

Chapter 1

GENERAL PROPERTIES OF THERMOLUMINESCENCE

Q 1. What is **radio-thermoluminescence (RTL)**?

A. It is the old name for thermoluminescence.

Q 2. How is it possible to decide if the **TL response vs dose** is linear or not?

A. Plot the TL emission against the dose on a log–log paper. We get linearity if the obtained straight line makes an angle of 45° with the logarithm axis.

Q 3. What is an **activator**?

A. It is a chemical element which is added to a thermoluminescent material for enhancing its luminescence efficiency.

Q 4. What is the **annealing** procedure?

A. The annealing procedure is a thermal treatment which erases from a thermoluminescent material any previous irradiation effects.

Q 5. What is the meaning of the term “**afterglow**”?

A. The term “afterglow” is used to indicate the luminescence emitted from a thermoluminescent material immediately after its irradiation. In general this phenomenon is temperature independent. A correlation between afterglow and a thermal fading has been observed.

Q 6. What is **anomalous fading**?

A. It is the phenomenon in which the trapped charges can escape from the traps at a rate much faster than the one expected from the calculated mean lifetime. It is weakly dependent on the temperature.

Q 7. What is the **calibration factor**?

A. The calibration factor, Φ_C , allows us to transform the light emission from a phosphor to the dose received by the phosphor itself. The calibration factor includes both reader and phosphor properties.

Q 8. How is the **calibration factor**, Φ_C , defined?

A. If we indicate with D_C a calibration dose and with M_C the light signal from a phosphor, corrected by the background, the calibration factor is given by the following expression

$$\Phi_C = \frac{D_C}{M_C}.$$

Q 9. How is the **phosphor sensitivity**, S , defined?

A. The sensitivity of a phosphor is generally expressed by the following expression:

$$S = \frac{\text{light emission}}{D \cdot m}$$

where D is the given dose, generally in the linear region of the calibration curve, and m is the mass of the phosphor.

Q 10. How do we set the **heating rate** for determining the kinetics parameters relative to a TL glow peak?

A. The heating rate has to set as slow as possible for the following reasons: (i) to obtain the best separation among the peaks (ii) to get the best thermal contact between the TL sample and the heating planchet.

Q 11. How can a **trap** be considered stable at room temperature?

A. A trap, having an activation energy E , is stable at room temperature if $E \gg kT$, where T is the room temperature value.

Q 12. What is the **optical bleaching** of the TL signal?

A. An irradiated material is exposed to visible light and, very often, the TL signal results to be reduced compared to the one obtained if the material had not been exposed to the light. This effect is due to eviction of charges from the trap owing to optical stimulation.

Q 13. What is the **light-induced fading**?

A. It is the other name of the optical bleaching of the TL signal (see Q12).

Q 14. What is the **phototransferred TL**?

A. This phenomenon indicates the transfer of charges from deep traps to shallower traps. It is caused by the light exposure of an irradiated sample.

Q 15. What is the **optically-induced TL**?

A. This effect concerns an unirradiated sample exposed to light: optical stimulation can allow transitions of electronic charge from pre-existing defects. The free charges so obtained can be trapped at empty trapping levels and give, then, a TL signal.

Q 16. What is the method called “**in vivo dosimetry**”?

A. It is a method to check the absorbed dose which has been delivered to a patient during radiological inspection or during therapeutic treatment.

Q 17. How do we perform the “**in vivo dosimetry**”?

A. It is performed by putting dosimeters on the patient’s skin or in natural body cavities.

Q 18. What is the aim of “**in vivo dosimetry**”?

A. The aim of “in vivo dosimetry” is to check the target dose (ICRU 1993), in order to verify the correct delivery of irradiation to patients. In other words, the method allows us to compare the dose obtained from the detector’s signal placed on the patient skin, with the theoretical value as calculated by the TPS.

Q 19. What is the meaning of **TPS**?

A. It refers to the Treatment Planning System. This system allows us to calculate the irradiation dose delivered to a patient during external radiotherapy.

Q 20. How are the **entrance dose**, D_{entrance} , and the **exit dose**, D_{exit} , defined?

A. The entrance and exit doses are defined at points a certain distance from the patient surface at the entrance and exit of the beam. This distance is equal to the depth of maximum build-up, d_{max} .

Q 21. How is the **surface dose**, D_{surface} , defined?

A. The surface dose is defined at 0.05 cm below the entrance surface.

Q 22. What is the intrinsic **precision** of a TL dosimeter?

A. The intrinsic precision is the reproducibility of a given thermoluminescent material associated with a given readout system.

Q 23. Which are the parameters that affect the **reproducibility** of a given thermoluminescent material associated to a given readout system?

A. The reproducibility is dependent on the quality of the thermoluminescent material, the annealing procedure, the reader characteristics, the thermal readout cycle and the purity of the nitrogen gas.

Q 24. How can the **reproducibility** evaluated?

