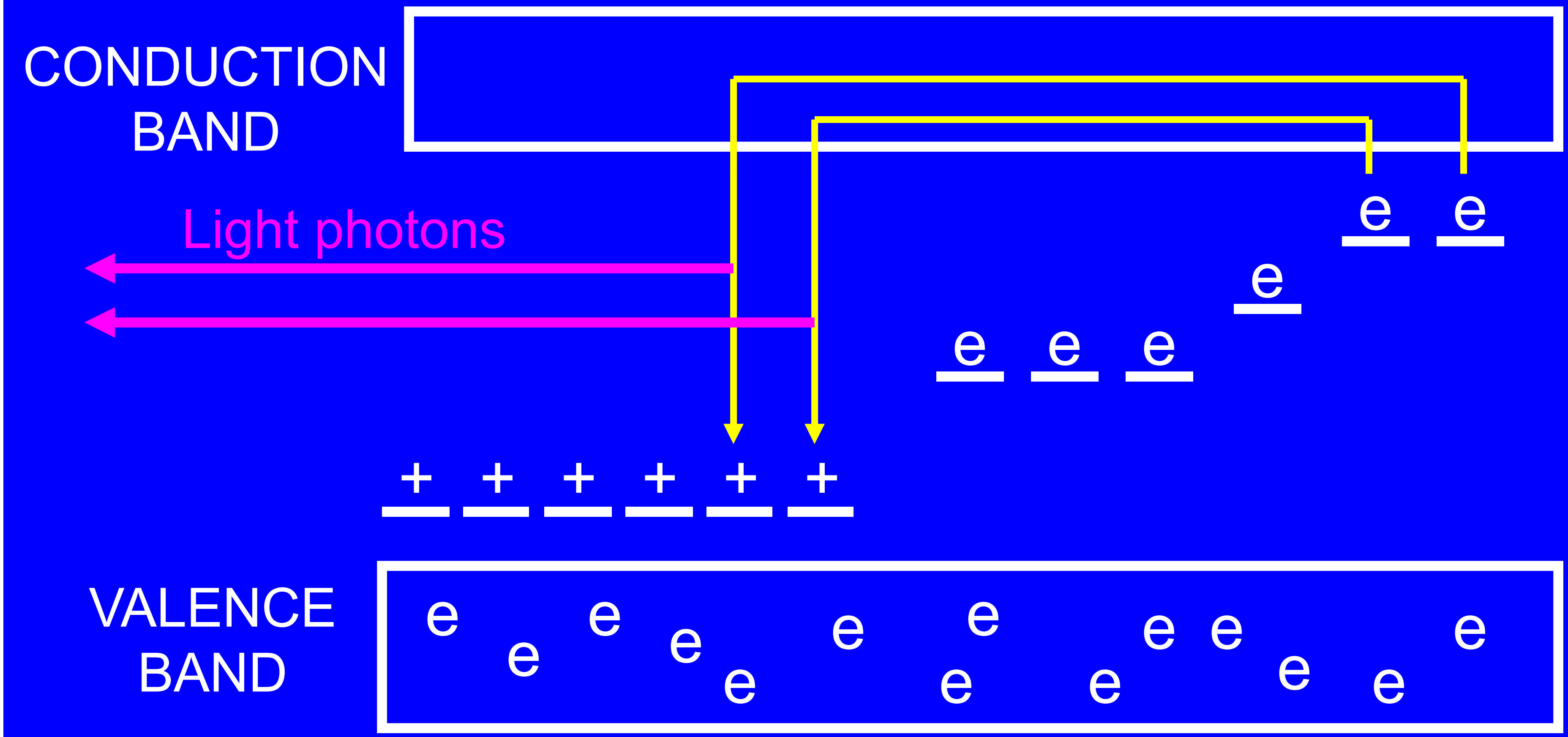
Full hole traps

VALENCE BAND

Heating, Recombination and Light Emission

4. Effect of Multiple Trap Depths

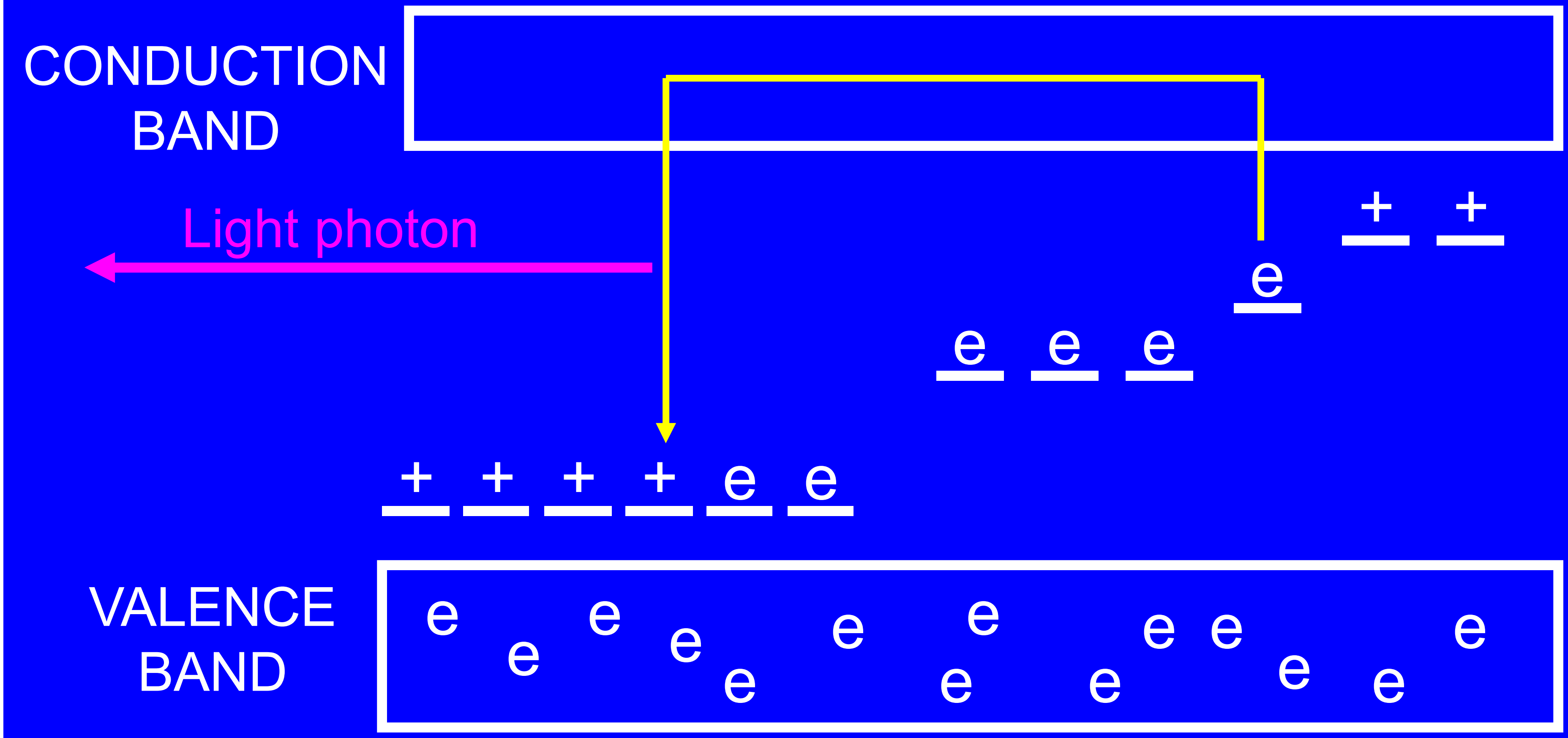
TL material is heated: the initial temperature is only high enough to free electrons from shallow traps.



Heating, Recombination and Light Emission

4. Effect of Multiple Trap Depths

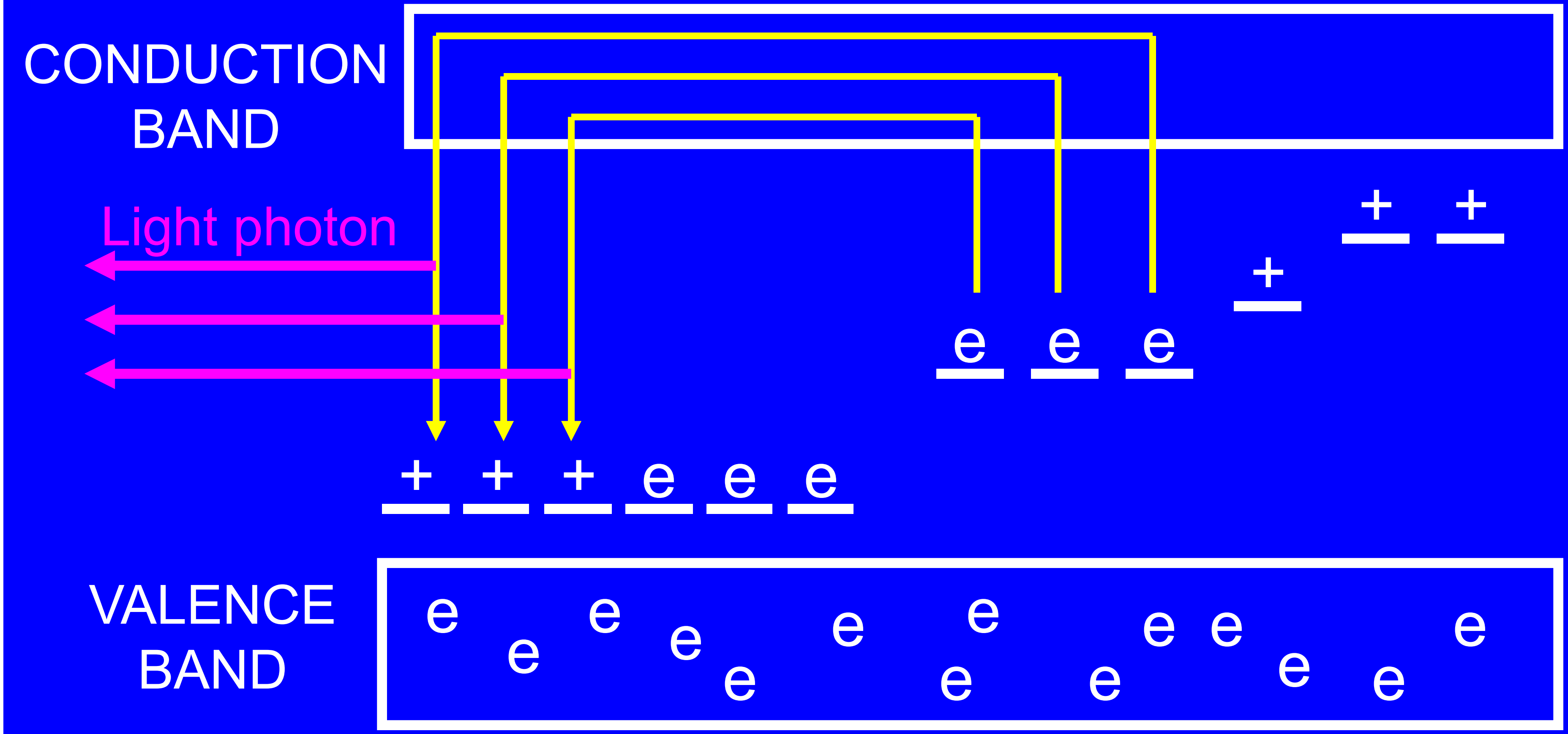
Heating continues: temperature now high enough to free electron from middle trap.



