JAYNES, MICHAEL LEON. The Kinetics and Thermodynamics for Isothermal Germination of Grand Rapids Lettuce Seeds. (1976) Directed by: Dr. Gaylord T. Hageseth.

The purpose of this study was to see if the "Hageseth Model" (See G. T. Hageseth and R. D. Joyner, "Kinetics and Thermodynamics of Isothermal Seed Germination," J. Theor. Biol., 53, 1975, 51-65.) is also applicable to the germination of Grand Rapids Lettuce Seeds, as well as turnip seeds for which the mathematical model was formulated. Also, an underlying purpose was to provide a control group for additional study of the effect of sound on the germination rate of Grand Rapids Lettuce Seeds.

The mathematical model developed by Dr. Hageseth and Mr. Joyner was based on a study made with turnip seeds. With the aid of this model, I made a study with Grand Rapids Lettuce Seeds to see if the model can be applied to the germination of another type seed.

The experiments were conducted by the same person by a visual observation of the seeds during the germination periods of each lot. Effort was taken to maintain all environmental conditions at a constant level.

The data was analyzed graphically and mathematically using the same computer programs that were used to formulate the model. The theoretical curves were compared to the experimental data by means of the minimum chi-square test.

I found that the model is applicable to the germination of Grand Rapids Lettuce Seeds. However, the values of the reaction parameters within the lettuce seeds are different from those in turnip seeds.

THE KINETICS AND THERMODYNAMICS FOR ISOTHERMAL GERMINATION OF GRAND RAPIDS LETTUCE SEEDS

by

Michael Leon Jaynes

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Approved by

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APPROVAL PAGE

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CHAPTER I

INTRODUCTION

Seed germination is an area in which very few successful attempts have been made at fitting a mathematical model to the germination process of seed populations. The most successful model that fits both the differential and the integral germination rates seems to be the same autocatalytic reaction model that describes biochemical reactions involving enzymes.[1]

The model gives the initial concentrations of two enzymes. From these concentrations an equilibrium constant for the reaction can be calculated. Since the experiments are run over a range of temperatures, the equilibrium constants for the reactions are calculated as a function of temperature. The laws of thermodynamics predict that the natural logarithm of the equilibrium constants plotted as reciprocals of the absolute temperature should be a straight line.[2]

This model needs further testing because it was only applied to turnip seeds. Is this model applicable to another type seed? This is the basic question that has led to this study.

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[1] "Kinetics and Thermodynamics of Isothermal Seed Germination," J. Theor. Biol., 53, (1975) p. 51.

[2] Ibid.

CHAPTER II

DISCUSSION OF THEORY

The kinetics and thermodymanics of isothermal seed germination has been formulated for turnip seeds. Autocatalysis seems to be the most applicable means to describe the biochemical, enzymatic reactions occurring during the germination process, from which the rate of germination can be determined. The process is a self-perpetuating one in which enzymes A and B react to from AB, and complex AB forms the final product given by

$$A + B \rightleftarrows AB, \tag{1}$$

$$AB \rightleftarrows F + B, \tag{2}$$

and

$$AB + F \rightleftarrows 2F + B. \tag{3}$$

If we assume the reactions follow in order converting enzyme A into enzyme F, then the initial rate and the final rate of the reactions are given by

$$\frac{d[F]}{dt} = k_1[A], \tag{4}$$

and

$$\frac{d[F]}{dt} = k_2 ([A]_o - [F]) ([F]_o + [F]), \tag{5}$$

where $[F]$ is the concentration of F, $[A]$ is the concentration of A, k_1 is the initial rate constant, $[F]_o$ is the initial concentration of F, $[A]_o$ is the initial concentration of A, and k_2 is the autocatalytic reaction rate constant.

The proposed kinetics allow us to calculate the equilibrium constant for each reaction because any reversible reaction tends to establish a state of equilibrium. Since we can calculate this equilibrium constant for the total process over a range of temperatures, calculations of the change in enthalpy, Gibb's free energy, and entropy can be made.

The initial equilibrium constant is

$$K_1 = \frac{[AB]_o}{[A]_o[B]_o} . \tag{6}$$

For the second reaction the equilibrium constant is

$$K_2 = \frac{[B]_o[F]_o}{[AB]_o} . \tag{7}$$

And for the autocatalytic reaction,

$$K_3 = \frac{[F]_o^2[B]_o}{[AB]_o[F]_o} = \frac{[F]_o[B]_o}{[AB]_o} = K_2 . \tag{8}$$

For the entire process,

$$K = K_1K_2 = \frac{[F]_o}{[A]_o} , \tag{9}$$

which depends only on the initial concentrations of enzyme F and enzyme A.

An S-shaped curve results from the integration of equation (5), which is exactly the observed cumulative result of the germination of a sample of seeds.

Since we cannot go inside the seed and measure directly the concentrations of A and F which are continually changing, we must find another parameter to infer from the observed quantities. And since the autocatalytic reaction hinges on the conversion of A to F, the seed is considered to be germinated when [F] reaches a critical value.

The average concentration of F for each seed is equal to the number of seeds germinated if we let each germinated seed contribute one unit of $[F]c$ and the rest of the seeds that have not germinated contribute zero $[F]c$. The average $[F]$ would be the number of seeds times the critical concentration of F, divided by the total number of seeds in the sample. $[F]$ now has the significance of being the total number of seeds germinated.[3]

So, equation (5) becomes

$$\frac{dN}{dt} = k_2([A]o - N)([F]o + N) \ . \tag{10}$$

The quantity dN/dt is now the differential rate of germination, $[A]o$ is the number of seeds that will germinate by way of the autocatalytic reaction, and N is the total number of seeds that have germinated.

The change in Gibb's free energy, enthalpy, and entropy for a reversible reaction carried out at constant pressure is related thermodynamically by

$$\Delta G = \Delta H - T\Delta S \ . \tag{11}$$

Partial differentiation of equation (11) with respect to T gives the change in entropy by

$$\frac{d(\Delta G)}{dT} = -\Delta S \ . \tag{12}$$

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[3] "The Effects of Temperature and Single Frequency Audio Sound on the Germination Rate of Seeds," Master Thesis, Greensboro (1973), p. 5.

Also, the change in Gibb's free energy can be calculated by

$$\Delta G = -RT \ln K = -RT \ln [F]o/[A]o, \tag{13}$$

or equivalently by

$$K = e^{-\Delta G/RT} , \tag{14}$$

where R is 1.98 cal/mole-K.°, the universal gas constant.

Now combining equations (11) and (13) gives

$$-\ln K = \frac{H}{R}\frac{1}{T} - \frac{\Delta S}{R} . \tag{15}$$

Differentiating with respect to (1/T) gives van't Hoff's equation:

$$\frac{-d(\ln K)}{d(1/T)} = \frac{\Delta H}{R} . \tag{16}$$

If the ln K is plotted as a function of 1000/T, the slope at any point times -R is ΔH (kcal/mole), the enthalpy change. For a reversible process the change in enthalpy is nearly constant. So equation (15) becomes

$$\ln \frac{K(T_2)}{K(T_1)} = \frac{-\Delta H}{R}\left(\frac{1}{T_2} - \frac{1}{T_1}\right) , \tag{17}$$

where T_1 and T_2 give the temperature range. A negative slope for ln K plotted against 1000/T gives a positive change in enthalpy, indicating an endothermic reaction.[4] Likewise, if the slope is positive, a negative change in enthalpy would imply that the reaction is exothermic.

The slope of the change in Gibb's free energy, ΔG, plotted as a function of the absolute temperature, T, is the change in entropy for the process, given by equation (12). Also, the changes in enthalpy should be equivalent, as calculated by the two different approaches in equations (11) and (16). Equation (11) should be a straight line whose slope is equal to the change in entropy and whose intercept is the change

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[4] *Ibid.*, p. 8.

in enthalpy.

"A germination model for natural seed populations (Goloff and Bazzaz, 1975) and a theoretical model describing the kinetics and thermodynamics of isothermal seed germination (Hageseth and Joyner, 1975) are related since each set of data shows the amount of time it takes for the first seed to germinate, (t_o), is temperature dependent. The models along with the data show that the number of seeds, (a_o), that will germinate via the autocatalytic reaction is proportional to the Boltzman factor $\exp(-E_a/RT)$."[5]

---

[5] "Activation Energy and Germination Times for Isothermal Seed Germination," (at Press), Physics Dept., The University of North Carolina at Greensboro, p. 1.