A. It can be evaluated by randomly taking some thermoluminescent dosimeters of the same batch, i.e. 10 samples, and by irradiating them to a same dose. After readout and annealing treatment, the procedure is repeated several times. A standard deviation of $\pm 2\%$ or less is the index for a good reproducibility.

Q 25. What is the **thermal treatment** for thermoluminescent dosimeters?

A. The thermal treatment, usually called annealing, is a procedure performed in an oven before and after use of the dosimeters.

Q 26. Why is the **thermal treatment** important?

A. The thermal treatment or annealing allows us to stabilize the sensitivity and the background of the dosimeters in such a way that their dosimetric properties remain constant during the use.

Q 27. Which types of **heating systems** are encountered in TLD readers?

A. There are mainly two different systems: (i) heating by contact and (ii) non-contact systems.

Q 28. How does the **contact readout system** work?

A. The metallic support of the TL sample is heated by an electric current or by a hot finger moved by a lift mechanism.

Q 29. How does the **non-contact readout system** work?

A. The TL sample is heated by hot nitrogen gas, or by a laser beam, or by a light pulse from an halogen lamp.

Q 30. Which type of **heating cycle** has to be used for kinetics studies?

A. The most usual cycle is a linear one: the TL sample is progressively heated using the lowest possible heating rate.

Q 31. What is the definition of **fading**?

A. Fading is the spontaneous escape, at ambient temperature, of charge carriers from traps.

Q 32. What is the **fading factor**?

A. The fading factor is a parameter which allows us to calculate how much thermoluminescent information is lost per unit of time.

Q 33. How do we calculate the **fading factor**?

A. Considering the first order expression as a function of time, i.e.

$$\Phi = \Phi_0 \exp(-pt)$$

where

Φ is the peak area at the elapsed time t

Φ_0 is the peak at time $t = 0$

The fading factor p is given by

$$p = -\frac{1}{t} \ln \left(\frac{\Phi}{\Phi_0} \right).$$

Q 34. Is there an expression which takes into consideration the competition between **fading** and irradiation at the same time?

A. The expression is the following

$$\Phi = \frac{\dot{D}}{F_c s \exp\left(-\frac{E}{kT}\right)} \left\{ 1 - \exp \left[-ts \exp \left(-\frac{E}{kT} \right) \right] \right\}$$

where

\dot{D} is the dose rate

F_c is the calibration factor of the TL system (dose/TL)

t is the observation time

T is the storage temperature.

Q 35. Is there a **desensitization** effect caused by UV exposure?

A. Yes. The thermoluminescent sensitivity can be increased artificially by irradiation with ionizing radiation or thermal treatment. The exposure to UV rays can reverse the sensitization effect of the previous procedure.

Q 36. Is there a thermoluminescence transferred effect as a consequence of the UV exposure?

A. Yes. The UV rays exposure can transfer some charges from deep traps to shallow ones, so that the peaks corresponding to the shallow traps, i.e. low temperature peaks, increase their sensitivity.

Q 37. What is the meaning of the term “**regeneration**” for a given peak?

A. It means an increase of the thermoluminescent intensity as a consequence of the charge transfer induced by UV exposure.

Q 38. Can a **pressure** applied on a thermoluminescent sample cause some effect?

A. The pressure application can excite valence electrons which can then be trapped or de-excite any trapped electron which can recombine. In both cases the thermoluminescence observed will be different from the one observed prior to the stress application.

Q 39. Which kind of **stress** applied to a sample can affect its thermoluminescent emission?

A. Stress can arise from operations such as crushing, grinding, packing and so on.

Q 40. Which are the possible **excitation agents** in thermoluminescence?

A. The excitation is achieved by conventional agents as ionizing radiations and, in some cases, also by UV rays.

Q 41. Is heat an **excitation agent** for thermoluminescence?

A. No. Heat is only a stimulating agent.

Q 42. How do we distinguish between **luminescence** and **incandescence** emissions?

A. Luminescence usually lies in a spectral region where the material of interest is not absorbing; incandescence occurs where absorptivity of the material is the maximum.

Q 43. Are there any differences in temperatures of occurrences between **thermoluminescence** and **incandescence**?

A. Yes. Incandescence occurs at very high temperatures, near the melting point of materials. The thermoluminescence occurs at much lower temperatures.

Q 44. Which are the most **sensitive thermoluminescent materials**?

A. The most sensitive thermoluminescent materials are the solid dielectrics. However, thermoluminescence is exhibited by minerals contained in inorganic crystals, glasses, ceramics, polymers and so on.

Q 45. How do we carry out **thermoluminescence spectra** measurements?

A.

- use band pass filters between sample and PMT while taking the glow curve
- periodical spectral scanning during glow curve measurements
- spectral scanning during isothermal decay measurements
- construction of the spectrum for any temperature of emission from the monochromatic thermoluminescent glow curve

Q 46. What is the effect of the **linear energy transferred (LET)** on the thermoluminescence response?