Heating, Recombination and Light Emission

4. Effect of Multiple Trap Depths

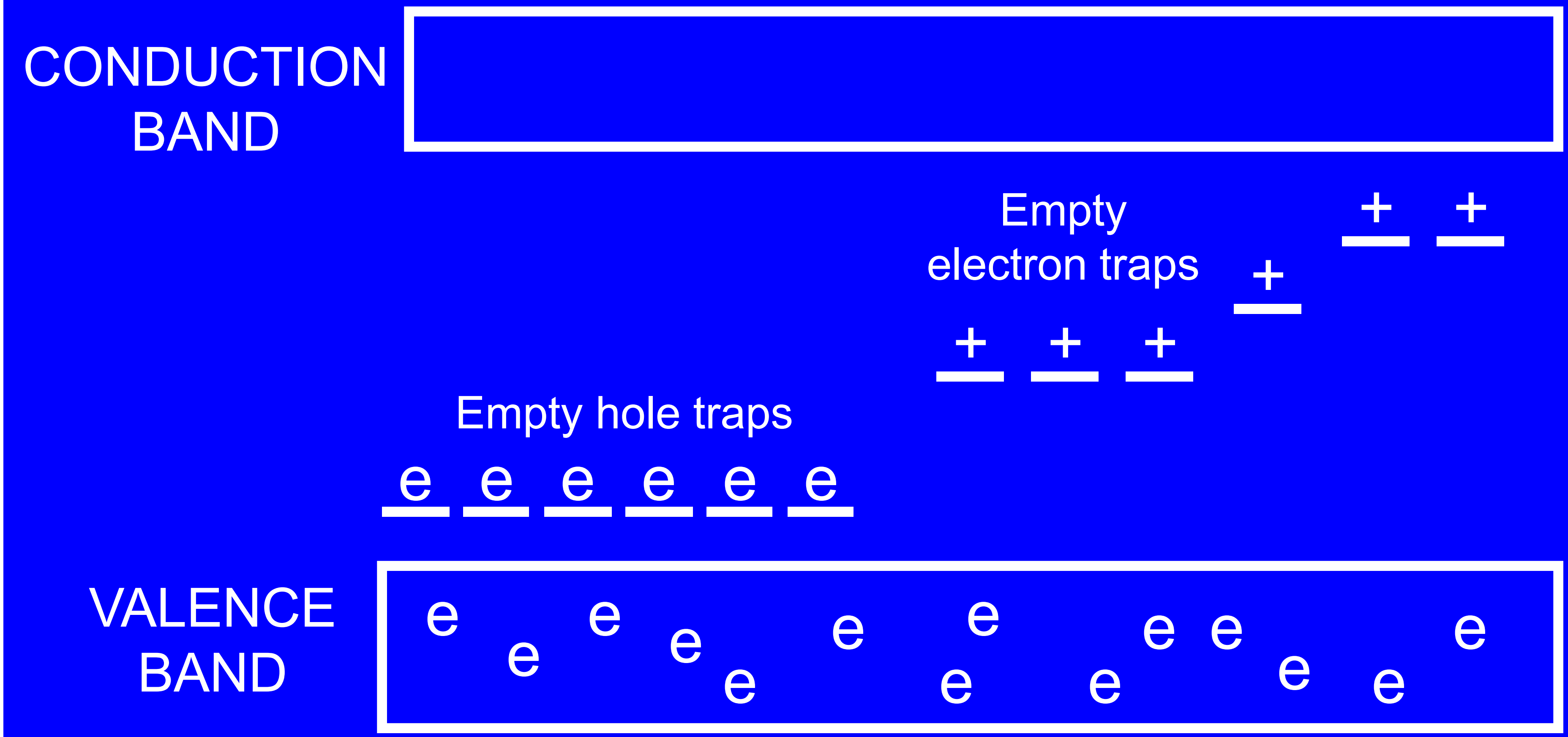
Heating continues: temperature now high enough to free electrons from deep trap.



Heating, Recombination and Light Emission

4. Effect of Multiple Trap Depths

Pre-exposure situation: electron and hole traps are empty.

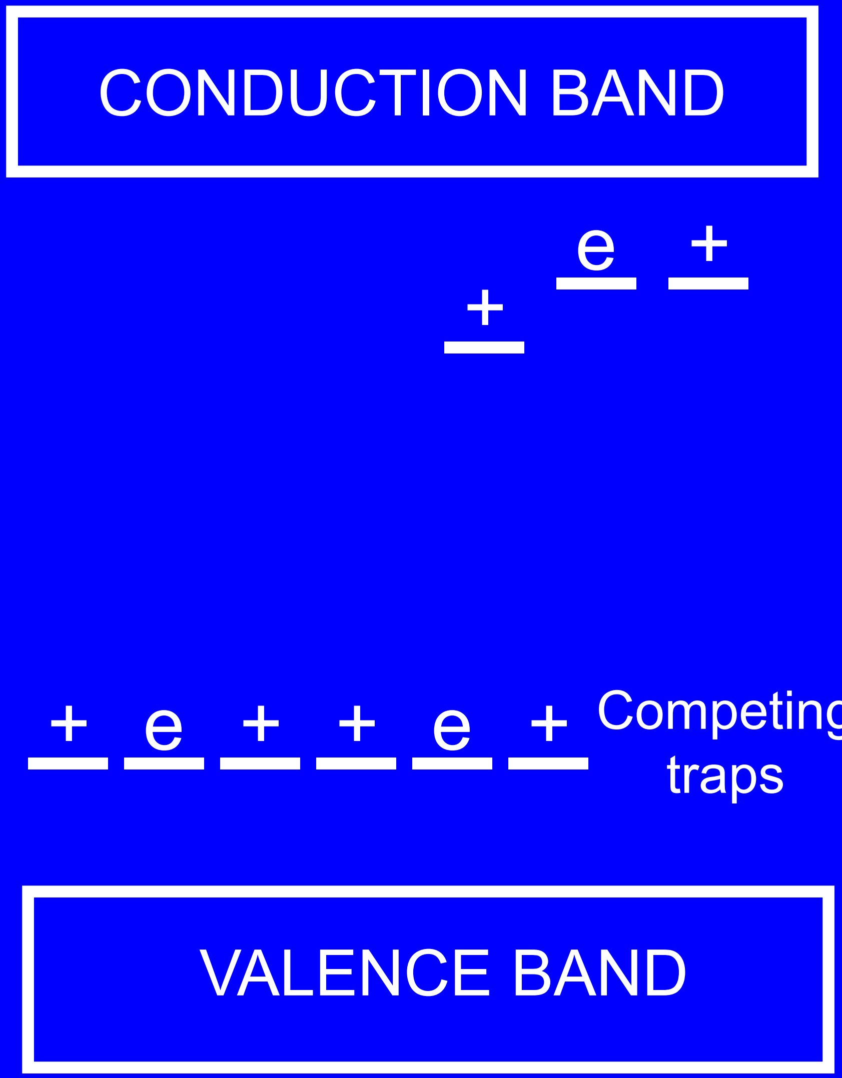


Heating, Recombination and Light Emission

5. Competing Traps

Competing traps are so deep that the heating process ceases before reaching a temperature high enough to free the electrons.

These competing traps reduce the sensitivity of the TL material: the larger the fraction of electrons going to competing traps, the lower the light output per unit dose.



CONDUCTION BAND

e +

\+

\+ e + + e +

Competing traps

VALENCE BAND

Heating, Recombination and Light Emission

5. Competing Traps

There is an upper limit on the temperature to which TL materials can be heated for two reasons:

- Over heating can damage the material’s crystalline structure. This will affect the light output and make the material unsuitable for re-use

