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STUDY ON THE THERMOKINETIC PROPERTIES OF BACTERIAL GROWTH

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Abstract

The power–time curves of bacterial growth at different temperatures were determined by using the 2277 Thermal Activity Monitor (Sweden). From these curves, the growth rate constant (μ) and activation energy (E_a) were calculated. According to the transition state theory of reaction dynamics, the activation entropy ($\Delta S^{\neq}$), activation Gibbs free energy ($\Delta G^{\neq}$) and equilibrium constant ($K^{\neq}$) of the activation state could be calculated. These results permitted thermodynamic analysis of the bacterial growth metabolism.

Keywords: bacterial growth, microcalorimetry, thermokinetic properties

Introduction

In any living system, various metabolic events occurring within the cells are all reactions producing heat. Thus, by monitoring the heat effects with sufficiently sensitive calorimeters, one can study the metabolic processes of living cells. It has recently been demonstrated that calorimetric methods can be used for fundamental growth studies of bacteria [1, 2].

In a previous paper [3], we have reported on the determination of power–time curves for bacterial growth and calculation of growth rate constant (μ). In this paper, the power–time curves of *S. sonnei, B. cereus, E. coli* and *P. mirabilis* at different temperatures were determined again by using a 2277 Thermal Activity Monitor (Sweden). Further study of these power–time curves has enabled us to calculate the activation energy (E_a), activation entropy ($\Delta S^{\neq}$), activation Gibbs free energy ($\Delta G^{\neq}$) and equilibrium constant ($K^{\neq}$) of the activation state.

Experimental

Instrument and method

The instrument used in this experiment and methods used for determining the power–time curves of bacterial growth and calculating the growth rate constant were the same as described in [3].

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Materials

The following bacterial were employed: *S. sonnei, B. cereus, E. coli* and *P. mirabilis*. A soluble medium (pH=7.2 –7.4) was used which contained 1 g NaCl, 2 g Peppone and 1 g beef extract in every 200 ml.

Theoretical

Generally, the metabolism of bacteria is very complicated. For convenience, we assumed that the metabolic processes of bacteria conform to the transition state theory of reaction dynamics, then

$$X + S \leftrightarrows (XS) \xrightarrow{\mu} 2X + P \tag{1}$$

where X means the bacteria; S is the substrate; $(X \cdot S)$ is the bacteria –substrate complex; P is the metabolic product; μ is the growth rate constant.

According to the transition state theory of reaction dynamics,

$$u = (kT/h)\exp(\Delta S^{\neq}/R)\exp(-E_a/RT) \tag{2}$$

$$\Delta G^{\neq} = \Delta H^{\neq} - T\Delta S^{\neq} = E_a - T\Delta S^{\neq} \tag{3}$$

$$K^{\neq} = \exp(-\Delta G^{\neq}/RT) \tag{4}$$

where E_a is the activation energy, $\Delta S^{\neq}$ is the activation entropy, $\Delta G^{\neq}$ is the activation Gibbs free energy and $K^{\neq}$ is the equilibrium constant.

Once the values of μ and E_a are determined, the corresponding the values of $\Delta S^{\neq}$, $\Delta G^{\neq}$ and $K^{\neq}$ can be obtained from Eqs (2), (3) and (4).

Results and discussion

We determined the power–time curves of *S. sonnei, B. cureus, E. coli* and *P. mirabilis* at different temperatures, and calculated the growth rate constants (μ) and activation energies (E_a). These data are shown in Table 1. The activation en-

Table 1 Growth rate constans (μ) and activation energies (E_a) of bacteria at different temperatures

Bacteria	μ / min^{-1}				E_a / kJ mol^{-1}
	304.15 K	307.15 K	310.15 K	313.15 K	
S. sonnei	0.0227	0.0242	0.0282	0.0320	31.266
B. cereus	0.0271	0.0318	0.0339	0.0375	27.435
E. coli	0.0182	0.0264	0.0315	0.0355	57.771
P. mirabilis	0.0215	0.0235	0.0251	0.0293	26.171

Table 2 Activation entropies ($\Delta S^{\neq}$) of bacterial growth

Bacteria	$\Delta S^{\neq}$/J K^{-1} mol^{-1}			
	304.15 K	307.15 K	310.15 K	313.15 K
S. sonnei	−169.40	−170.51	−169.83	−169.80
B. cereus	−180.57	−180.21	−180.62	−180.71
E. coli	−84.10	−82.95	−83.37	−84.25
P. mirabilis	−186.66	−186.86	−187.20	−186.61

Table 3 Activation Gibbs free energies ($\Delta G^{\neq}$) of bacterial growth

Bacteria	$\Delta S^{\neq}$/J K^{-1} mol^{-1}			
	304.15 K	307.15 K	310.15 K	313.15 K
S. sonnei	82.764	83.456	83.904	84.414
B. cereus	82.238	82.759	83.455	83.997
E. coli	83.337	83.237	83.616	84.141
P. mirabilis	82.914	83.536	84.202	84.643

Table 4 Equilium constans ($K^{\neq}$) of the activation state of bacterial growth

Bacteria	$K^{\neq}\times10^{15}$			
	304.15 K	307.15 K	310.15 K	313.15 K
S. sonnei	6.007	6.307	7.274	8.171
B. cereus	7.136	8.288	8.658	9.588
E. coli	4.787	6.873	8.135	9.071
P. mirabilis	5.659	6.112	6.478	7.484

tropy ($\Delta S^{\neq}$), activation Gibbs free energy (ΔG) and equilibrium constant (K) obtained from Eqs (2), (3) and (4) are shown in Tables 2–4.

From Tables 2–4 the following conclusions can be drawn:

(a) The value of the activation entropy (ΔS) was always negative, indicating that the degree of disorder was reduced after the activation complex was formed, that is the activation complex was more ordered than the reaction substance.

(b) The values of the activation Gibbs free energy ($\Delta G^{\neq}$) were all between 82 −84 kJ mol^{-1}. It means that if the medium was the same, the values of $G^{\neq}$ were about equal that is the activation processes of bacteria were similar in the same medium.

(c) The values of the equilibrium constant ($K^{\ominus}$) were about equal (10^{-15}) which means that the equilibrium limit of bacteria was about the same in the same medium.

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