A. The effect of LET on the thermoluminescence response is, mostly, a decrease of thermoluminescence **sensitivity** with increase of LET of the incident radiation.

Q 47. What are the effects of high **LET** radiation on the thermoluminescence emission?

A. The main effect is a saturation of the thermoluminescent signal. Sometimes the LET effects manifest in changes of the glow curve, of the fading rate and on the thermoluminescent emission spectrum.

Q 48. Is there any intrinsic thermoluminescence **sensitivity** to UV rays exposure?

A. Upon UV excitation by an appropriate frequency, luminescence may be emitted during thermal stimulation, depending on the type of phosphor used.

Q 49. Are the **glow curves** obtained after UV rays exposure the same as the ones obtained after X or gamma irradiation?

A. The glow curves obtained after the two kinds of excitations are not usually the same.

Q 50. Is the **thermoluminescence sensitivity** to UV rays exposure the same as that of X or gamma irradiation?

A. In general the thermoluminescence sensitivity to UV rays exposure is very small compared to the one of X or gamma radiation.

Q 51. Is there a special procedure to enhance the **UV sensitivity** of phosphors?

A. Some materials, such as LiF, CaF₂, BeO and others, become UV sensitive or increase their intrinsic UV sensitivity after a high temperature treatment.

Q 52. Does the thermoluminescent glow curve shape depend on the **UV wavelength**?

A. Yes, the thermoluminescent glow curve shape is generally UV wavelength dependent.

Q 53. Is there a **UV effect** on phosphors already irradiated using X or gamma radiation?

A. If a sample has already been irradiated by X or gamma radiation, one may observe some bleaching effect in the ionizing radiation induced thermoluminescence. The bleaching effect is

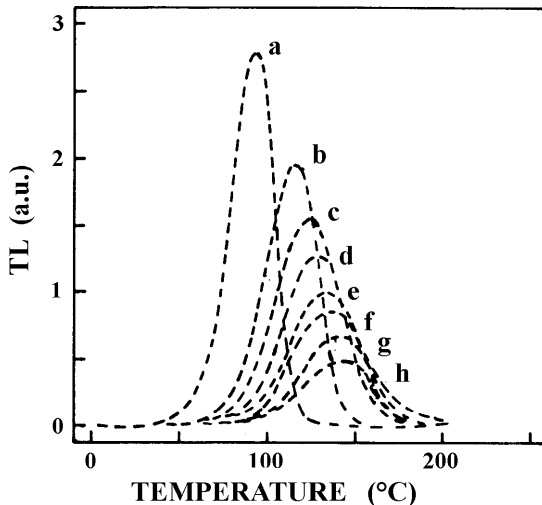
usually not the same for all the peaks, if there more than one in the glow curve, because each peak may have a different dependence for the bleaching effect.

Q 54. Which are the effects of the **heating rate** on the peak characteristics?

A. In the hypothesized situation of very good thermal contact between the thermoluminescent sample and the heating element, the following results are obtained:

- the peak temperature at the maximum of the peak, T_M , shifts to higher temperature values as the heating rate increases
- the thermoluminescent intensity, peak area and peak height decreases as the heating rate increases

The following figure shows the behavior of the two above characteristics as a function of the heating rate.



Change of the peak shape and shift in the peak position as a function of the heating rate. From (a) to (h) = 2, 8, 20, 30, 40, 50, 57, 71°C/s.

Q 55. Why does the thermoluminescent intensity decreases as the **heating rate** increases?

A. The thermoluminescent intensity decreases as the heating rate increases because of a thermal quenching effect, whose efficiency increases as the temperature increases, i.e. the glow peak shifts to higher temperature values as a consequence of the increase of the heating rate.

Q 56. What is the **thermal quenching** effect?

A. In general, the luminescence efficiency is a factor that is temperature dependent, so the efficiency decreases with increase the temperature.

Q 57. How can the **thermal quenching** effect be explained?

A. Thermal quenching effect is explained by competition between radiative transitions (almost temperature independent) and non-radiative transitions which increase with temperature.

Q 58. How can the **thermal quenching** effect be studied?

A. The thermal quenching effect can be studied by employing two extremely different heating rates and measuring the total light emitted in each case.

Q 59. Can an **electric field** have an effect on thermoluminescence when applied to a phosphor sample?

A. Some effects on the thermoluminescent emission have been observed during sample heating, i.e. to enhance the thermoluminescent emission.

Q 60. What is the order of magnitude of the **electric field** to be applied to a phosphor to get the effects?

A. The electric field should be of the order of 10^5 V/cm.

Q 61. What are the factors affecting the thermoluminescent emission when an **electric field** is applied to a phosphor?

A. It seems that the factors are:

- field ionization of the electron traps
- acceleration of electrons after their thermal release from traps and subsequent ionization

Q 62. What is the **detection threshold**?

A. The detection threshold is defined as the smallest dose that can be distinguished significantly from the zero dose.

Q 63. How do we calculate the **detection threshold**?