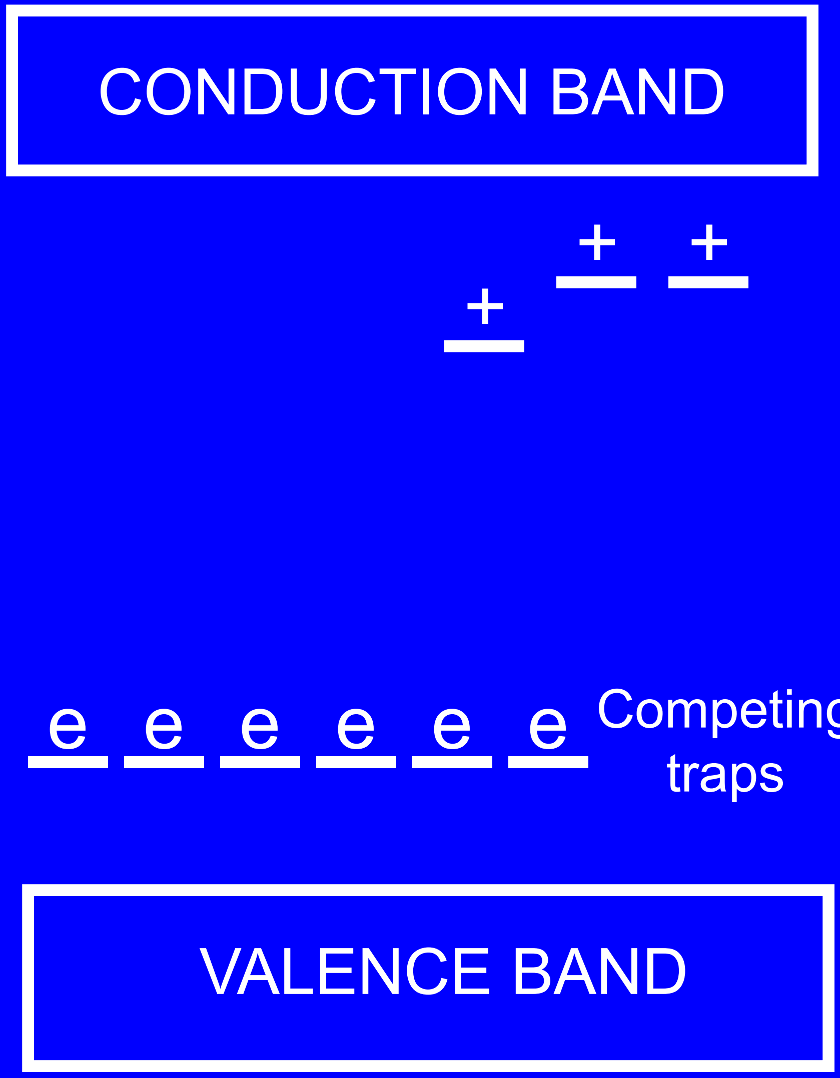
- If the TL material gets hot enough, it will emit incandescent light that is unrelated to the radiation exposure.

Heating, Recombination and Light Emission

5. Competing Traps

With some TL materials, sufficiently high exposures can fill the competing traps and thereby increase the sensitivity of the material to subsequent exposures.

In the case of LiF, the competing traps can be filled by exposures on the order of 70,000 R.



Glow Curves

Glow Curves

1. General

A thermoluminescent glow curve is a plot of light output as a function of a TL material's temperature (or time during heating).

As the temperature increases during readout, waves of light are produced.

Each wave of light manifests itself on the glow curve as peak, and each peak represents a trap.

By trap, we mean impurities or imperfections of a specific type at which electrons will possess a particular energy in the band gap.

The glow curve serves as the record of a TLD reading.

Glow Curves

1. General

Since LiF is said to have 12 traps, we would expect 12 peaks on the LiF glow curve. However, all 12 peaks aren't seen because:

- Some traps are so shallow that electrons escape them before the TL material is analyzed
- Different traps might be at such similar depths that their peaks overlap and cannot be resolved (distinguished);
- Other traps are so deep that electrons in them are not freed during the heating process. These are the competing traps.

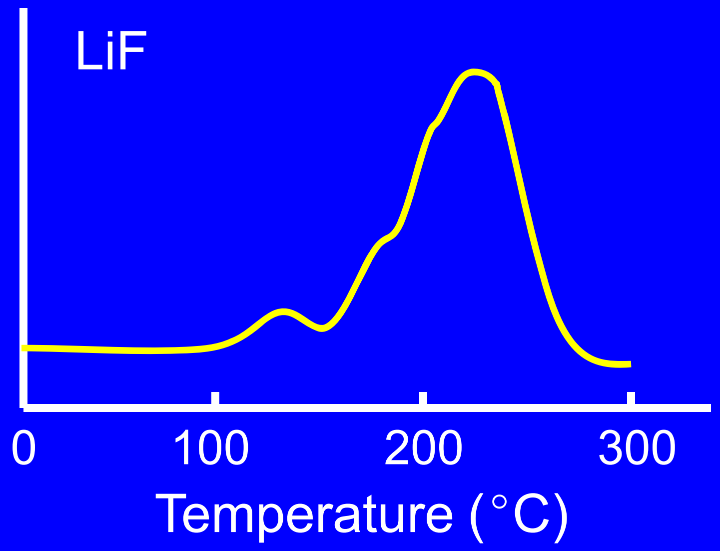
Glow Curves

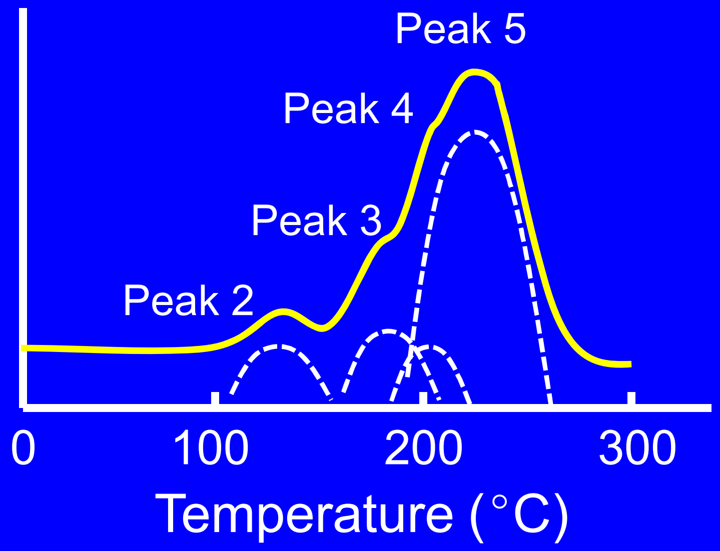
1. General

Only three or four peaks are discernible in a LiF glow curve.

The temperature at which a peak is produced reflects the depth of the corresponding trap.

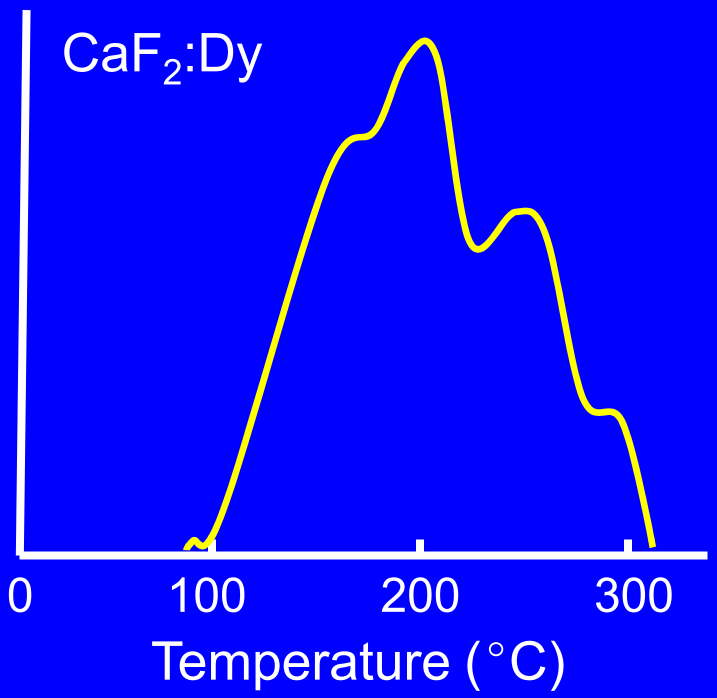
A peaks height reflects the number of electrons in that trap.

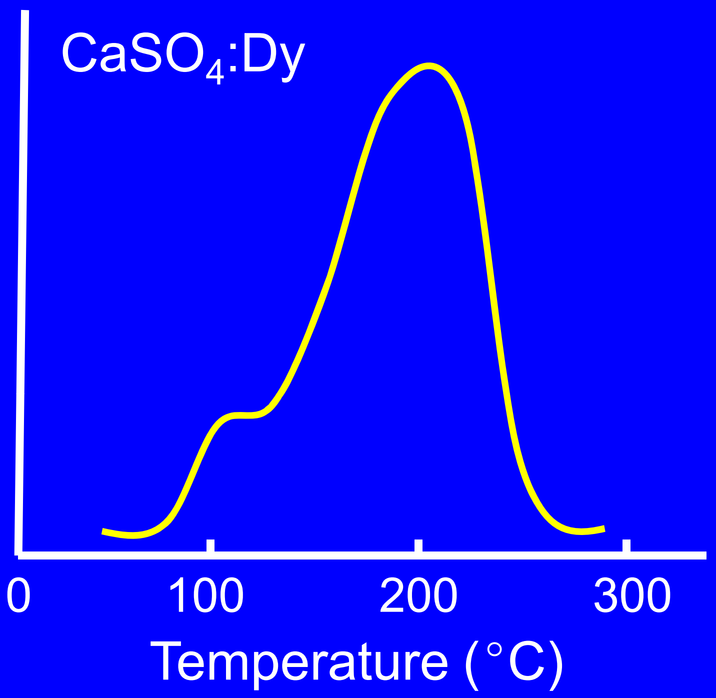




Glow Curves

1. General





The absorbed dose is related to the total amount of light (area under glow curve) emitted during the readout via a calibration. It is less common, but possible, to estimate the exposure using the height of the main glow peak.

Glow Curves

2. Things that Can Affect the Glow Curve Shape

Some TL materials (e.g. LiF) have glow curves that are more susceptible to modification than others.

Things that might affect the glow curve shape include the:

- type of activator
- type of radiation
- rate at which the TL material is heated (ramp rate)
- thermal and exposure history of the material
- handling

Glow Curves

3. Handling and Cleaning of TL Materials

Handle with vacuum tweezers, not standard tweezers that could scratch the material. Do not handle with fingers.

Rinse (not soak) with anhydrous methyl alcohol. Air dry.

4. UV Sensitivity

The following are very UV sensitive and should be handled in the absence of UV. Store in opaque containers.

CaF_2:Dy (TLD-200)
Al_2O_3 (TLD-500)
$CaSO_4$:Dy (TLD-900)

TLD Readers

TLD Readers

1. General

TL materials can be heated using:
- heating element or coil
- heated nitrogen gas
- infrared light

It is desirable that all parts of the TL material be at the same temperature during heating. As such, TL materials are usually quite thin (rarely more than 1/8" thick).

To permit the temperature to be raised and lowered quickly, there should be no large heat sinks in the vicinity of the heating chamber or in contact with the TL material.

TLD Readers

1. General

When a TL material comes into direct contact with a heating element or other component of the reader, it might be contaminated with any trace chemicals that might be present.

TLD readers that expose the TL material to heated nitrogen gas might partially or completely eliminate any direct physical contact, but any components of the reader that are exposed to the gas will also be heated.