CHAPTER III

EXPERIMENTAL DISCUSSION

Each experiment was carried out with a sample of 400 seeds at approximately 3 C.° temperature increments from 10.2 C.° to 28.5 C.°. A refrigeration-heating unit assembled to study the effects of sound on the parameters that control seed germination was utilized to control the temperature. (See Joyner, Roger D., 1973 for a complete discussion of design.) It consisted of a Haake Model E 12 0--100 C.° heater-pumping unit, a Polyscience Corporation KR 30 refrigeration unit, and a water reservoir. A thermometer was used to measure the temperature since the apparatus was capable of maintaining the temperature within 0.1 C.° of the desired temperature. The thermometer used was marked in increments of 1.0 C.°. The study was terminated at a low temperature of 10.2 C.°, which was the lower limit of the apparatus.

To control the humidity, a germination chamber of dimensions approximately 43.5cm. x 38.5cm. x 3.5cm. was used. The tight fitting, removable lid allowed a visual observation while maintaining the desired environmental conditions. The seeds were wetted with 200ml. of water. The humidity inside was near 100%, as evidenced by the condensed water on the lid. The experiments were carried out in total darkness, except for observation times which lasted five minutes and plating-out times which lasted thirty-five minutes. To insure the same light intensities, observations and platings were made with one 40 watt incandescent light at approximately 33cm. from the seeds.

The germination chamber was located in a quiet room isolated from the heating-refrigeration unit, which was located in another room. The noise level was the ambient noise of the room.

The seeds were plated out in a 20 x 20 matrix array to allow easy observation. The lots were plated out on dark brown Crown Singlefold Paper Towels, three layers thick, to provide equal wetting and a desired dark background to observe the white radical. A seed was scored as being germinated when the radical appeared through the seed coating.

The only parameter that was changed between experiments was the temperature.

The dead time, which is the time after wetting until the first seed germinates, is highly temperature dependent, as observed from previous work. The dead time for each experimental temperature was approximated to the hour at which the first seed germinated and observations were begun in advance of the approximated time.

CHAPTER IV

DISCUSSION OF EXPERIMENTAL RESULTS

By use of a computer program written to give a chi-square fit of parameters [A]o and [F]o to equation (10), the differential and integral rates have been calculated. Also, the rate constants for each process have been calculated. Figures # 1--8 are plots of the integral rates plotted against the amount of elapsed time. They verify that the rates of germination of Grand Rapids Lettuce Seed can be successfully predicted by selecting the parameters [A]o and [F]o as proposed by the "Hageseth Model." Tables # 1--8 are the tabulated data, both experimental and theoretical for each experimental temperature with the goodness of fit.

Examining the plots in Figures # 1--8 and comparing the curves, one can see that the S-shaped curves of the low temperature 10.2 C.^{o} and the high temperature 28.5 C.^{o} have become flattened-out, which indicates that the reactions within the seed are very slow. The enzymes within the seed are not as open to the chemical processes observed for the ranges between these limits. The study was terminated at the lower limit attainable with the experimental unit. The upper limit was chosen to be the temperature at which the reaction process had been significantly altered. At 28.5 C.^{o} the enzymes appear to have become denatured, and at 10.2 C.^{o} they appear to have their reaction sites thermally closed to reaction.

Figure # 9, Curves (a) and (b) are plots of the natural logarithm of the dead times, t_o, as a function of 1000/T with the theoretical curve fitted by a linear regression. At temperatures above and below about 23.0 C.^{o} (1000/T = 3.375/K.^{o}), the dead times are increasing exponentially. The confidence level of Curve (b) is 99%. A regression on Curve (a) is non-meaningful, as there are only two data points.

The best temperature for producing enzyme F is at 1000/T = 3.422/K.^{o} or 19.2 C.^{o}, according to Figure # 10. Also, this is the best approximate temperature for germination as [A]o, the number that will germinate by the autocatalytic reaction, is at a maximum, as shown in Figure # 12. Both the rates and the total number germinated are maximum at this temperature.

Looking at Figures # 11, 13, and 15 which are plots of the natural logarithms of [F]o, [A]o, and [F]o/[A]o as a function of 1000/T, respectively, there appeared to be linear ranges. Linear regressions were run on each range since the model hinges on linearity. The results of the regressions for all the curves are tabulated in Tables # 9 and 10. For an Arrhenius plot the activation energy is -R times the slope of the curve. From Figure # 11, Curve (b), the activation energy for [F]o, which is +94.0 ±8.6 kcal/mole, is calculated at a confidence level of 94%. Likewise for Figure # 13, Curve (b) the activation energy of [A]o is +24.9 ±2.7 kcal/mole with a confidence level of 98%. One point has been omitted because it was thought to be in error. If this data point is included, the confidence level drops to about 80% giving a slope of -8.89 ±4.32 and activation energy of +17.8 ±8.6 kcal/mole. These activation energies are significantly different from the values obtained from the quiet group for the turnip seeds, which are +52.67 ±8.87 kcal/mole for [F]o and +8.30 ±0.98 kcal/mole for [A]o.[6] The value for [F]o has been calculated using data from turnip seed experiments, and is listed in Table # 13. The activation energies of [F]o and [A]o obtained for lettuce seeds are approximately one-half the magnitude of those for turnip seeds.

One interesting calculation can be made from the relation:

$$N = N_o e^{-E_a/RT} \quad , \qquad (18)$$

or

$$\ln N = -\left(\frac{Ea}{R}\right)\left(\frac{1}{T}\right) + \ln N_o \quad . \qquad (19)$$

From the intercept of Figure # 13, Curve (b), N_o has been determined to be 1.72×10^{21}, which is the initial number of molecules of enzyme A. But an initial number of [F]o of the order 10^{40} is too large to have meaning. Curves (a) and (c) in Figure # 11 and Curve (a) in Figure # 13, have no real phyiscal significance.

Figure # 14 is a plot of the autocatalytic reaction rate constant, k_2, as a function of 1000/T. The slope of Curve (a) in Figure # 14 gives an activation energy of +79.0 ±11.5 kcal/mole for the autocatalytic reaction with a confidence level of 92%. This compares to +71.4 ±11.6 kcal/mole for turnip seeds.[7] From Figure # 14, Curve (b) again has no known meaning as described by the model. It only says that the rate constants for the autocatalytic reactions increase exponentially as the temperature decreases.

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[6] Ibid.

[7] Joyner, op. cit., p. 37.

The slope here is +9.02 ±0.97, with a 99.99+% confidence level which compares with +12.6 ±1.7 for turnip seeds.[8] One data point was also omitted in Curve (b) because it was thought to be in error.

The model predicts that [F]o/[A]o is the equilibrium constant for the overall process, as seen from equation (9). The slopes of Figure # 15, Curves (a), (b), and (c) give the change in enthalpy. As predicted by equation (15), ΔH = -R x slope ln [F]o/[A]o versus 1000/T. From 10.2 C.° to 14.5 C.°, ΔH was determined to be -67.24 ± 21.21 kcal/mole; from 14.5 C.° to 17.3 C.°, +72.61 ± 1.33 kcal/mole; and from 17.3 C.° to 26.0 C.°, -62.05 ± 8.99 kcal/mole. The confidence levels are 80%, 99.99 +%, and 90%, respectively. These curves imply that there are three processes taking place inside the seed as the temperature changes. The first reaction and the last reaction have approximately the same change in enthalpy. The reactions are exothermic, endothermic, and exothermic, respectively, as determined by the sign of ΔH.

Since the Gibb's free energy can be calculated by ΔG = -RT ln K = -RT ln [F]o/[A]o, a plot can be made of ΔG as a function of the absolute temperature. Figure # 16, Curves (a), (b), and (c) is such a plot. According to the model, the slope of each curve should be in the enthalpy.

---

[8] Ibid., p. 30.