A. The detection threshold is calculated taking three times the standard deviation of the zero dose reading, expressed in units of the absorbed dose.

Q 64. In which way do we measure the **zero-dose**?

A. It is the signal obtained from a non-irradiated dosimeter, i.e. the dosimeter's background, L_{BKG} .

Q 65. How to calculate the **zero-dose** reading?

A. The zero-dose reading is the result of two components:

- the signal of the TL reader obtained without a dosimeter using the read out cycle used for a dosimeter reading. This quantity is called R_0 and it corresponds to the dark current of the TL system
- the signal from an annealed and unirradiated dosimeter, i.e. R_U

Several measurements of R_0 and R_U have to be performed. The zero-dose reading, or its average value, is then given by

$$\bar{R}_{BKG} = \bar{R}_0 + \bar{R}_U.$$

Q 66. How is the **net reading** of N dosimeters irradiated at the same dose defined?

A. It is defined as the difference between the mean value of the readings of the N irradiated dosimeters and the mean of their individual backgrounds. The following expression gives the net reading

$$R_{net} = \frac{1}{N} \left[\sum_{i=1}^N R_{irr,i} - \sum_{i=1}^N R_{BKG,i} \right].$$

Q 67. How is it possible to repeat a **thermoluminescent experiment** reported in literature to get the same results?

A. The question has two different folders. The first one is concerned with the dosimetric characteristics of a given thermoluminescent material. Also, using the same kind of phosphor, it is normal to have differences in the thermoluminescent characteristics from batch to batch as well as within the same batch, from sample to sample. The only way to obtain similar results is to know exactly what are the experimental conditions used in literature. A second important factor is the TL instrument: in the case of using the same type of equipment, the electronic characteristics cannot be equal depending on the age, use and other factors affecting the electronic components. So, the dosimetric characteristics of a given material can be quite different from one laboratory to another. In principle, the only characteristics of a material which should be the same in any laboratory, everywhere, are the kinetics parameters, i.e. the activation energy, the frequency factor and the kinetics order, because they are independent of the instruments used.

Q 68. What is **fluorescence**?

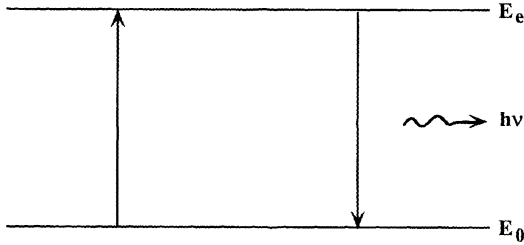
A. Fluorescence is a luminescent process, a luminescent decay, which only persists for as long as the excitation is continued.

Q 69. Is **fluorescence decay** temperature dependent?

A. No, fluorescence decay is independent of temperature.

Q 70. What is the mechanism of **fluorescence**?

A. The fluorescence is determined by the transition probability from an excited level E_e to the ground state E_0 . The following figure shows this effect.



The fluorescent phenomenon.

Q 71. What is **phosphorescence**?

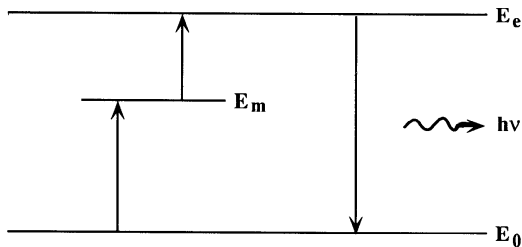
A. Phosphorescence is a luminescent phenomenon observable after removal of the exciting source.

Q 72. Is **phosphorescence** dependant on temperature?

A. Yes.

Q 73. Why does the **phosphorescence** depends on temperature?

A. This is because it can be delayed by some trapping levels E_m in the forbidden gap. An increase in temperature provides enough energy for detrapping. The following figure shows the phosphorescence phenomenon.



The phosphorescence phenomenon.

Q 74. How should the **spectrum** of the emitted thermoluminescent light be?

A. The spectrum of the emitted thermoluminescent light should be in the range where the detector system (photomultiplier and filter combination) responds at its best.

Q 75. Which glow peak characteristics are affected by the **heating rate**?

A. The heating rate, during a thermoluminescent measurement, affects the glow peak temperature position, the intensity of the peak and its shape.

Q 76. What is the main problem in the preparation of **artificial thermoluminescent materials**?

A. To find a very efficient activator impurity.

Q 77. Which are the main techniques for growing single **thermoluminescent crystals**?

A. The most important methods are those due to Bridgeman and Stockberger.

Q 78. In which way can **polycrystalline TL materials** be prepared?

A. An efficient method consists of precipitating the basic material and the activator, followed by drying and firing at high temperature in an inert atmosphere or in vacuum.

Q 79. Are the **thermoluminescent materials** poor or good thermal conductors?

A. In general they are rather poor thermal conductors.

Q 80. How can the **temperature difference** between the two faces of a thermoluminescent chip be estimated?