Heating the TL material with infrared light can eliminate both problems.

Heating, Annealing and Readout

2. Nitrogen Quenching

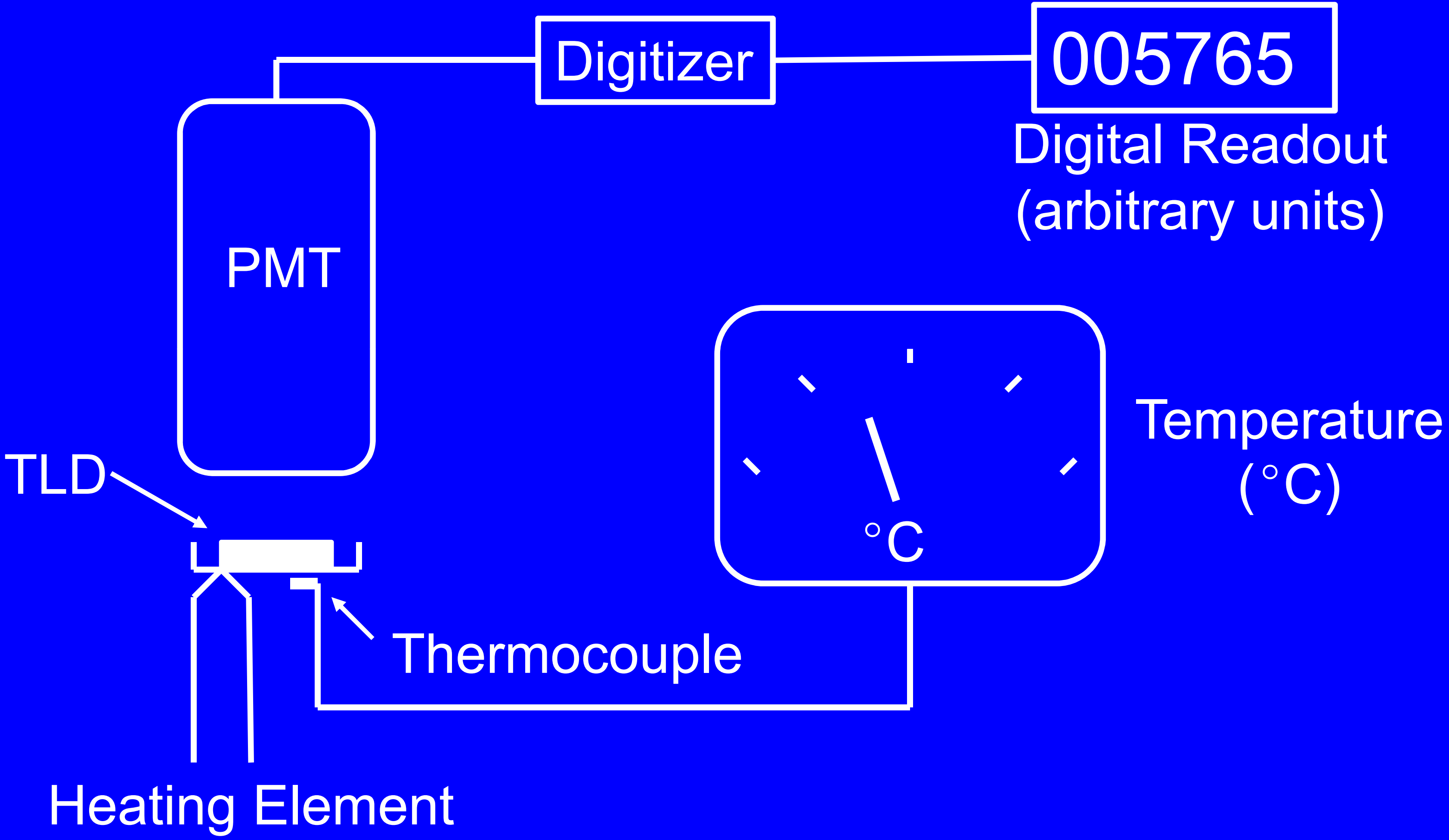
Because oxidation can lead to a contamination of the TL material that would affect its response, the heating process is usually performed in an atmosphere of pure nitrogen.

Oxidation can also change the reflectivity in the heating chamber and affect the amount of light reaching the PMT.

The presence of oxygen during heating is also undesirable because it can enhance the spurious emission of light, i.e. light unrelated to a radiation exposure. Because nitrogen suppresses this spurious luminescence, its use is sometimes referred to as **nitrogen quenching.**

