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# On the effect of optical and isothermal treatments on luminescence signals from feldspars

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## HIGHLIGHTS

- CW-IRSL and CW-OSL measurements are preceded by heating or optical bleaching.
- New analytical equations are derived to describe these double experimental procedures.
- Equations are compared with data from a feldspar sample following isothermal procedure.
- Equations are compared with data from a feldspar sample following optical bleaching.

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## ABSTRACT

During luminescence dosimetry and luminescence dating applications it is often necessary to precondition the geological samples by applying a thermal or optical treatment before measuring the luminescence signal. In luminescence applications using apatites or feldspars, measurement of continuous-wave infrared or optically stimulated signals (CW-IRSL and CW-OSL) are customarily preceded by either an isothermal heating of the samples at a fixed temperature for a short time interval, or alternatively by optically bleaching the samples using light from LEDs with the appropriate wavelength. This paper presents new analytical equations which can be used to describe these commonly employed double experimental procedures. The equations are based on a recently published model which assumes that tunneling processes are taking place in random distributions of donor–acceptor pairs. The concentration of charge carriers during the CW-IRSL or CW-OSL experiment is expressed in terms of the parameters of the preceding thermal or optical bleaching procedure, and depends also on the distribution of distances between electron and hole pairs. The analytical equations in this paper are compared with experimental data from a feldspar sample which undergoes an isothermal procedure followed by measurement of the CW-IRSL signal. Additional comparisons with experiment are provided using a feldspar sample which undergoes an infrared bleaching process, followed by measurement of the CW-OSL signal. These results and conditions under which the equations can be used are discussed within the framework of the model.



## 1. Introduction

During the past decade there has been significant progress in our understanding of luminescence processes in feldspars. In particular recent experimental and modeling work has helped researchers understand the non-exponential shape of continuous-wave infrared stimulated luminescence (CW-IRSL) signals from feldspars (Li and Li, 2013; Morthekai et al., 2012; Jain and Ankjærgaard, 2011; Thomsen et al., 2011; Bailiff and Poolton, 1991).

Specifically the model developed by Jain et al. (2012) has been a major development in this research area, and has helped in the understanding of tunneling phenomena in a random distribution of electron–hole pairs. Kitis and Pagonis (2013) quantified the semi-analytical model of Jain et al. (2012) by deriving exact analytical expressions for different experimental stimulation modes. This was used to describe luminescence signals from a variety of feldspars

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and apatites (Polymeris et al., 2014; Sfampa et al., 2014; Pagonis et al., 2013). In a recent comprehensive study Pagonis et al. (2014a) examined CW-IRSL signals from a variety of feldspars and described mathematically the shape of these signals in terms of the kinetic parameters in the model of Jain et al. (2012). Kitis and Pagonis (2014) simulated the geometrical shape factor of thermoluminescence (TL) glow curves within the model, and showed that standard kinetic methods of initial rise and variable heating rate can be used to obtain the kinetic parameters for the TL process. Pagonis et al. (2013) obtained approximate expressions for the time development of nearest neighbor distribution during various types of luminescence experiments, and compared their analytical expressions with experimental data on linearly modulated IRSL (Bulur, 1996).

During luminescence dosimetry and luminescence dating applications it is often necessary to precondition the geological samples by applying a thermal or optical treatment before measuring the luminescence signal. In luminescence applications using apatites or feldspars, measurements of CW-IRSL or optically stimulated signals (CW-OSL) are customarily preceded by either an isothermal heating of the samples at a fixed temperature for a short time interval, or alternatively by optically bleaching the samples using light from LEDs with the appropriate wavelength. Murray et al. (2009) reviewed previous research on the effect of preheating on the IRSL signal from feldspar (Bøtter-Jensen et al., 2003; Duller and Bøtter-Jensen, 1993; Duller, 1994; Duller and Wintle, 1991). These authors concluded that IR stimulation is changing the luminescence recombination probability. They proposed that electrons are not necessarily stimulated from the TL traps by IR, but the loss of recombination sites during measurement of the IRSL signal causes a reduction of the photon yield during subsequent measurement of the luminescence signal. Recently Pagonis et al. (2014b) reviewed previous research on the shape and kinetics of TL glow curves in feldspars, on possible correlations between TL and IRSL signals and on the effect of IR illumination on the TL signal (Duller, 1995; Visocekas et al., 1994; Chruścińska, 2001).