A. The temperature difference can be estimated using the following expression

$$\Delta T = \frac{\beta \cdot t^2 \cdot c \cdot \rho}{k}$$

where

β = heating rate

t = sample thickness

c = specific heat

ρ = density

k = thermal conductivity

Q 81. What are the factors affecting the **sensitivity** of a thermoluminescent instrument?

A. Voltage variations, PM tube fatigue, electronic instability, extremities in ambient weather, deposition of dirt and vapor on optical parts.

Q 82. Which factors can affect the **glow curve** of a thermoluminescent material?

A. The factors to take into consideration to get the same glow curves after similar irradiations are:

- reproducibility of the annealing procedures, i.e. pre- and post-irradiation annealing
- reproducibility of the red out cycle
- storage of the irradiated samples in constant and controlled environmental conditions
- reproducible cooling rate of the samples after the annealing procedure
- to avoid high irradiation doses if the samples are normally used in the linear region of response
- to avoid the exposure to sunlight, artificial light and sources of radiation
- use a cleaning procedure if contamination of samples is suspected
- regular check of the PM tube background using the reference light source included in the TL reader
- use vacuum tweezers when handling the samples
- take into account the elapsed time between irradiation and read out for fading corrections

Q 83. How do we define the **superlinearity** in the plot TL vs Dose?

A. The superlinearity is defined as the increase of the derivative of the dose dependence function.

Q 84. Is there any expression for a quantitative measure of the **superlinearity**?

A. Yes. It is the superlinearity index, defined by Chen and McKeever, given by the following expression:

$$g(D) = \left[\frac{D \cdot S''(D)}{S'(D)} \right] + 1$$

where $S'(D)$ is the first derivative of the dose dependence function, i.e. the TL signal vs dose D , and $S''(D)$ the second derivative.

Q 85. What kind of indication does the **superlinearity** index give?

A. It gives an indication of the change in the slope of the dose response.

Q 86. What is the **supralinearity** index $f(D)$?

A. It gives the amount of deviation from linearity in the TL vs Dose function.

Q 87. How is the **supralinearity** index $f(D)$ defined?

A. It is defined according to the following expression:

$$f(D) = \left[\frac{S(D) - S_0}{D} \right] \bigg/ \left[\frac{S(D_l) - S_0}{D_l} \right]$$

where D_l is the normalization dose in the linear range of the TL vs D response and S_0 is the intercept on the TL axis of the extrapolated linear region.

Q 88. What is the physical reason that the area under a thermoluminescent **glow peak** is proportional to the dose absorbed by the TL dosimeter?

A. The trapped charge concentration, n , is evaluated from the area under the peak according to the following equation

$$n = \frac{1}{\beta} \int_{T_i}^{T_f} I \cdot dT'$$

where β is the linear heating rate, T_i and T_f are the temperatures at the beginning of the peak and at its end respectively, and I is the TL intensity. In turn, n is proportional to the absorbed dose D through the calibration factor of the system, F_C , i.e. $n = D/F_C$. So, we get

$$D = \frac{F_C}{\beta} \int_{T_i}^{T_f} I \cdot dT'.$$

Q 89. What is the meaning of **physicochemical stability** for a dosimetric material?

A. It means that a material used for dosimetric purposes should not undergo any physicochemical changes during repeated use, i.e. annealing process, repeated exposures, read out cycles.

Q 90. What is **tribothermoluminescence**?

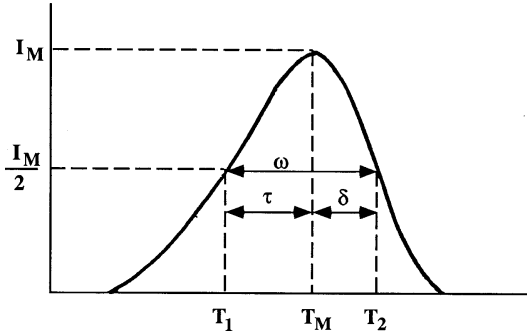
A. This phenomenon is produced by friction during heating, giving some spurious signals. A large triboluminescence can be observed when monocrystalline powder is used.

Q 91. Which are the characteristics of a **first order peak**?

A. According to the following figure

- The first order peaks are asymmetrical and $\tau = T_M - T_1$, the half-width at the low temperature side of the peak, is almost