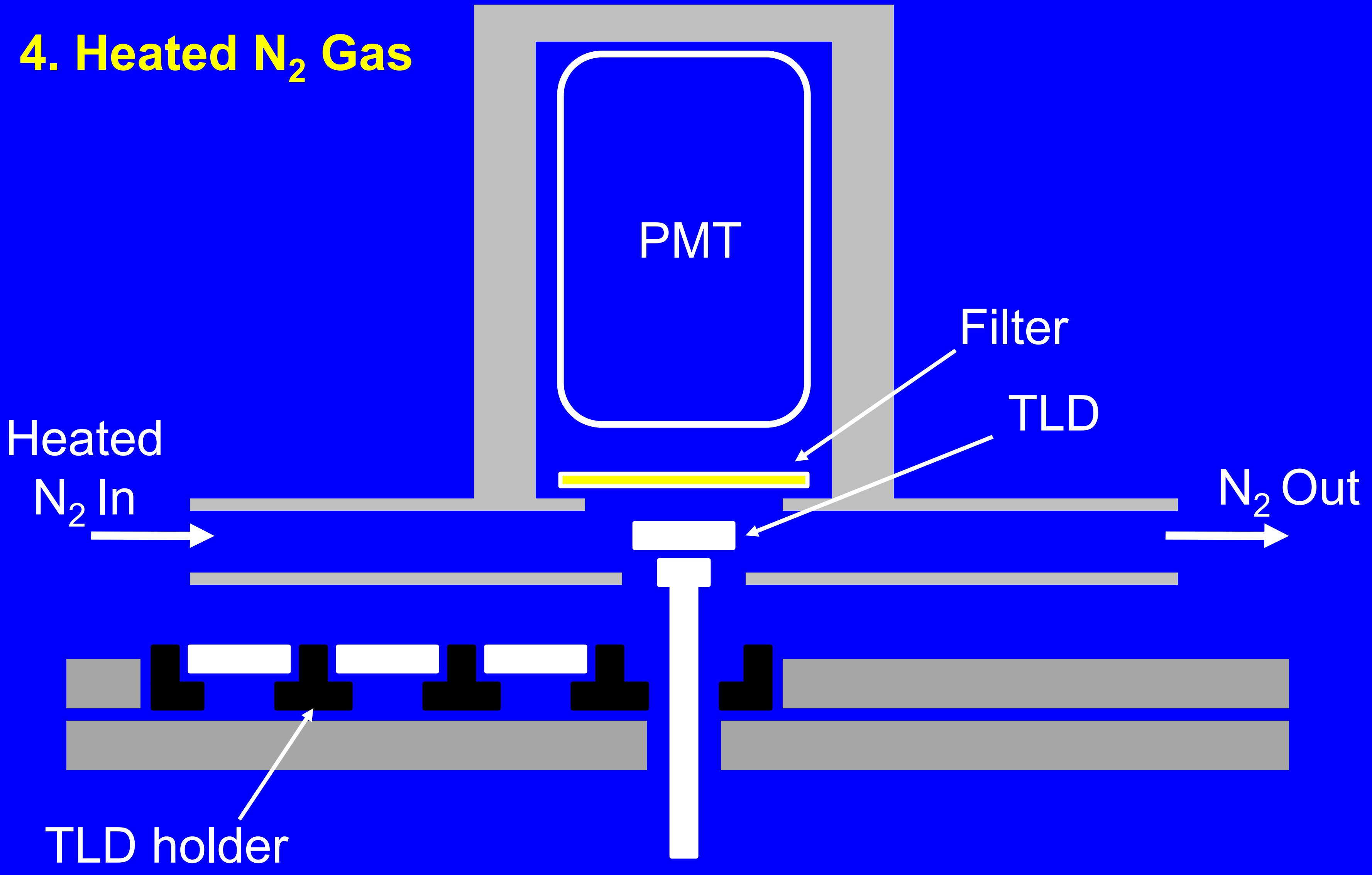
TLD Readers

3. Contact Heating Element



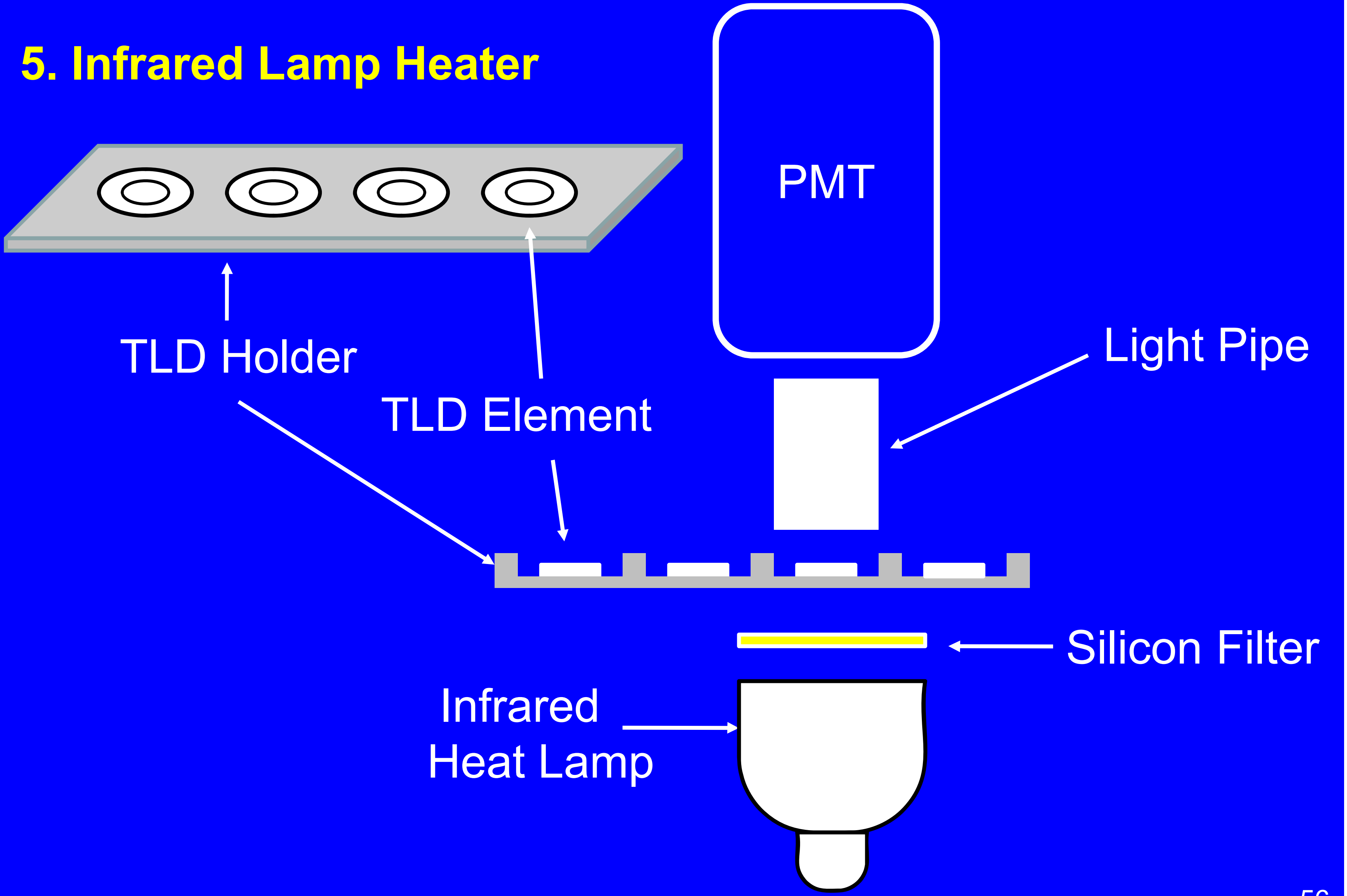
TLD Readers

4. Heated N_2 Gas



TLD Readers

5. Infrared Lamp Heater



Heating, Annealing and Readout

Heating, Annealing and Readout

1. Annealing

Annealing refers to the heating of the TL material for some other purpose than measuring the light output.

Pre-read Anneal. Performed prior to reading the TLD (the measurement of light output). Also known as a pre-heat or post-irradiation anneal. The purpose might be to eliminate light production during readout by unreliable shallow traps (low temperature peaks)

Post-read Anneal. Performed after reading the TLD. Also referred to as a post-heat or pre-irradiation anneal. The purpose might be to ensure that no residual light will be emitted the next time the TL material is used. In other words, ensure that the TL material is a “blank slate.”

Heating, Annealing and Readout

1. Annealing

The following table indicates suggested temperatures and durations of pre-read and post-read anneals. These times may have to be much shorter if a large number of TLDs are to be read.

TL Material	Pre-read Anneal	Post-read Anneal
LiF	10 min at 100 °C	2 hr at 100 °C
CaF_2 (Dy)	20 min at 100 °C	10 min at 320 °C
CaF_2 (Mn)	none	1 min at 320 °C
$Li_2B_4O_7$ (Mn)	10 min at 100 °C	none
$CaSO_4$ (Dy)	10 min at 100 °C	1 hr at 600 °C

Heating, Annealing and Readout

2. Readout

In general, temperatures between 100 and 300°C are employed to produce the peaks of interest on the glow curve.

In the case of LiF, the material is usually heated to 250°C.

Excessive temperatures are avoided because they might damage the TL material and/or result in the emission of incandescent light, i.e. light unrelated to the radiation exposure history of the material.

Heating, Annealing and Readout

3. Ramp Rate

The ramp rate is the rate at which the temperature of the TL material is raised. A typical ramp rate is 10°C/s although rates can vary from 0.5 to 30°C/s.

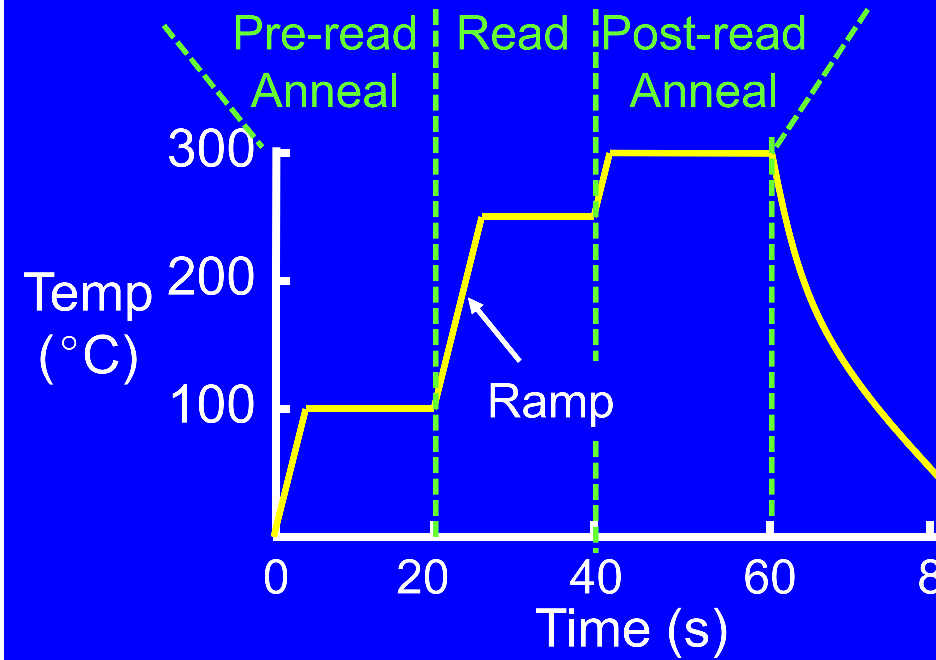
The ramp rate can affect the relative heights of various glow peaks and it can also affect the temperature at which the peaks are produced: the higher the heating rate the higher the temperature at which the peak occurs. Increasing the ramp rate also decreases the dose at which supralinearity commences.

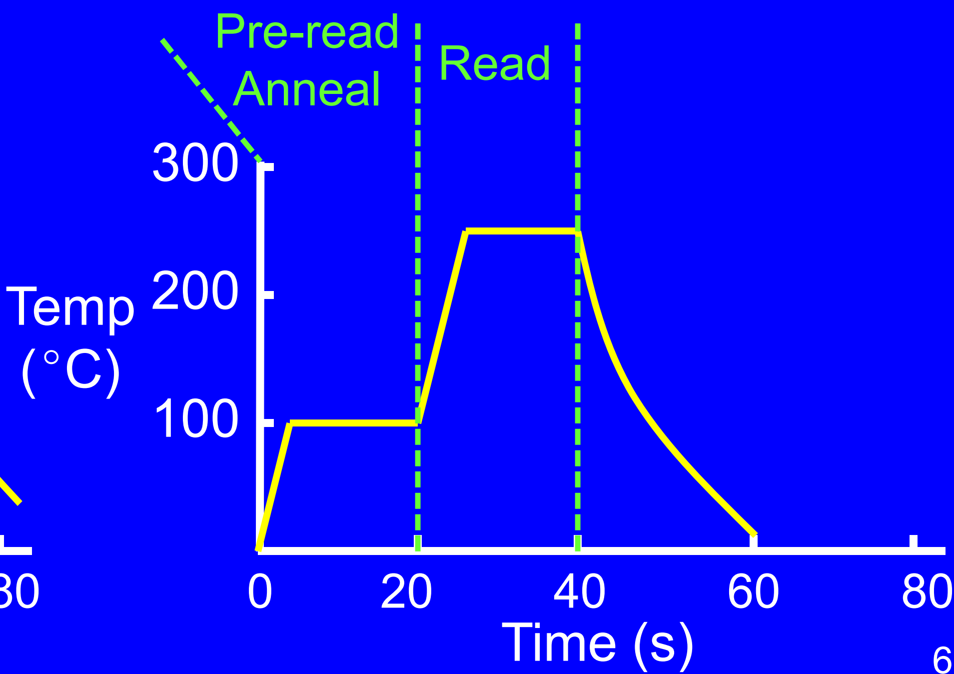
Although the exact ramp rate being employed is not extremely important, it is important to choose a specific ramp rate and stick to it.

Heating, Annealing and Readout

4. Heat Cycle

The following figures show typical heating cycles for LiF. In general, the post-read anneal is done immediately after the readout (figure on left). Sometimes the TLDs are cooled immediately after readout (figure on right) and annealed later as a batch.





TL Material Characteristics

TL Material Characteristics

1. Fading

Fading is an undesirable decrease in light output that occurs between the irradiation and readout of a TLD.

Even at room temperature, some of the electrons in a TL material might have enough thermal energy to climb out of the traps.

Fading is most likely to involve shallow traps where the energy required to free electrons is least. As such, the peaks on the glow curve produced at low temperatures (i.e. peaks associated with shallow traps) can be expected to show the most fading.