The curves give changes in entropy of +0.249 ± 0.074 kcal/mole-K.^{o}, -0.242 ± 0.002 kcal/mole-K.^{o}, and +0.222 ± 0.030 kcal/mole-K.^{o}, respectively, which compare to the values calculated from the intercepts of ln $[F]_o/[A]_o$ versus 1000/T of +0.246 ± 0.070 kcal/mole-K.^{o}, -0.240 ± 0.004 kcal/mole-K.^{o}, and +0.221 ± 0.030 kcal/mole-K.^{o}. Also, the intercepts of Curves (a), (b), and (c) are the changes in enthalpies which are -67.87 ± 21.03 kcal/mole, -72.94 ± 0.45 kcal/mole, and -62.42 ± 8.77 kcal/mole, respectively. These values are readily comparable to the changes in enthalpies calculated from the slopes of ln $[F]_o/[A]_o$ which are -67.24 ± 21.21 kcal/mole, +72.61 ± 1.33 kcal/mole, and -62.05 ± 8.99 kcal/mole. It is evident that the changes in enthalpy and entropy as calculated each way are equivalent. The fact that the slope of one graph is equal to the intercept of another informs us that the plots are independent; this fact further substantiates the model.

CHAPTER V

INTEGRATION OF RESULTS WITH CURRENT EFFORTS

At the time of the writing of this thesis, research was being conducted to determine the effect of sound on the parameters that cause seed germination of Grand Rapids Lettuce Seed. Previous results have shown that sound affects turnip seed germination.

Cooperatively, I have obtained data from experiments run with sound treatment (4000 Hz, 100db sound for one hour). My experiments have been duplicated with the only change in the environment being the sound treatment. The integrated results are tabulated in Tables # 14 and 15.

Examination of these combined efforts by linear regressions in the same linear regions consistently reproduced my results within one standard deviation, except for the activation energies.

The thermodynamic parameters, change in enthalpy and change in entropy, are well within one standard deviation. Combining the results gives a minimum of six data points for each linear region, where as there were only three previously. The six data points give higher confidence level.

Literature gives the change in enthalpy, ΔH, and change in entropy, ΔS, for an enzyme trypsin to be 67.6 kcal/mole and

0.213 kcal/mole-K.°.[9] The changes of enthalpy and entropy calculated for Grand Rapids Lettuce Seeds are very close in magnitude to these values. However, the reactions are thermodynamically different, as previously stated according to the sign of the change in enthalpy. The activation energies are about half those calculated for turnips.

The kinetics for turnip seeds and lettuce seeds are different, but the thermodynamic parameters calculated are on the same order of magnitude.

Table # 16 shows that the activation energies of the composite group for [F]o, [A]o, and k_2 were lower than the quiet group.

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[9] Anson and Mirsky, J. Gen. Physiol., p. 393.

CHAPTER VI

CONCLUDING REMARKS

The model has been successful in predicting both the differential and integral rates of environmentally controlled samples of Grand Rapids Lettuce Seeds. The thermodynamic parameters calculated indicate that enzymes are important in lettuce seed germination, as they apparently are in turnip seed germination. The fact that three efforts have been so interrelated lends further credibility to the model.

The two mathematical parameters calculated, $[F]_o$ and $[A]_o$, indicate that the ambient temperature affects the reactions inside the seed. There are three reactions that apparently dominate the process.

From 10.2 C.° to 14.5 C.° the process is very slow, but exothermic. From 14.5 C.° to 19.2 C.° an endothermic process occurs. From 19.2 C.° to 26.0 C.° the process is exothermic. The process of germination has a higher rate and the best yield at about 19.2 C.° for lettuce seeds.

The integration of my efforts with current efforts show that the model gives very reproducible results.

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APPENDIX I

EXPERIMENTAL DATA

TABLE 1

EXPERIMENT VIII, DATA

DIFFERENTIAL AND INTEGRAL RATES, CONDUCTED FEB.9-FEB.12, 1976

Temp. (C.°)	Elapsed Time(hrs.)	Obs. ΔN/ΔT	Theor. ΔN/ΔT	Chi-Sqr.	Obs. N	Theor. N	Chi-Sqr.
10.0	47	0	-	-	0	-	-
10.1	48	1	0.7	0.18	1	1	0.18
10.2	49	1	0.9	0.01	2	2	0.12
10.3	50	1	1.4	0.62	4	3	0.36
10.4	51	0	1.4	1.40	4	4	0.03
10.5	52	1	1.6	0.25	5	6	0.17
10.5	53	2	2.1	0.00	7	8	0.15
10.5	54	3	2.8	0.02	10	11	0.07
10.5	55	3	3.4	0.04	13	14	0.10
10.5	56	3	3.9	0.22	16	18	0.25
10.5	57	4	4.6	0.08	20	23	0.33
10.5	58	7	5.6	0.73	27	28	0.06
10.5	59	9	6.5	1.01	36	35	0.04
10.5	60	7	6.8	0.00	43	42	0.05
10.5	61	7	7.0	0.00	50	49	0.04
10.4	62	6	6.9	0.12	56	55	0.00
10.3	71	92	-	-	148	-	-
10.3	80	64	-	-	212	-	-

The sum of the chi-square is 3.950 for the differential curve.

The sum of the chi-square is 1.971 for the integral curve.

TABLE 2

EXPERIMENT VII, DATA

DIFFERENTIAL AND INTEGRAL RATES, CONDUCTED JAN.26-JAN.29, 1976

Temp. ($C.^{o}$)	Elapsed Time(hrs.)	Obs. $\Delta N/\Delta T$	Theor. $\Delta N/\Delta T$	Chi-Sqr.	Obs. N	Theor. N	Chi-Sqr.
11.7	34	0	-	-	0	-	-
11.7	35	1	0.7	0.18	1	1	0.18
11.7	36	1	0.9	0.01	2	2	0.12
11.7	37	1	1.2	0.03	3	3	0.02
11.7	38	0	1.2	1.18	3	4	0.22
11.6	39	2	1.7	0.05	5	6	0.07
11.6	40	3	2.5	0.12	8	8	0.00
11.5	41	4	3.5	0.08	12	12	0.02
11.5	42	6	4.9	0.24	18	16	0.14
11.5	43	5	6.1	0.18	23	23	0.01
11.5	44	5	7.2	0.65	28	30	0.10
11.5	45	6	8.4	0.70	34	38	0.44
11.5	46	8	10.0	0.41	42	48	0.78
11.5	47	11	12.0	0.09	53	60	0.85
11.5	48	16	14.5	0.15	69	75	0.43
11.5	49	22	17.2	1.33	91	92	0.01
11.5	50	24	19.2	1.22	115	111	0.14
11.5	51	20	20.0	0.00	135	131	0.12
11.5	52	19	20.1	0.06	154	151	0.05
11.5	53	18	19.6	0.13	172	171	0.01
11.5	57	64	-	-	236	-	-

TABLE 2

EXPERIMENT VII, DATA

DIFFERENTIAL AND INTEGRAL RATES, CONDUCTED JAN.26-JAN.29, 1976

(CONTINUED)

Temp. (C.°)	Elapsed Time(hrs.)	Obs. $\Delta N/\Delta T$	Theor. $\Delta N/\Delta T$	Chi-Sqr.	Obs. N	Theor. N	Chi-Sqr.
11.5	60	48	-	-	284	-	-

The sum of the chi-square is 6.811 for the differential curve.

The sum of the chi-square is 3.718 for the integral curve.

TABLE 3

EXPERIMENT VI, DATA

DIFFERENTIAL AND INTEGRAL RATES, CONDUCTED JAN.14-JAN.16, 1976

Temp. (C.°)	Elapsed Time(hrs.)	Obs. ΔN/ΔT	Theor. ΔN/ΔT	Chi-Sqr.	Obs. N	Theor. N	Chi-Sqr.
14.6	25	0	-	-	0	-	-
14.6	26	1	-	-	1	-	-
14.6	27	1	-	-	2	-	-
14.7	28	1	0.9	0.00	3	1	1.20
14.6	29	2	1.7	0.06	5	3	0.71
14.5	30	2	2.4	0.08	7	5	0.17
14.5	31	3	3.5	0.07	10	9	0.02
14.5	32	3	4.6	0.53	13	13	0.10
14.5	33	9	7.5	0.30	22	21	0.01
14.5	34	14	11.5	0.56	36	32	0.27
14.5	35	15	14.9	0.00	51	47	0.19
14.5	36	16	17.7	0.16	67	65	0.03
14.5	37	20	19.8	0.00	87	85	0.03
14.5	38	22	20.4	0.13	109	106	0.10
14.5	39	16	19.7	0.68	125	125	0.00
14.5	40	18	17.7	0.00	143	143	0.00
14.5	41	15	15.2	0.00	158	158	0.00
14.6	42	13	12.4	0.03	171	171	0.00
14.6	48	110	-	-	281	-	-

The sum of the chi-square is 2.621 for the differential curve.