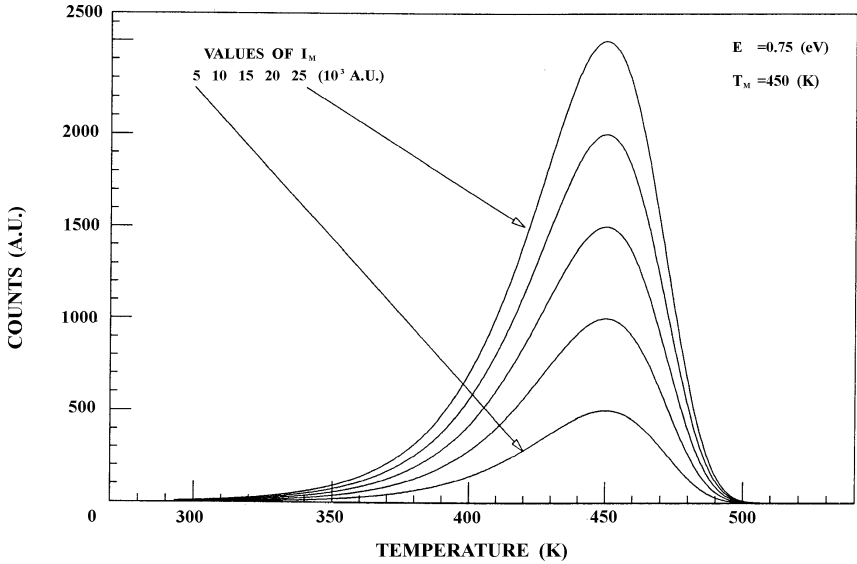
50% larger than $\delta = T_2 - T_M$, the half-width towards the fall-off of the glow-peak $\tau \sim 1.5\delta$. The shape and the peak temperature depend on the heating rate.



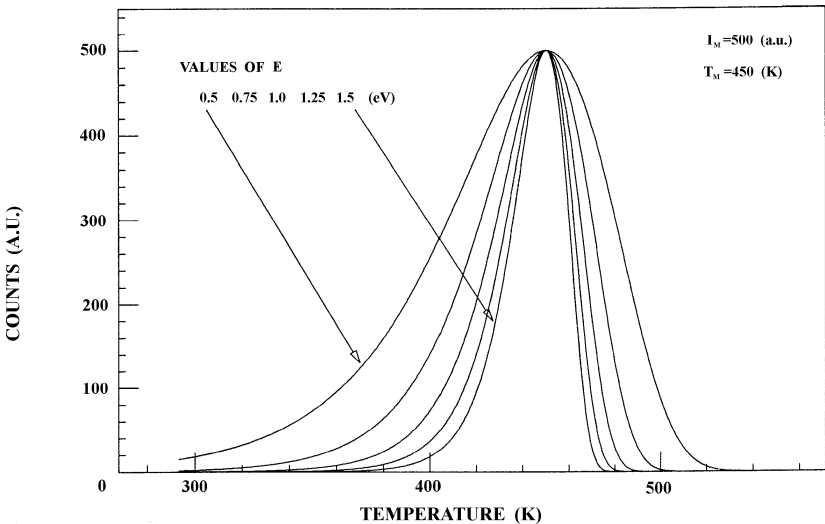
- The low temperature side of the peak, is almost 50% larger than $\delta = T_2 - T_M$, the half-width towards the fall-off of the glow-peak $\tau \sim 1.5\delta$. The shape and the peak temperature depend on the heating rate.
- For a fixed heating rate, both peak temperature and shape are independent of the initial trapped electron concentration n_0 , as can be observed from the condition at the maximum

$$\frac{\beta E}{kT_M^2} = s \exp\left(-\frac{E}{kT_M}\right).$$

- The value of n_0 depends on the pre-measurement dose.
- The TL glow-curve obtained for any n_0 value can be superimposed onto the curve obtained for a different n_0 by multiplying by an appropriate factor.
- A first order peak is characterized by a geometrical factor $\mu = \delta/\omega = (T_2 - T_M)/(T_2 - T_1)$ equal to about 0.423.
- For fixed values of dose and heating rate, the ω value increases as E decreases.
- The decay at constant temperature of a first order peak is exponential.



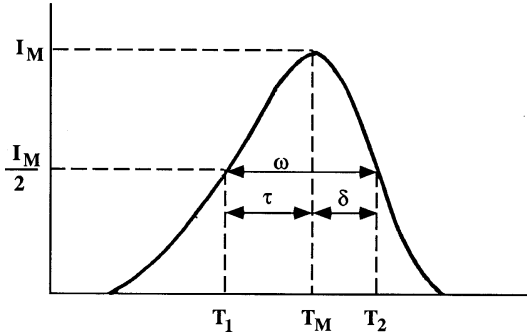
A computed first order glow-peak showing the linear increase of I_M as a function of dose.



A computed first order glow-peak showing the increase of ω as E decreases.

Q 92. Which are the characteristics of a **second order peak**?