TL Material Characteristics

1. Fading

A glow peak half-life is the time it takes, at ambient temperature, for the area under the peak to decrease by one half. For LiF:

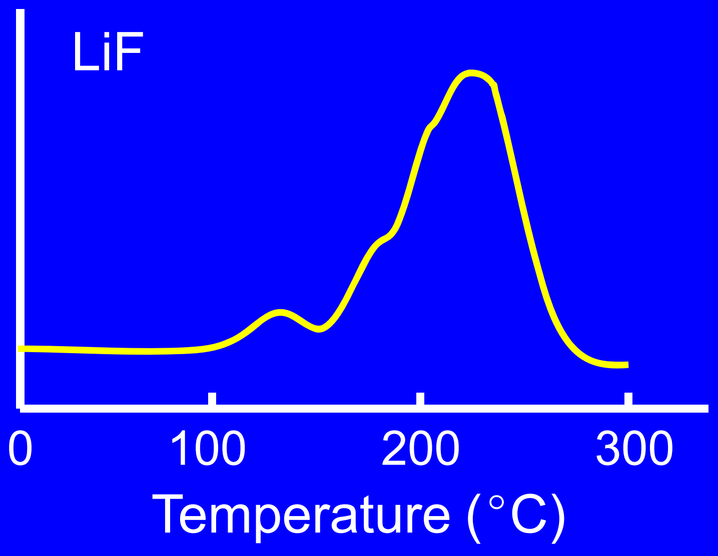
Peak 1	associated with the shallowest trap, has a half life of approximately 10 minutes
Peak 2	associated with the next shallowest trap, has a half life of approximately 10 hours
Peak 3	has a half life of 0.5 years
Peak 4	has a half life of approximately 7 years
Peak 5	has a half life of 80 years

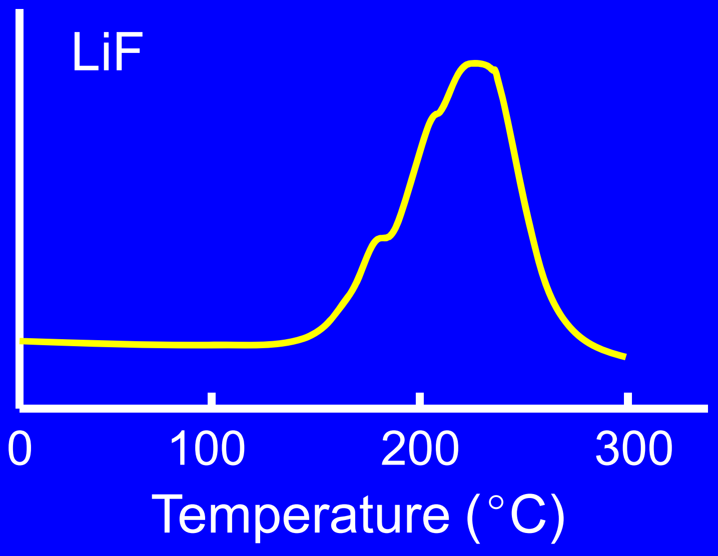
The intense fading of peaks 1 and 2 make them unsuited for routine dosimetry.

TL Material Characteristics

1. Fading

The figure on the left shows a LiF glow curve produced immediately after the exposure. The curve on the right was produced two days after the exposure - note the complete disappearance of peak 2.





TL Material Characteristics

1. Fading

With some TL materials, light (especially UV) can enhance the rate of fading. Such materials are said to be light sensitive. The following materials are particularly light sensitive: Al_2O_3, CaF_2:Mn, $CaSO_4$:Mn

It is wise to keep any exposure to light as short as possible. Indoors, low UV (gold) fluorescsent lights could be employed.

Light induced fading can be a concern when TLDs are used in environmental dosimetry because of the possible exposure to intense sunlight and the long exposure periods.

TL Material Characteristics

1. Fading

LiF with its high temperature main glow peak at 200^{o}C has less than 10% fading per year.

CaSO$_4$(Mn), due to a low temperature main glow peak at 110^{o}C, exhibits 40% fading the first year!

	LiF (Mg, Ti)	**CaF$_2$ (Mn)**	**CaF$_2$ (Dy)**	**CaSO$_4$ (Dy)**	**CaSO$_4$ (Tm)**	**CaSO$_4$ (Mn)**	**Li$_2$B$_4$O$_7$ (Mn)**
	TLD-100	TLD-400	TLD-200	TLD-900			TLD-800
Main Glow Peak Temp.	200 °C	300 °C	180 °C	220 °C	220 °C	110 °C	200 °C
Fading	<10%/yr	7% 1st 24 hrs 10% 1st month	10% 1st 24 hrs. 16% in 2 wks	little	little	40% 1st day	10% in 3 months 5% 1st month

TL Material Characteristics

2. Sensitivity

Sensitivity is the intensity of the emitted light per unit dose. The greater the sensitivity, the lower the absorbed dose that can be measured.

All TL materials have the same sensitivity for beta particles.

The key characteristic that determines a TL material’s sensitivity to photons (gamma and x-rays) is its effective atomic number. The higher the effective atomic number , the greater the sensitivity.

Nevertheless, sensitivity depends on a number of other factors, e.g., the number of competing traps, the wavelength of the emitted light.

TL Material Characteristics

2. Sensitivity

It is common to report the sensitivity of a given TL material relative to that of LiF. Sensitivity depends on the energy of the radiation, and it is standard practice to report the sensitivity for Co-60.

	LiF (Mg, Ti)	**CaF_2 (Mn)**	**CaF_2 (Dy)**	**$CaSO_4$ (Dy)**	**$CaSO_4$ (Tm)**	**$CaSO_4$ (Mn)**	**$Li_2B_4O_7$ (Mn)**
	TLD-100	TLD-400	TLD-200	TLD-900			TLD-800
Effective Atomic Number	8.2	16.3	16.3	15.3	15.3	15.3	7.4
Sensitivity Relative to LiF for Co-60	1.0	10	30	20	70	70	0.15

TL Material Characteristics

2. Sensitivity

The sensitivity of a TL material depends in part on how they are doped.

For example high sensitivity LiF materials are available (e.g., TLD-100H) that are doped with magnesium, copper and phosphorous: LiF:Mg, Cu, P. They have 15 times the sensitivity of standard LiF.

TL Material Characteristics

3. Energy Response

The accuracy of a TLD's measurement of dose should be independent of the radiation energy, i.e. the same amount of light would be emitted for a dose of 1 rad from 100 keV gamma rays as for 1 rad from 1000 keV gamma rays.

The response of all TL materials is essentially energy independent for photon energies above 300 keV. As such, TLDs calibrated with Cs-137 (662 keV) can make accurate assessments of an absorbed dose due to Co-60 (1173 and 1332 keV).

TL Material Characteristics

3. Energy Response

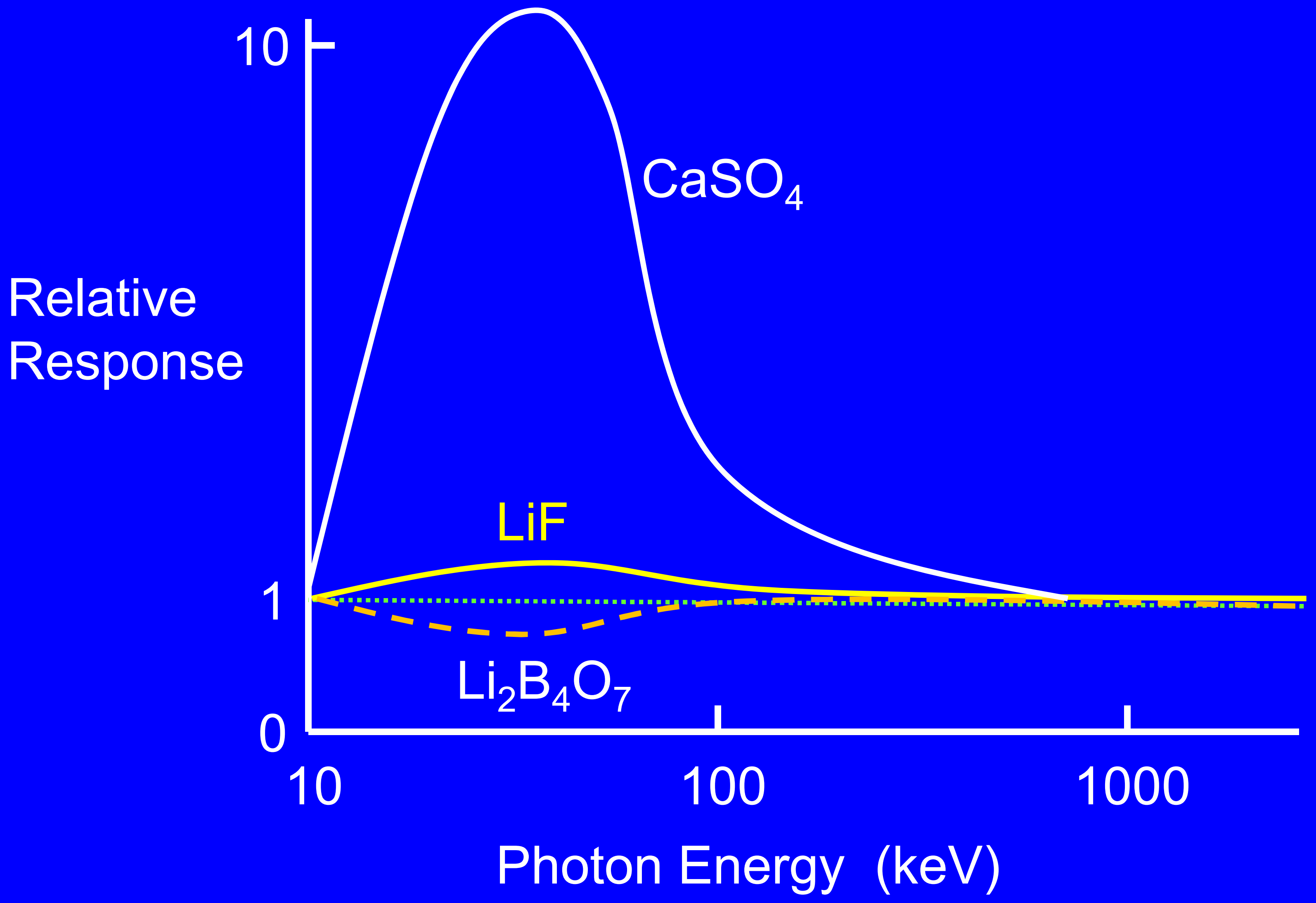
However, at energies below 300 keV or so, many TLDs over respond because the light output per unit dose increases as the energy of the radiation decreases.

If calibrated with Cs-137 (662 keV), these TLDs would "report" a higher absorbed dose than occurred if the actual exposure was due to Am-241 (60 keV).

To be energy independent below 300 keV, a TL material must be tissue equivalent. That is, it must have the same effective atomic number as human tissue (ca. 7.42). Of the various TL materials available, LiF and $Li_2B_4O_7$ come the closest to being tissue equivalent.

TL Material Characteristics

3. Energy Response



TL Material Characteristics

3. Energy Response

The following table indicates a TL material’s energy independence (or dependence) by giving its response at 30 keV (where the maximum over-response occurs) relative to that at 1173 and 1332 keV (i.e. Co-60). The ideal relative response is1.0 which indicates that the material is energy independent.