The sum of the chi-square is 2.835 for the integral curve.

TABLE 4

EXPERIMENT V, DATA

DIFFERENTIAL AND INTEGRAL RATES, CONDUCTED DEC.17-DEC.19, 1975

Temp. ($C.^o$)	Elapsed Time(hrs.)	Obs. $\Delta N/\Delta T$	Theor. $\Delta N/\Delta T$	Chi-Sqr.	Obs. N	Theor. N	Chi-Sqr.
17.3	20	0	-	-	0	-	-
17.2	21	1	-	-	1	-	-
17.2	22	3	2.7	0.03	4	3	0.60
17.3	23	4	4.3	0.03	8	7	0.13
17.3	24	7	7.1	0.00	15	14	0.05
17.3	25	10	10.8	0.05	25	25	0.00
17.3	26	17	16.5	0.02	42	41	0.01
17.3	27	22	22.8	0.03	64	64	0.00
17.3	28	35	30.6	0.64	99	95	0.19
17.2	29	33	35.1	0.13	132	130	0.03
17.0	30	31	37.0	0.98	163	167	0.09
17.0	31	43	35.8	1.45	206	203	0.05
17.0	32	31	32.1	0.04	237	235	0.02
17.0	33	26	27.3	0.06	263	262	0.00
17.0	34	22	21.9	0.00	285	284	0.00
16.9	35	18	16.6	0.11	303	301	0.02
16.9	36	12	12.7	0.04	315	313	0.01
16.9	48	48	-	-	364	-	-

The sum of the chi-square is 3.608 for the differential curve.

The sum of the chi-square is 1.211 for the integral curve.

TABLE 5

EXPERIMENT IV, DATA

DIFFERENTIAL AND INTEGRAL RATES, CONDUCTED DEC.9-DEC.12, 1975

Temp. (C.°)	Elapsed Time(hrs.)	Obs. $\Delta N/\Delta T$	Theor. $\Delta N/\Delta T$	Chi-Sqr.	Obs. N	Theor. N	Chi-Sqr.
19.2	18	0	-	-	0	-	-
19.2	19	2	3.0	0.31	2	3	0.31
19.2	20	7	5.4	0.46	9	8	0.05
19.2	21	9	8.4	0.04	18	17	0.08
19.2	22	13	12.5	0.02	31	29	0.09
19.2	23	14	16.5	0.39	45	46	0.02
19.2	24	25	22.7	0.22	60	69	0.03
19.2	25	32	28.9	0.34	92	97	0.21
19.2	26	25	32.2	1.63	117	130	0.06
19.1	27	40	35.1	0.70	157	165	0.03
19.1	28	32	35.0	0.26	189	200	0.00
19.1	29	31	33.1	0.13	220	233	0.04
19.1	30	29	29.5	0.01	249	262	0.04
19.1	31	29	24.2	0.94	278	287	0.01
19.0	32	21	19.4	0.13	299	306	0.03
19.0	33	13	16.0	0.55	322	322	0.00
19.3	48	52	-	-	364	-	-

The sum of the chi-square is 6.119 for the differential curve.

The sum of the chi-square is 0.993 for the integral curve.

TABLE 6

EXPERIMENT III, DATA

DIFFERENTIAL AND INTEGRAL RATES, CONDUCTED NOV.23-NOV.26, 1975

Temp. ($C.^{o}$)	Elapsed Time(hrs.)	Obs. $\Delta N/\Delta T$	Theor. $\Delta N/\Delta T$	Chi-Sqr.	Obs N	Theor. N	Chi-Sqr.
22.5	15	0	-	-	0	-	-
22.5	16	1	-	-	1	-	-
22.5	17	5	3.3	0.82	6	3	2.11
22.5	18	7	6.4	0.05	13	10	1.07
22.5	19	6	9.0	0.98	19	19	0.00
22.5	20	6	11.4	2.57	25	30	0.88
22.5	21	17	17.8	0.04	42	48	0.74
22.5	22	33	27.9	0.93	75	76	0.01
22.5	23	50	37.5	4.15	125	113	1.19
22.5	24	37	40.2	0.26	162	154	0.46
22.4	25	35	39.3	0.47	197	193	0.09
22.4	26	31	35.6	0.61	228	229	0.00
22.4	27	23	31.2	2.17	251	260	0.29
22.4	28	33	22.4	5.05	284	282	0.01
22.4	29	17	16.6	0.01	301	299	0.02
22.4	30	12	12.1	0.00	313	311	0.01
22.3	31	7	9.3	0.65	320	320	0.00
22.2	47	28	-	-	348	-	-
22.0	65	23	-	-	371	-	-

The sum of the chi-square is 18.658 for the differential curve.

The sum of the chi-square is 6.894 for the integral curve.

TABLE 7

EXPERIMENT I, DATA

DIFFERENTIAL AND INTEGRAL RATES, CONDUCTED NOV.4-NOV.6, 1975

Temp. (C.°)	Elapsed Time(hrs.)	Obs. ΔN/ΔT	Theor. ΔN/ΔT	Chi-Sqr.	Obs. N	Theor. N	Chi-Sqr.
26.2	15	0	-	-	0	-	-
26.2	16	1	0.7	0.14	1	1	0.14
26.1	17	2	2.1	0.00	3	3	0.02
26.1	18	3	4.1	0.28	6	7	0.09
26.3	19	0	4.1	4.06	6	11	2.17
26.3	20	9	9.8	0.07	15	21	1.55
26.0	21	12	16.9	1.41	27	38	2.96
26.1	22	27	30.2	0.33	54	68	2.77
26.0	23	61	47.1	4.13	115	115	0.00
26.0	24	68	44.4	12.56	183	159	3.57
26.0	25	31	35.7	0.61	214	195	1.89
26.0	26	20	27.5	2.06	234	222	0.61
26.0	27	12	21.7	4.34	246	244	0.02
26.0	28	10	16.3	2.44	256	260	0.07
26.0	29	12	9.2	0.86	268	270	0.01
26.0	30	6	5.4	0.07	274	275	0.00
26.1	44	24	-	-	298	-	-
26.1	48	13	-	-	311	-	-

The sum of the chi-square is 33.339 for the differential curve.

The sum of the chi-square is 15.894 for the integral curve.

TABLE 8

EXPERIMENT II, DATA

DIFFERENTIAL AND INTEGRAL RATES, CONDUCTED NOV.11-NOV.13, 1975

Temp. (C.°)	Elapsed Time(hrs.)	Obs. ΔN/ΔT	Theor. ΔN/ΔT	Chi-Sqr.	Obs. N	Theor. N	Chi-Sqr.
28.6	18	0	-	-	0	-	-
28.6	19	2	0.7	2.56	2	1	2.56
28.7	20	0	0.7	0.68	2	1	0.30
28.5	21	0	0.7	0.68	2	2	0.00
28.5	22	1	0.9	0.00	3	3	0.00
28.5	23	0	0.9	0.94	3	4	0.22
28.5	24	0	0.9	0.94	3	5	0.72
28.5	25	3	1.6	1.71	6	6	0.04
28.4	26	4	2.3	1.34	10	9	0.18
28.5	27	3	2.5	0.08	13	11	0.26
28.4	28	2	2.6	0.15	15	14	0.08
28.5	29	2	2.6	0.16	17	17	0.01
28.5	30	5	2.3	3.02	22	19	0.51
28.5	31	0	2.3	2.34	22	21	0.03
28.5	32	1	2.2	0.67	23	23	0.01
28.7	44	11	-	-	34	-	-

The sum of the chi-square is 14.749 for the differential curve.

The sum of the chi-square is 4.916 for the integral curve.

APPENDIX II

GERMINATION CURVES

All curves in this appendix are based on the model. The points are the observed data.

FIGURE 1

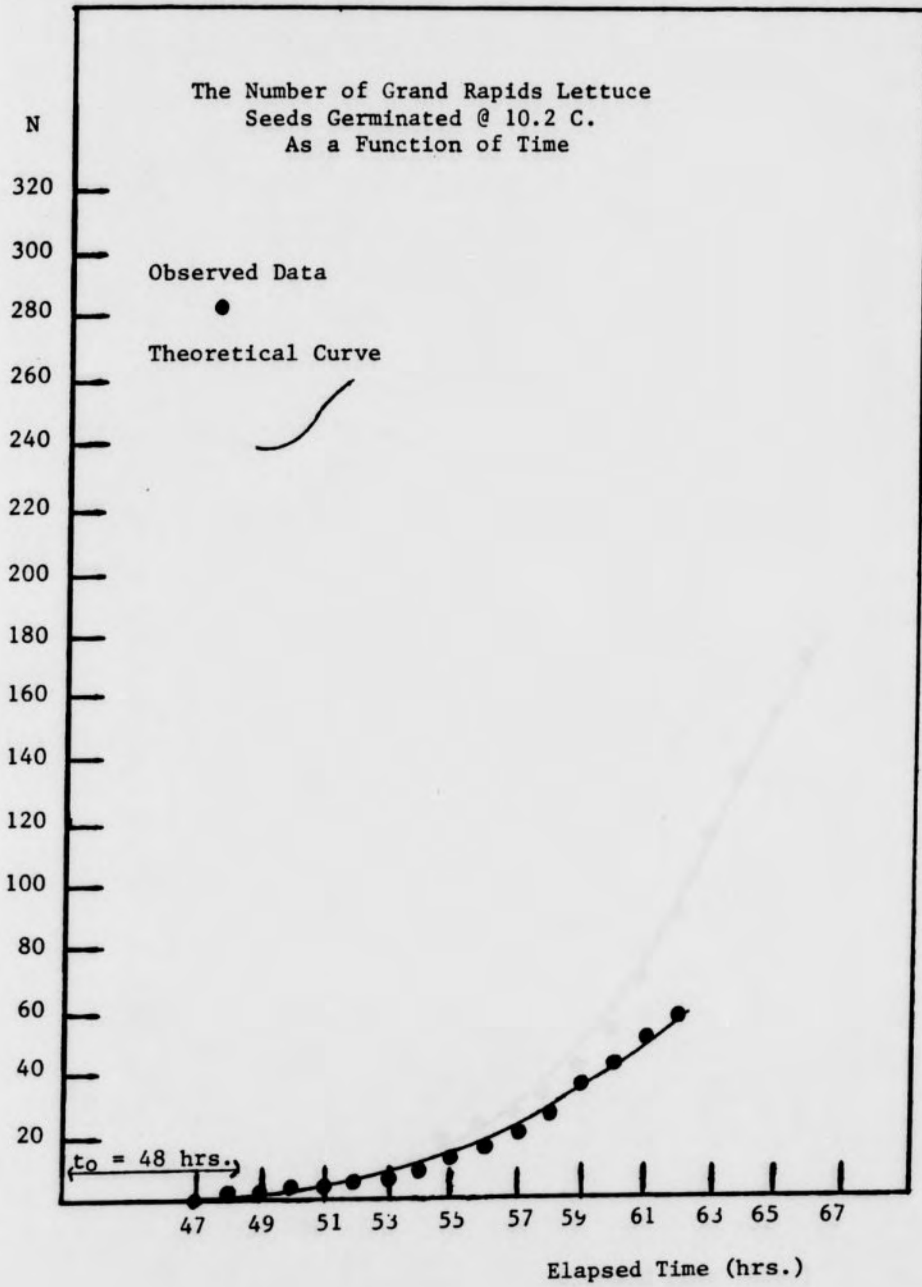

The Number of Grand Rapids Lettuce
Seeds Germinated @ 10.2 C.
As a Function of Time
N
320
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
Observed Data
Theoretical Curve
t_o = 48 hrs.
47
49
51
53
55
57
59
61
63
65
67
Elapsed Time (hrs.)

FIGURE 2

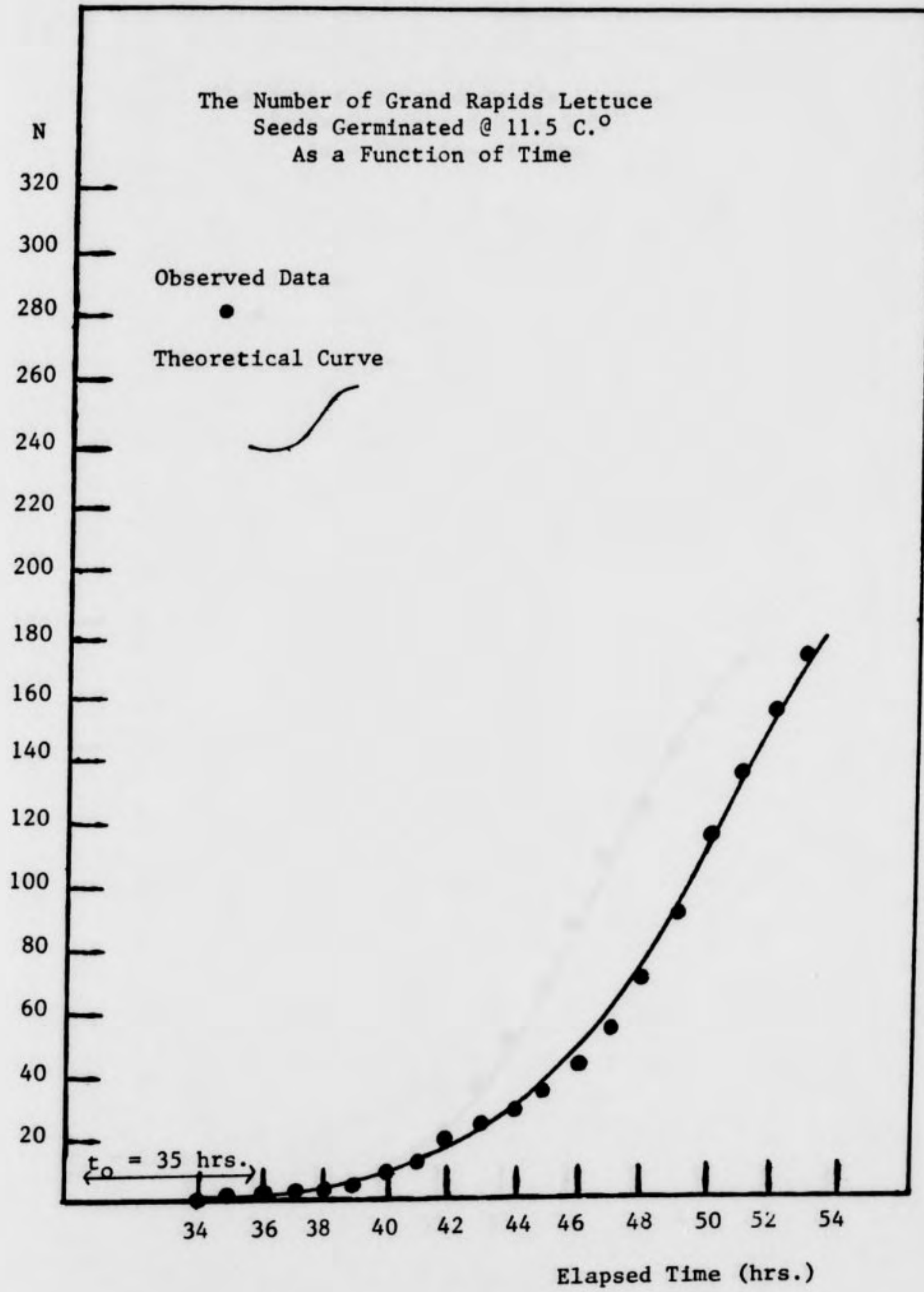

The Number of Grand Rapids Lettuce
Seeds Germinated @ 11.5 C.°
As a Function of Time
N
320
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
Observed Data
Theoretical Curve
t_o = 35 hrs.
34
36
38
40
42
44
46
48
50
52
54
Elapsed Time (hrs.)

FIGURE 3

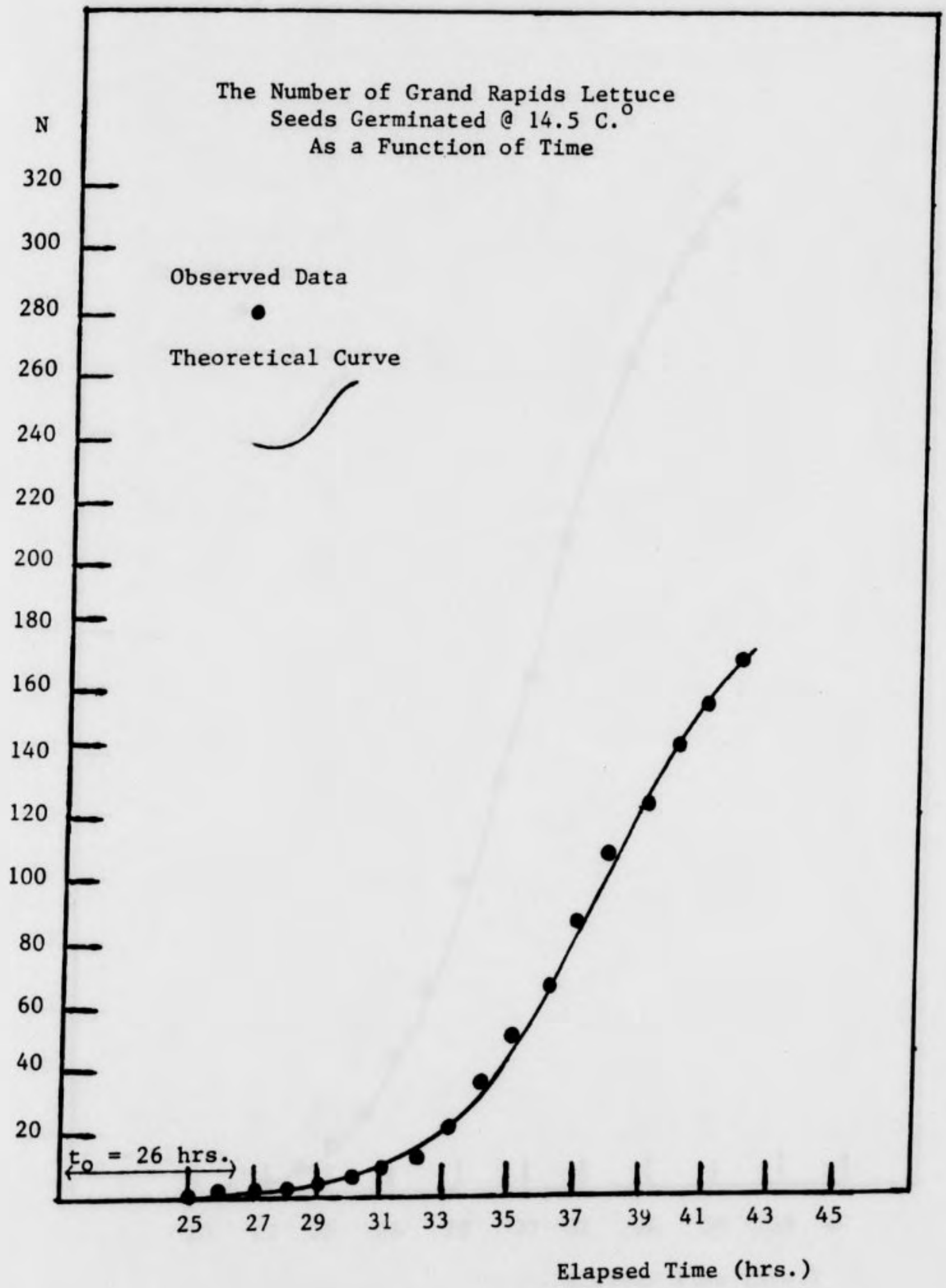

The Number of Grand Rapids Lettuce
Seeds Germinated @ 14.5 C.°
As a Function of Time
N
320
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
Observed Data
Theoretical Curve
t_o = 26 hrs.
25
27
29
31
33
35
37
39
41
43
45
Elapsed Time (hrs.)

FIGURE 4

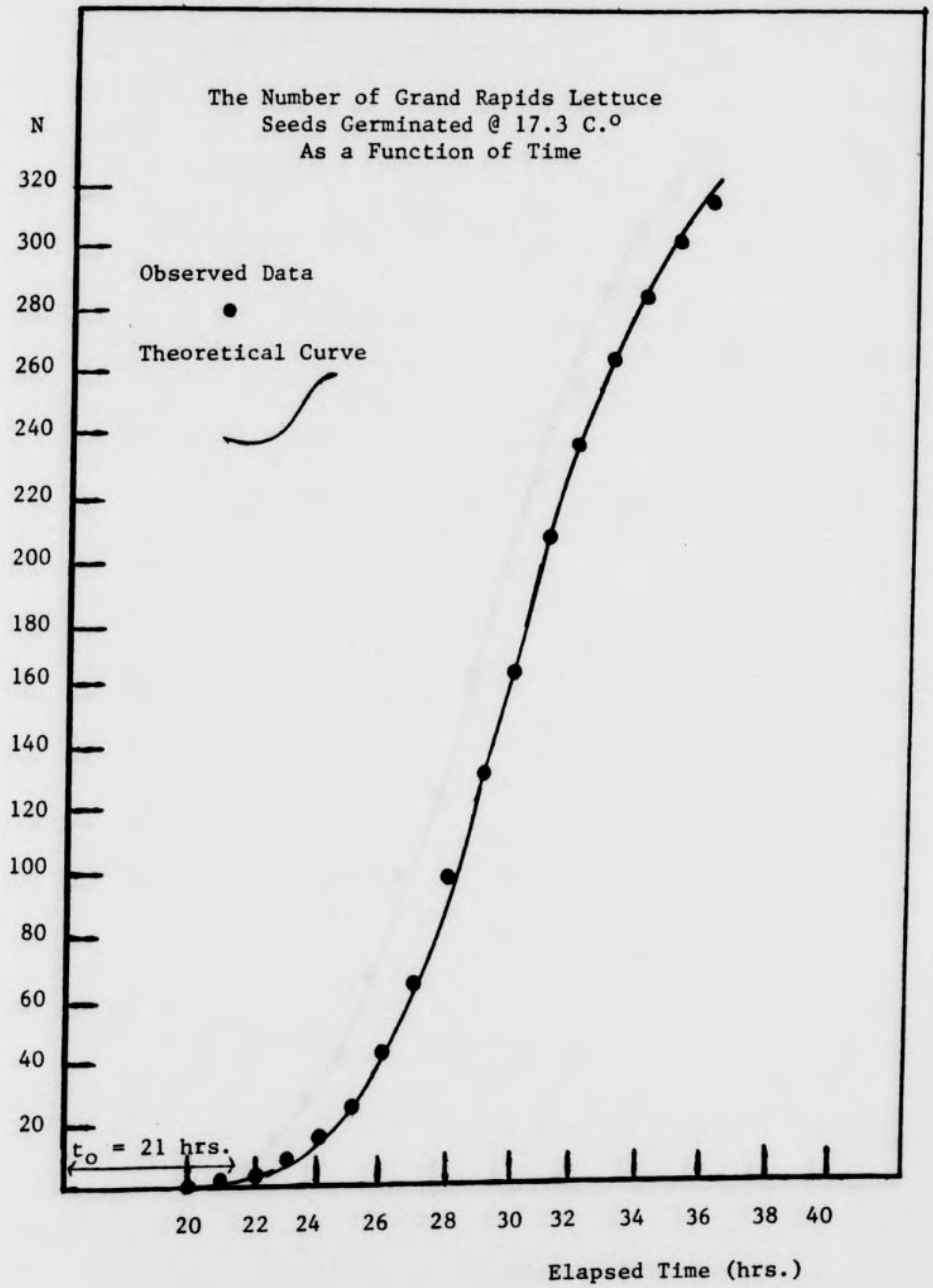

The Number of Grand Rapids Lettuce
Seeds Germinated @ 17.3 C.°
As a Function of Time
N
320
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
Observed Data
Theoretical Curve
t_o = 21 hrs.
20
22
24
26
28
30
32
34
36
38
40
Elapsed Time (hrs.)

FIGURE 5

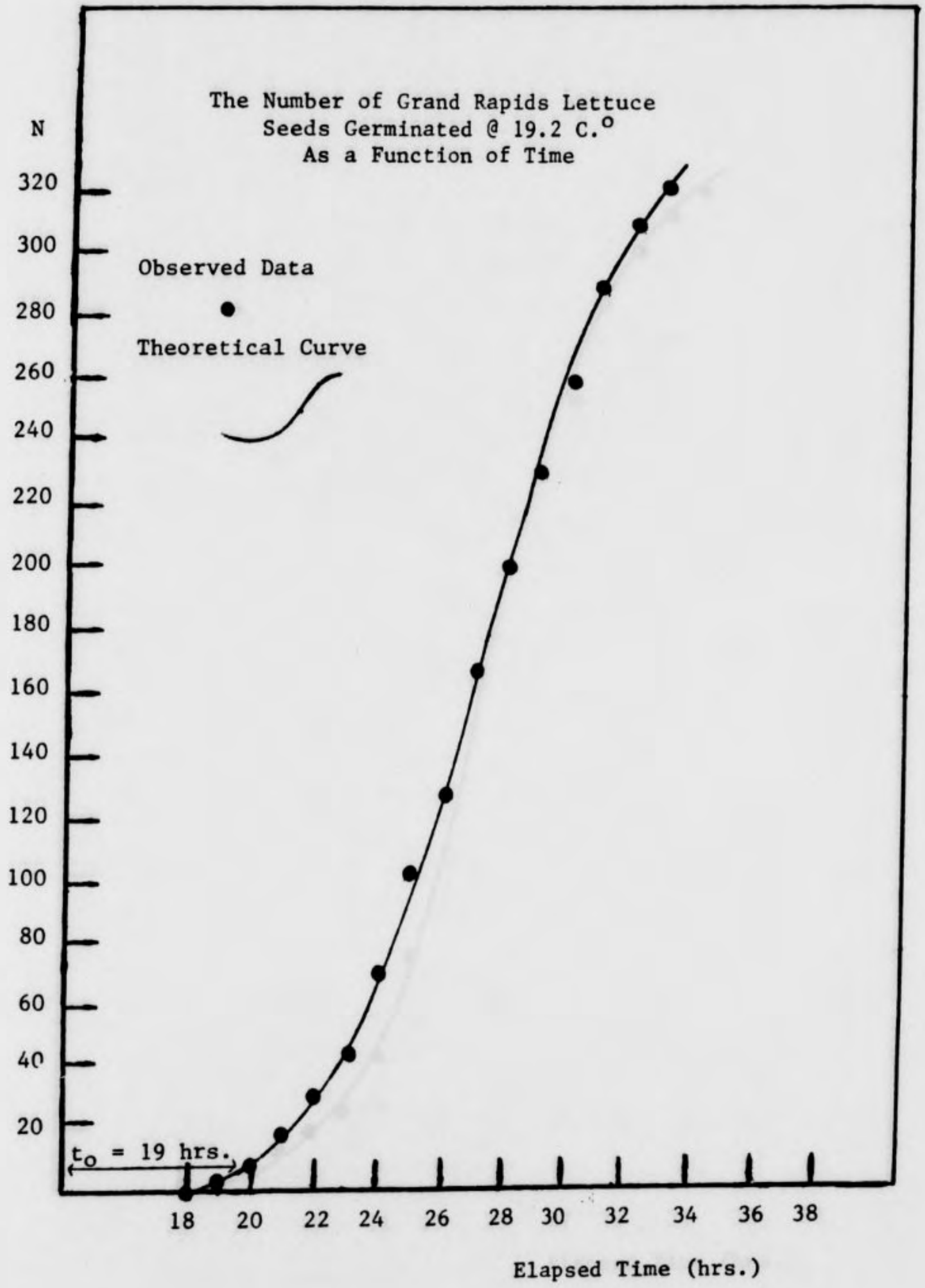

The Number of Grand Rapids Lettuce
Seeds Germinated @ 19.2 C.°
As a Function of Time
N
320
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
Observed Data
Theoretical Curve
t$_o$ = 19 hrs.
18
20
22
24
26
28
30
32
34
36
38
Elapsed Time (hrs.)

FIGURE 6

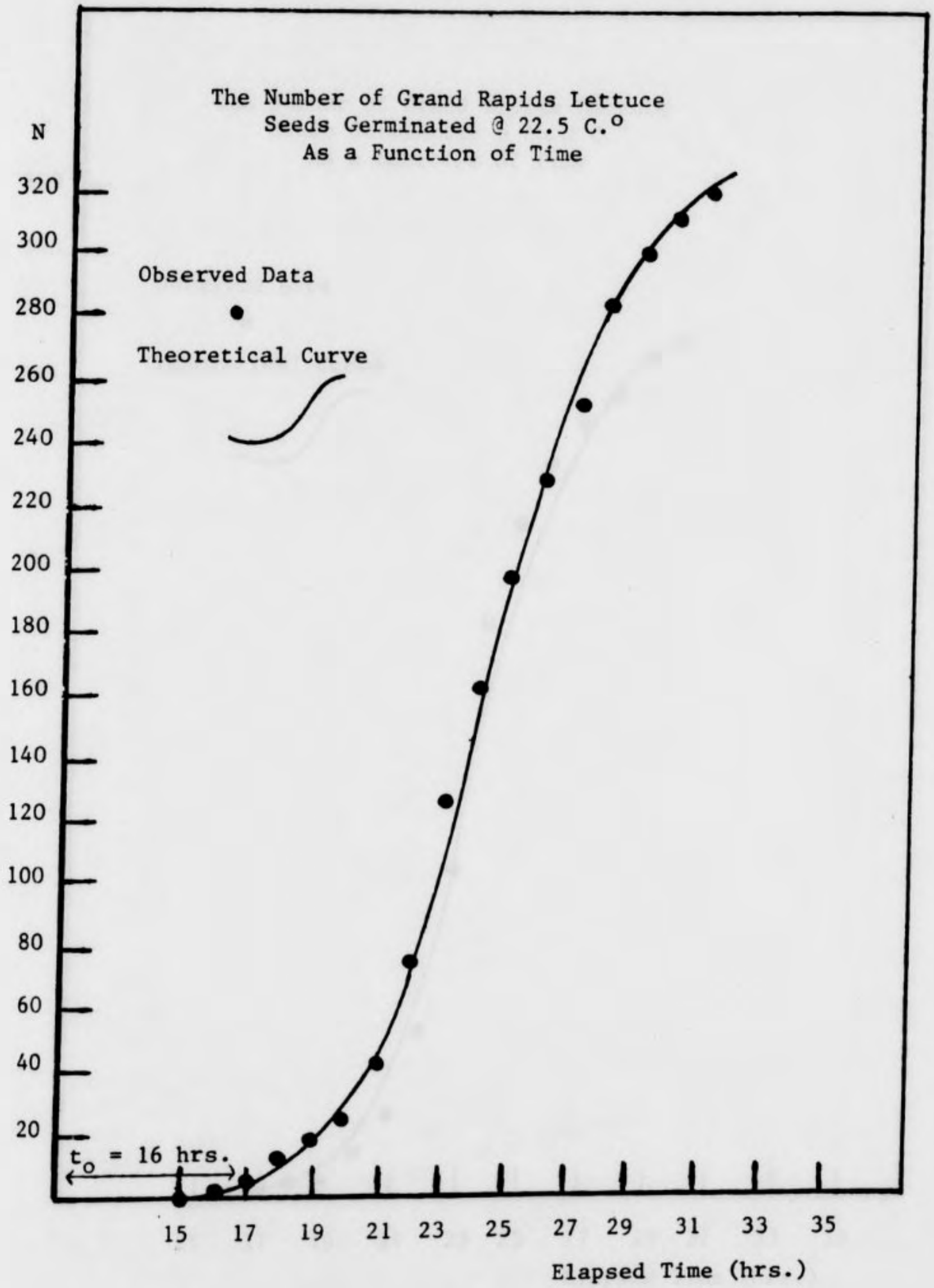

The Number of Grand Rapids Lettuce
Seeds Germinated @ 22.5 C.°
As a Function of Time
N
320
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
Observed Data
Theoretical Curve
t_o = 16 hrs.
15
17
19
21
23
25
27
29
31
33
35
Elapsed Time (hrs.)