A. According to the following figure

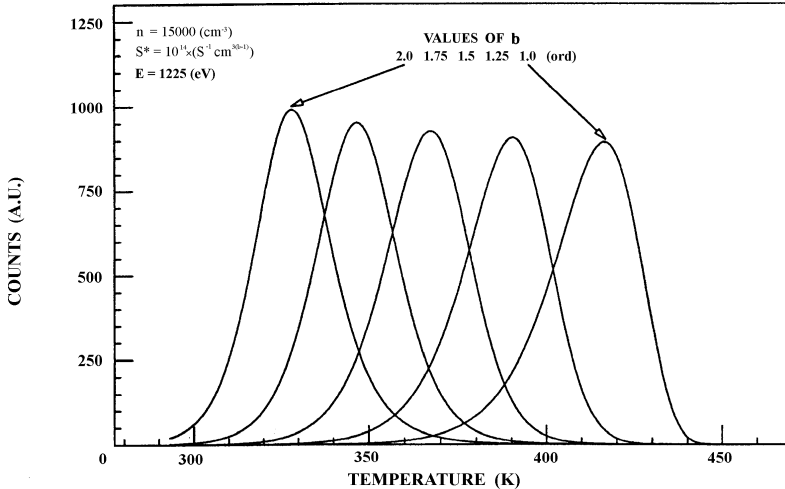


- A second order peak is practically symmetrical ($\delta \approx \tau$).
- To keep all other parameters constant, the shape and the peak temperature depend on the heating rate.
- For a fixed heating rate, the peak temperature and shape are strongly dependent on the initial trapped charge concentration, n_0 . Peaks obtained for different initial trapped charge concentrations cannot be superimposed by multiplying by a factor.
- The glow-peaks obtained for different n_0 values tend to superimpose at the high temperature extremity of the glow-peak.
- An increase of n_0 produces a decrease in the temperature of the peak, according to the maximum condition

$$\frac{\beta E}{2kT_M^2} \left[1 + \frac{s'n_0}{\beta} \int_{T_0}^{T_M} \exp\left(-\frac{E}{kT'}\right) dT' \right] = s'n_0 \exp\left(-\frac{E}{kT_M}\right).$$

- The isothermal decay of a second order peak is hyperbolic.
- A second order peak is characterized by a geometrical factor $\mu \cong 0.524$.

- Furthermore, a decrease in the temperature of the peak, T_M , is observed as a function of the kinetics order changing from 1 to 2. This effect is illustrated in the figure below.



Computerized glow-peaks showing the effect of the kinetics order on the position of the peak temperature.

Q 93. What are the procedures if **contamination** of the thermoluminescent dosimeters is suspected?

A. A standard cleaning procedure is as follows:

- Ultrasonic treatment in 1% detergent solution for 2 minutes.
- Rinsing in running water for 2 minutes.
- Rinsing in distilled water for 0.5 minutes.
- Rinsing in alcohol for 0.5 minutes.
- Drying of TLDs in a dust-free atmosphere.

Q 94. Which are the main applications for the **integrating dosimeters**?

A. The main applications of integrating dosimeters are summarized in the following:

1. Radiological protection
 - routine personnel monitoring
 - diagnostic radiology
 - environmental monitoring
2. Radiotherapy
3. Radiobiology
4. Radiation chemistry
5. Nuclear reactors

Q 95. What are the main practical characteristics which must be considered when choosing a **dosimetric system**?

A. The main practical characteristics to be considered are the following:

- the system should be able to measure the integrated dose
- to be able to distinguish between different types of radiation
- to have a large linear relationship between dosimeter response and dose
- to have a good accuracy according to the application
- to have a good precision of repeated measurements with a single dosimeter and with a batch of dosimeters
- the dosimeter should respond to radiation in the same manner as the medium in which the dose is to be measured
- the radiation field strength should not change throughout the volume of the dosimeter

Q 96. To which quantities is the **emitted light**, $L(\lambda)$, from a dosimeter proportional to?

A. The emitted quantity of light $L(\lambda)$, due to an absorbed dose, detected and measured during the readout cycle will be proportional to:

D_0 the absorbed dose

$P(\lambda)$ the light generated in the dosimeter per unit absorbed dose

K_1 the geometrical-optical factor summarizing the effects of dosimeter shape and transparency, the dose distribution throughout the dosimeter and the effective geometrical efficiency of light collection

K_2 the fraction of the total light sum measured

Q 97. To which quantities is the **light generated** in the dosimeter **per unit absorbed dose**, $P(\lambda)$, proportional to?

A. $P(\lambda)$ is a complex function depending on:

- the mean phosphor sensitivity
- the mean absorbed dose
- the thermal and radiation history of the dosimeter
- the time interval between irradiation and read out
- the heating rate during read out

Q 98. To which quantities is the **geometrical-optical factor**, K_1 , a function of?

A. K_1 is a function of:

- μ the mass absorption coefficient of the radiation
- $A(\lambda)$ the absorption coefficient of the dosimeter for light generated within the dosimeter
- G the geometrical efficiency of light collection

- r the effective tray reflectivity
- the orientation of the dosimeter in the readout instrument

Q 99. To which parameters is the fraction of the **total light sum** measured, K_2 , a function of?

A. The factor K_2 is a function of the heating cycle used and the interval over which the light is measured.

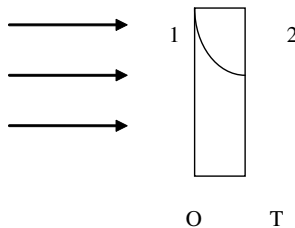
Q 100. How do we express analytically the **light $L(\lambda)$ emitted** by an irradiated dosimeter and reaching the PM tube of the reader?