	LiF (Mg, Ti)	**CaF_2 (Mn)**	**CaF_2 (Dy)**	**$CaSO_4$ (Dy)**	**$CaSO_4$ (Tm)**	**$CaSO_4$ (Mn)**	**$Li_2B_4O_7$ (Mn)**
	TLD-100	TLD-400	TLD-200	TLD-900			TLD-800
Effective Atomic Number	8.2	16.3	16.3	15.3	15.3	15.3	7.4
Energy Response (30 keV/Co-60)	1.35	13	12.5	10	10	10	0.9

TL Material Characteristics

3. Energy Response

Ideally, TLDs that significantly over-respond at low energies (e.g. $CaSO_4$) would be calibrated at the photon energy that they will be used to measure the dose.

Alternatively, a filter of the appropriate material (e.g., copper) and thickness might be placed over the TLD to reduce the over-response at low energies.

Another option is to estimate the photon energy and then apply a correction factor. The energy of the radiation can be estimated by comparing the response of a TL materials under different types of filtration.

TL Material Characteristics

4. Supralinearity

The calibration factor employed to calculate the dose should not vary with the magnitude of the dose.

Expressed another way, we want the intensity of the light emitted by a TL material to be linearly related to dose, i.e., doubling the dose doubles the light out put.

At low doses, this is always the case. Unfortunately, the light output per unit dose can increase when doses above a certain magnitude are exceeded.

Supralinearity refers to this increase in light output per unit dose.

TL Material Characteristics

4. Supralinearity

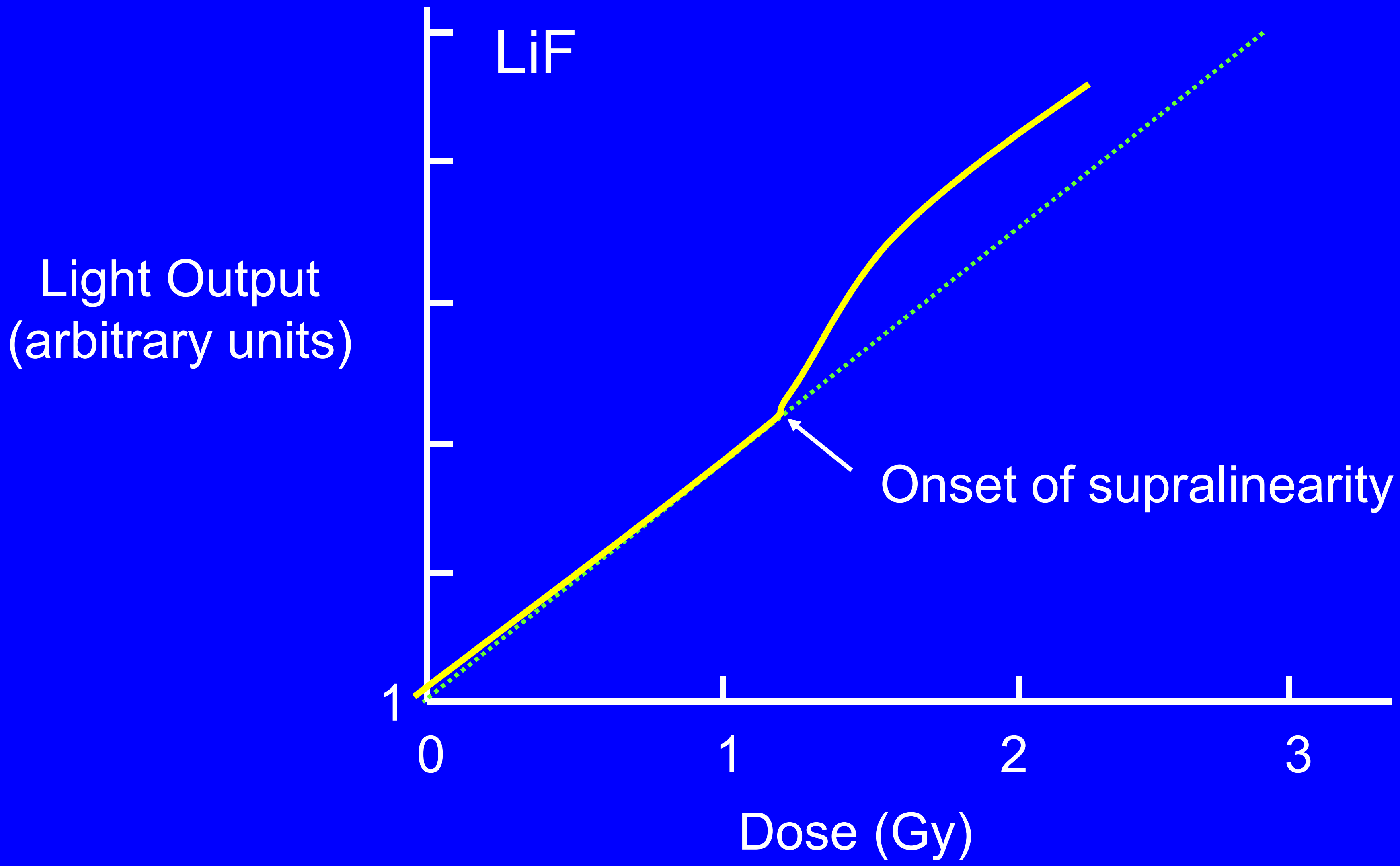
If the dose to a TL material exceeds that at which supralinearity occurs, the dose will be overestimated (assuming the calibration factor was determined at a lower dose in the linear region).

The higher the dose at which supralinearity begins, the better.

LiF is the worst TL material in terms of supralinearity. The onset of supralinearity with LiF is just above 1 Gy (100 rads). For this reason, LiF is sometimes paired wit h $Li_2B_4O_7$ for which supralinearity doesn't begin until 300 rads or so.

TL Material Characteristics

4. Supralinearity



TL Material Characteristics

5. Emission Spectrum

The TL emission spectrum of a material should overlap as much as possible with the absorption spectrum of the PMT. Most PMTs peak absorption efficiencies are in the 400 – 450 nm range.

	LiF (Mg, Ti)	**CaF_2 (Mn)**	**CaF_2 (Dy)**	**$CaSO_4$ (Dy)**	**$CaSO_4$ (Tm)**	**$CaSO_4$ (Mn)**	**$Li_2B_4O_7$ (Mn)**
	TLD-100	TLD-400	TLD-200	TLD-900			TLD-800
Emission Spectrum (nm)	350-600	440-650	350-590	460-590	350-530	450-600	530-630
Peak Emission (nm)	400	500	480-575	480-575	450-520	500	600

Neutron Dosimetry

Neutron Dosimetry

1. General

The errors associated with neutrons dosimetry tend to be large.

Accuracy, even in the best of circumstance, is expected to be on the order of ±50% and precision ±30%.

The major source of error is our inability to determine the neutron energy spectrum associated with the exposure. Relatively little progress has been made in this area over the last 20 years.

Neutron Dosimetry

1. General

Natural lithium is a mix of Li-6 and Li-7.

Li-6 has a high cross section for neutrons. Li-7 doesn’t.

TLDs using natural lithium (a mix of Li-6 and Li-7) are sensitive to neutrons because of their Li-6 content.

The Harshaw TLD-600 consists almost exclusively of Li-6.

The Harshaw TLD-700 consists almost exclusively of Li-7.

Neutron Dosimetry

2. Harshaw TLDs

TLD-100	LiF (Li-6 & Li-7)	neutron sensitive
TLD-200	CaF: Dy	neutron insensitive
TLD-400	CaF: Mn	neutron insensitive
TLD-600	LiF (Li-6)	neutron sensitive
TLD-700	LiF (Li-7)	neutron insensitive
TLD-800	$Li_2B_4O_7$ (Li-6 & Li-7)	neutron sensitive
TLD-900	$CaSO_4$: Dy	neutron insensitive

Neutron Dosimetry

3. Li-6 and Li-7

Some TLD systems used to estimate the neutron dose contain both TLD-600 and TLD-700 elements.

The difference between the readings of the two elements represents the response to neutrons (assuming that neither one is responding to beta particles).

The response of the TLD-700 element represents the response to photons.

Neutron Dosimetry

4. $Li_2B_4O_7$ and $CaSO_4$

Some TLD systems (e.g., Panasonic) that determine the neutron dose contain both $Li_2B_4O_7$ and $CaSO_4$ elements. The difference between the readings of the two elements represents the response to neutrons.

The Panasonic TLD determines the neutron dose as follows:

$$H = NF\,(E_2 - E_4)$$

The response E_2 ($Li_2B_4O_7$) is to neutrons and gammas. The response E_4 ($CaSO_4$) is due to gammas only. The neutron calibration factor (NF) converts this to a dose equivalent.

Not as sensitive as using TLD-600 and TLD-700.

Neutron Dosimetry

5. LiF Glow Curve

It is possible to evaluate neutron exposures by analyzing different peaks on the LiF glow curve:

A TLD is read at two temperatures: first 250°C, then 325°C.

The response at 250°C is due to neutrons and gammas.

Neutron, but not gamma, exposures produce a well-defined peak(s) around 300°C . The neutron dose is determined directly from the TL response at 325°C.

The latter is used to estimate the neutron contribution to the response at 250°C. The response at 250° is corrected for the neutron contribution and then used to calculate the gamma exposure.

Neutron Dosimetry

6. Albedo Dosimeters

Most exposures involve neutrons from 1 eV to 1 MeV. Unfortunately lithium-containing materials are almost entirely unresponsive to anything but thermal neutrons.

Any high energy neutrons must be moderated (slowed down) if they are to be measured.

Albedo dosimeters rely on the body to slow down the fast neutrons and scatter them towards the dosimeter.

For albedo dosimeters to work properly, they must be worn close to the body. Changes in the dosimeter position can affect its response and the accuracy of the measured dose.

Neutron Dosimetry

6. Albedo Dosimeters

Albedo dosimeters can be used for area and environmental monitoring if they are mounted next to hydrogenous material, e.g., a 4” thick piece of Lucite.

Appendix:

Correction Factors and Algorithms

Correction Factors and Algorithms

1. Correction Factors

No two TLD elements (individual chips) have exactly the same light output per unit dose.

As such, it is necessary to determine a “rank correction factor” for each element.