In an important recent work Jain et al. (2015) extended their localized transition model to include Arrhenius analysis and for truncated nearest neighbor distributions. Their extended model successfully described the thermal and optical kinetic behavior of IRSL signals from preheated feldspar samples, and was tested using experimental data. These authors found that different infrared stimulated luminescence emissions (UV, blue, yellow and far-red) follow the same kinetics, and most likely involve the same electron trap. A key result of their analysis is that a prior-treatment results in a shifted time domain of the luminescence data.

Pagonis et al. (2013) examined the exact version of the model developed by Jain et al. (2012), and developed analytical equations for the concentration of carriers during measurement of luminescence signals, as a function of two parameters, namely the distance between electron–hole pairs and the stimulation time.

This paper uses the analytical equations developed by Pagonis et al. (2013), in an attempt to describe double experimental procedures commonly used during luminescence dating and luminescence dosimetry protocols.

The goals of the present paper are:

(a) To develop an alternative mathematical approach to the work by Jain et al. (2015), by starting from the analytical equations derived by Pagonis et al. (2013).
(b) The specific goal of this new approach is to develop analytical equations for the intensity of continuous-wave stimulated luminescence (CW-IRSL or CW-OSL) signals for samples which have been pre-treated either optically or thermally. The equations developed in this paper are shown to be a special case of the more general formalism of Jain et al. (2015).
(c) To test the analytical equations by comparing with experimental data from a feldspar sample which undergoes an isothermal procedure, followed by measurement of the CW-IRSL signal. Similarly, the equations are tested for a sample which is first bleached using IR, followed by measurement of the CW-OSL signal.
(d) To discuss the experimental results within the framework of the model, and to also consider the conditions under which the analytical equations can be used to analyze experimental data.

## 2. Analytical equations for double experimental procedures

In this section analytical equations are developed for the time dependent concentration of charge carriers during two commonly used experimental procedures. In Section 2.1 we consider a freshly irradiated sample which undergoes an isothermal procedure (heating at a fixed temperature for a certain amount of time), followed by measurement of the CW-IRSL signal. In Section 2.2 a freshly irradiated sample undergoes an optical bleaching, followed again by measurement of the CW-IRSL or CW-OSL signal.

### 2.1. Isothermal procedure followed by measurement OF CW-IRSL signal

Kitis and Pagonis (2013) showed that the concentration of charge carriers during optical or thermal stimulation in the model by Jain et al. (2012) is given by

$$n(r',t)=n_0 3(r')^2\exp\left[-(r')^3\right]\exp\left[-\exp\left(-(\rho')^{-1/3}r'\right)\int_0^t A dt'\right], \quad (1)$$

where $A$ represents the probability of thermal/optical stimulation and $\rho'$ is the dimensionless charge density. Equation (1) describes the evolution of the distribution of electrons $n(r',t)$ in the ground state as a function of two parameters, namely the time $t$ elapsed since the beginning of the optical or thermal stimulation, and the dimensionless distance parameter $r'$. This equation is valid for several types of excitation used in typical TL or OSL experiments, and the integral $\int_0^t A dt'$ can be evaluated for the different experimental excitation modes. During an isothermal preheat experiment the probability of thermal excitation $A = A_{PH} =$ constant, and Equation (1) becomes:

$$n(r',t)=n_0 3(r')^2\exp\left[-(r')^3\right]\exp\left[-\exp\left(-(\rho')^{-1/3}r'\right)A_{PH}t\right], \quad (2)$$

where $n_o$ is the total initial concentration of charge carriers, and the quantity $A_{PH}\,(s^{-1})$ represents the probability of thermal stimulation given by:

$$A_{PH}=s_{thermal}e^{-E_{thermal}/kT_{PH}}, \quad (3)$$

where $T_{PH}$ is the preheat temperature and $s_{thermal}$, $E_{thermal}$ represent the thermal kinetic parameters of the trap. At the end of the preheat process at a temperature $T_{PH}$ and for a time interval $t_{PH}$, the distribution of remaining electron–hole pairs are then: