Thermal death kinetics

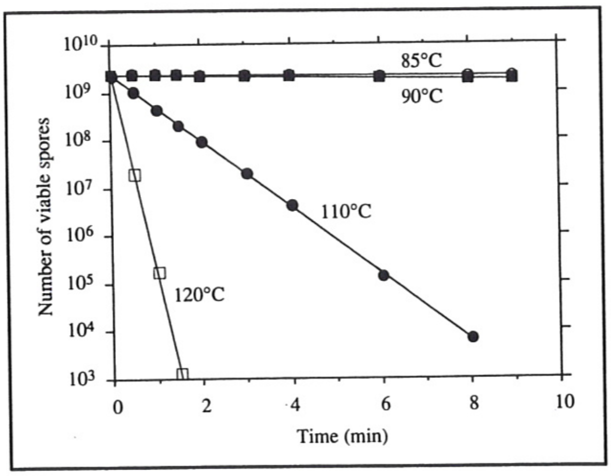
The number of viable spores of a new strain of *Bacillus subtilis* is measured as a function of time at various temperatures.

Time	Number of spores at:			
(min)	$T = 85°C$	$T = 90°C$	$T = 110°C$	$T = 120°C$
0.0	2.40×10^9	2.40×10^9	2.40×10^9	2.40×10^9
0.5	2.39×10^9	2.38×10^9	1.08×10^9	2.05×10^7
1.0	2.37×10^9	2.30×10^9	4.80×10^8	1.75×10^5
1.5	–	2.29×10^9	2.20×10^8	1.30×10^3
2.0	2.33×10^9	2.21×10^9	9.85×10^7	–
3.0	2.32×10^9	2.17×10^9	2.01×10^7	–
4.0	2.28×10^9	2.12×10^9	4.41×10^6	–
6.0	2.20×10^9	1.95×10^9	1.62×10^5	–
8.0	2.19×10^9	1.87×10^9	6.88×10^3	–
9.0	2.16×10^9	1.79×10^9	–	–

(a) Determine the activation energy for thermal death of *B. subtilis* spores.
(b) What is the specific death constant at 100°C?
(c) Estimate the time required to kill 99% of spores in a sample at 100°C?

Solution:
(a) A semi-log plot of number of viable spores versus time is shown in Figure 11E9.1.

Figure 11E9.1 Thermal death of *Bacillus subtilis* spores.

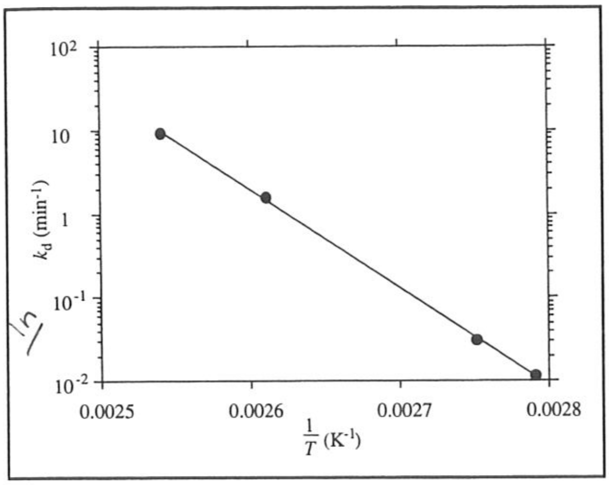


From Eq. (11.88), the slopes of the lines in Figure 11E9.1 are equal to $-k_d$ at the various temperatures. Fitting straight lines to the data gives the following results:

$k_d\,(85°C) = 0.012\ \text{min}^{-1}$
$k_d\,(90°C) = 0.032\ \text{min}^{-1}$
$k_d\,(110°C) = 1.60\ \text{min}^{-1}$
$k_d\,(120°C) = 9.61\ \text{min}^{-1}$.

The relationship between k_d and absolute temperature is given by Eq. (11.46). Therefore, a semi-log plot of k_d versus $^1/_T$ should yield a straight line with slope $= {}^{-E_d}/_R$ where T is absolute temperature. T is converted to degrees Kelvin using the formula of Eq. (2.24); $^1/_T$ values in units of K^{-1} are plotted in Figure 11E9.2.

Figure 11E9.2 Calculation of kinetic parameters for thermal death of spores.



The slope is −27 030 K. From Table 2.5, $R = 8.3144$ J K^{-1} gmol^{-1}. Therefore:

$$E_d = 27\,030 \text{ K } (8.3144 \text{ J K}^{-1} \text{ gmol}^{-1}) = 2.25 \times 10^5 \text{ J gmol}^{-1}$$
$$= 225 \text{ kJ gmol}^{-1}.$$

(b) The equation to the line in Figure 11E9.2 is:

$$k_d = 6.52 \times 10^{30}\, e^{-27\,030/T}.$$

Therefore, at $T = 100°C = 373.15$ K, $k_d = 0.23$ min^{-1}.

(c) From Eq. (11.88):

$$t = \frac{-(\ln N - \ln N_0)}{k_d}$$

or

$$t = \frac{-\left(\ln\left(\frac{N}{N_0}\right)\right)}{k_d}.$$

For N equal to 1% of N_0, $^N/_{N_0} = 0.01$. At 100°C, $k_d = 0.23$ min^{-1} and the time required is:

$$t = \frac{-\ln(0.01)}{0.23 \text{ min}^{-1}} = 20 \text{ min}.$$