A. $L(\lambda)$ is analytically expressed by the following relation:

$$L(\lambda) = P(\lambda) \cdot K_1 \cdot K_2 \cdot D_0$$

Q 101. How can be the **dose distribution** through a dosimeter simulated?

A. As it is illustrated in the following figure



The dose distribution through a dosimeter, having a thickness T , is given by

$$D_X = D_0 \exp(-\mu \cdot x)$$

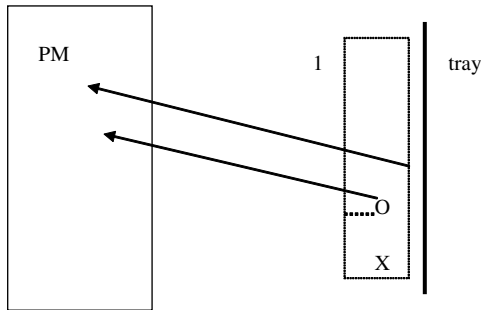
where μ is the mass energy absorption coefficient, x the distance from surface 1 within the dosimeter, and D_X is the dose deposited at a distance X from surface 1.

Q 102. How do we simulate the **self-attenuation of light** output by the dosimeter?

A. The light generated within a dosimeter will be attenuated in its path to the PM tube by absorption and scattering effects within the dosimeter. The attenuation is of the form

$$I_X = I_0 \exp[-A(\lambda) \cdot X]$$

where, according to the following figure



I_0 is the intensity of the light at point O, I_X is the intensity at a distance X from O, $A(\lambda)$ is the coefficient of attenuation by the dosimeter of its internally generated light.

Q 103. What is the **photon energy response** curve?

A. The photon energy response curve is the plot of the relative response of the thermoluminescent material to that of a reference material, i.e. air or tissue against photon energy for materials exposed to X or gamma rays. When the reference material is

tissue, this plot gives an indication of the tissue equivalence of the material.

Q 104. What is the behavior of the **photon energy response** curve as a function of the photon energy?

A. At low photon energies (below about 150 keV) photoelectric absorption is the dominant interaction process with a cross section for interaction which increases approximately as Z^4 , where Z is the effective atomic number of the absorbing material.

Q 105. What is the so called **individual correction factor**, S_i ?

A. The individual correction factor, S_i , or relative intrinsic sensitivity factor, is associated to a dosimeter and it is used as a multiplying factor of the net reading to correct the dosimeter response at any delivered dose. It is expressed by the following expression:

$$M_{i,net(cor)} = M_{i,net} \cdot S_i$$

Q 106. What is the **relative intrinsic sensitivity factor**?

A. Another name for the individual correction factor.

Q 107. What is the practical meaning of the **individual correction factor**, S_i ?

A. The S_i factor is a correction factor which is needed to avoid any reading variations owing to the individual sensitivity of each dosimeter.

Q 108. How to calculate the **individual correction factor**?

A. Considering a batch of N dosimeter, the individual correction factor is given by the following expression:

$$S_i = \frac{\bar{M}}{M_i - M_{0i}}$$

where

M_i is the reading of the i -th dosimeter

M_{0i} is the background reading of the i -th dosimeter

$M_i - M_{0i} = M_{i,net}$

\bar{M} is the average of the net readings of the N dosimeters

Q 109. Which are the factors that affect the dosimeter **background**?

A. The factors that affect the dosimeter background are several and they can be listed as following:

- transparency variability of the dosimeters
- exposure to sun light
- exposure to artificial light
- dusty contamination of the dosimeter surface
- ineffective and non-reproducible pre- and/or post-irradiation annealing procedures
- changes in sensitivity due to radiation damage
- non-reproducible thermal read-out cycle
- self-dose effect if the thermoluminescent material includes some radioactive elements

Q 110. Can the thermoluminescent dosimeters show any **self-dose** effect?

A. Yes. The self-dose effect arises from a possible radioactive content of the thermoluminescent materials.

Q 111. How do we carry out an estimation of the **self-dose** effect, if any?

A. Suspect self-dose effect can be estimated leaving the annealed dosimeters in a sufficiently thick lead shield of about 5 cm to stop most of the external radiation.

Q 112. What is a **thermally disconnected trap**?

A. It is a trap which is very deep in the band gap so that during the sample heating, the trapped electrons are not released.

Q 113. What is the **correction factor**?

A. The correction factor is a numerical value which should be evaluated when a thermoluminescent material has a TL response at photon energies below 100 keV significantly greater than that at higher energies, i.e. Cs and Co.

Q 114. How do we calculate the **correction factor**?

A. The correction factor is obtained as the ratio between the calibration factor obtained with a reference beam quality, i.e. Cs or Co, and the calibration factor obtained with another beam quality.