When an element's response is multiplied by its rank correction factor, the corrected response will be the same for a given radiation dose as the corrected response of any other element.

In some cases, it might be acceptable to use an average calibration factor for a group of batched elements , i.e., elements with similar responses.

Correction Factors and Algorithms

2. Desired TLD Output

A TLD dosimeter must assess the dose equivalent (equivalent dose) to the:

- skin/shallow dose (at a depth of 7 mg/cm^2)
- lens of the eye (at a depth of 300 mg/cm^2)
- deep dose (at a depth of 1000 mg/cm^2)

If the TL material over-responds to low energy photons, the dosimeter must be able to estimate the photon energy and correct for any over-response.

The following section describes the algorithms used by the Panasonic TLD system to accomplish the above as well as estimate any contribution from betas.

Correction Factors and Algorithms

3. Typical Panasonic TLD

The typical Panasonic TLD employs four TL elements.

Element Response Designation	Element Type	Filter Thickness	Filter Material	Radiation Detected
E_1	$Li_2B_4O_7$ (Cu)	14 mg/cm^2	plastic	beta and gamma
E_2	$Li_2B_4O_7$ (Cu)	300 mg/cm^2	plastic	beta and gamma
E_3	$CaSO_4$ (Tm)	300 mg/cm^2	plastic	beta and gamma
E_4	$CaSO_4$ (Tm)	1000 mg/cm^2	plastic and lead	gamma

Correction Factors and Algorithms

4. Determining the Type and Energy of Radiation

a. The exposure is considered to be only from photons (gamma rays and/or x-rays) when:

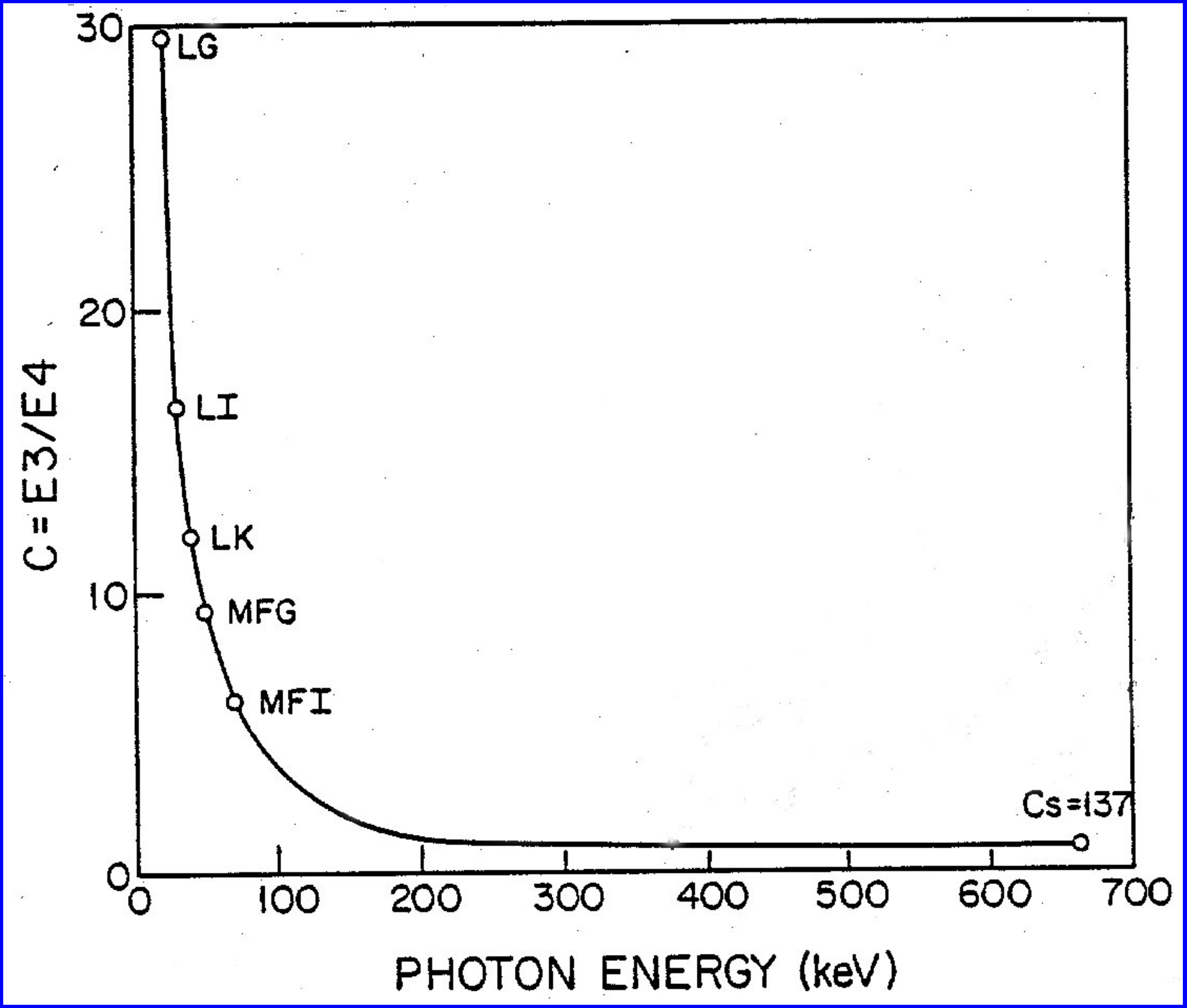
$$E_1/E_2 < 8 \quad \text{and} \quad E_3/E_4 > 1.5.$$

In this case, the energy of the photons is estimated via the curve on the following slide

Correction Factors and Algorithms

4. Determining the Type and Energy of Radiation

a.



Correction Factors and Algorithms

4. Determining the Type and Energy of Radiation

b. High energy photons are indicated when $E_3/E_4 < 1.5$.

In this case, the shallow dose, dose to the lens of the eye, and the deep dose are equal.

The dose assigned at these three depths is the response of element E_2.

Element E_2 provides the most accurate estimate of the dose because $Li_2B_4O_7$ is tissue equivalent and E_2, unlike E_1, is covered with enough plastic for electronic equilibrium to exist.

Correction Factors and Algorithms

4. Determining the Type and Energy of Radiation

c. Low energy photons are indicated when $E_3/E_4 > 1.5$.

In this case, shallow dose is greatest, the dose to the lens of the eye is next, and the deep dose is the lowest.

The equations that calculate these doses employ the response E_2. They also take into account the ratio E_3/E_4. The smaller this ratio, the higher the gamma energy and the more similar the three doses.

In the extreme case where $E_3/E_4 > 24$ (very low energy x-rays), the shallow dose is estimated to be 1.85 E_2, the dose to the lens of the eye is 1.43 E_2, and the deep dose is 0.8 E_2.

Correction Factors and Algorithms

4. Determining the Type and Energy of Radiation

d. A beta contribution to the dose is indicated when $E_1/E_2 > 8$. Betas are also indicated if E_3/E_2 is less than 1.5 and E_1/E_4 is greater than 1.1.

When the dose results from both beta and gammas, the gamma contribution is determined by E_4.

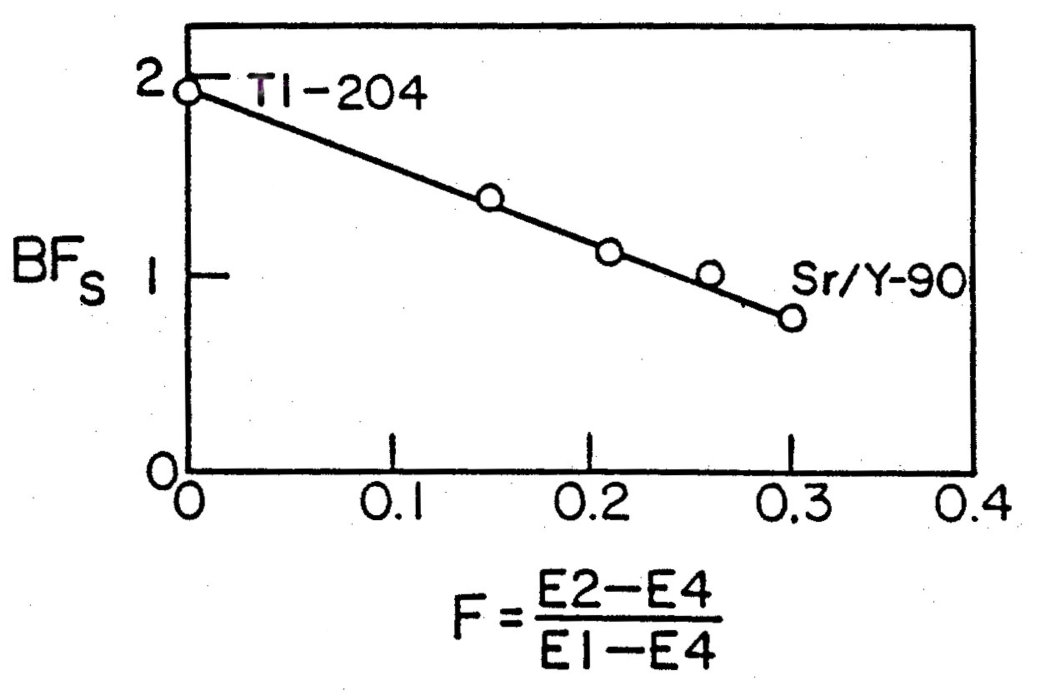
The filtration over this element is sufficiently thick to prevent a response to the betas. However, since the element is $CaSO_4$, it may over-respond if the gamma ray component is low energy. Fortunately, the lead filter over E_4 flattens the response at low energies.

Correction Factors and Algorithms

4. Determining the Type and Energy of Radiation

d. The shallow beta dose is based on E_1 (beta+gamma) minus E_4 (gamma only). The equation includes a beta factor (BF) that takes into account the beta energy.

$$\text{Shallow beta dose} = BF\,(E_1 - E_4)$$



Correction Factors and Algorithms

4. Determining the Type and Energy of Radiation

e. The dose to the lens of the eye is only calculated if high energy betas are present.

The latter is indicated when the ratio $(E_2 - E_4)/(E_1 - E_4)$ is greater than 0.25. In this case:

$$\text{beta dose to the lens of the eye} = 0.12\,(E_1 - E_4)$$