FIGURE 7

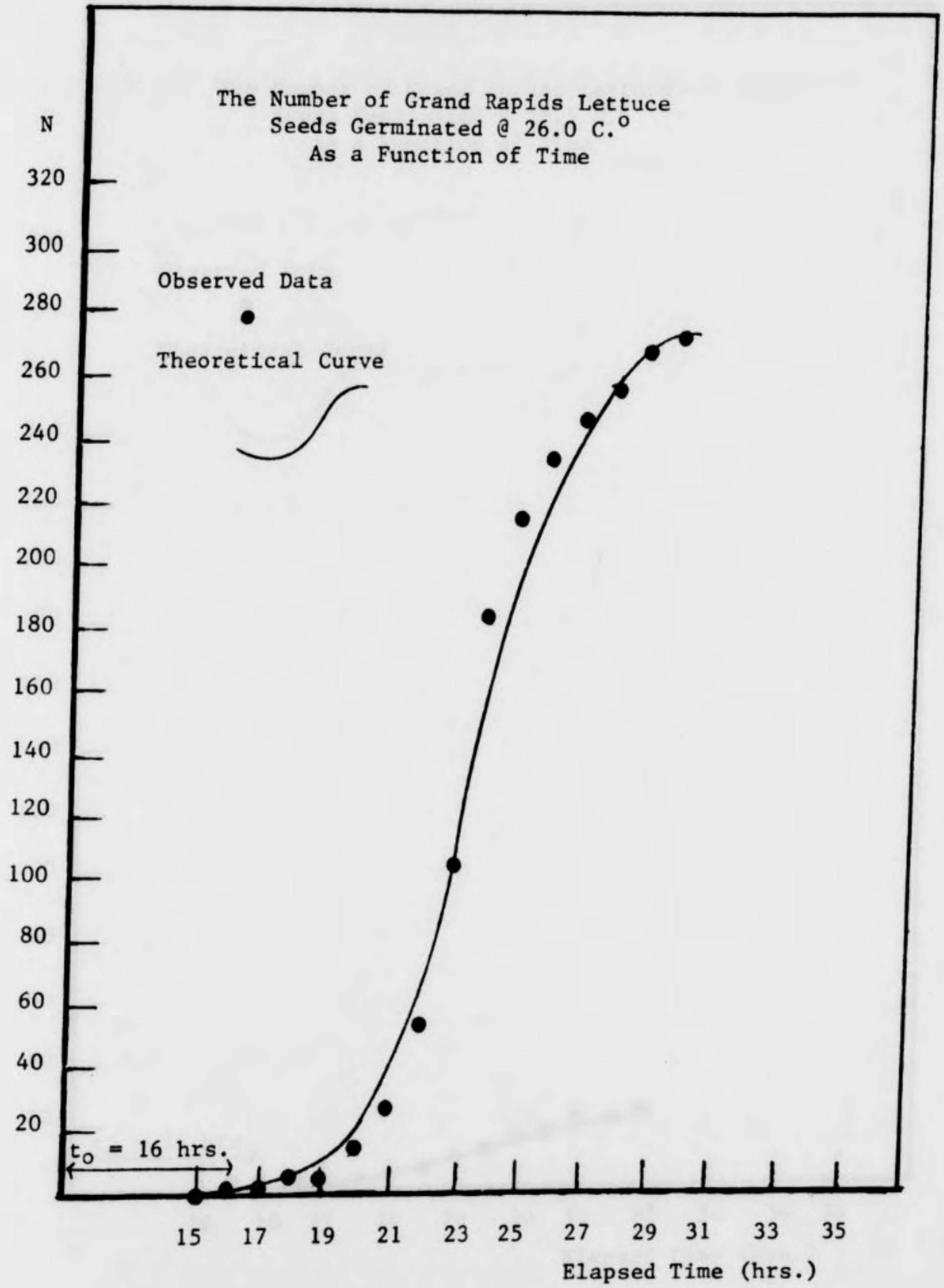
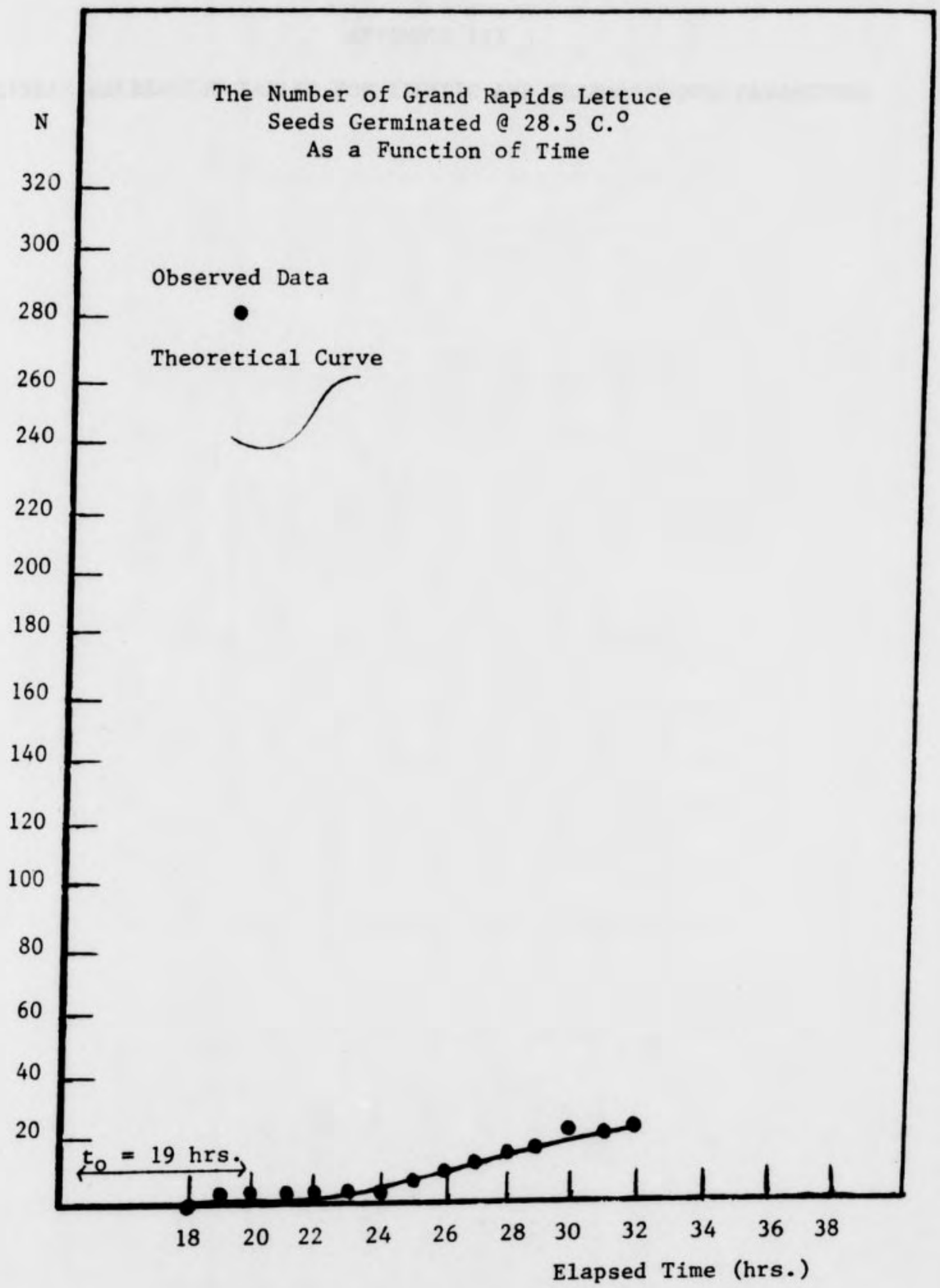

The Number of Grand Rapids Lettuce
Seeds Germinated @ 26.0 C.°
As a Function of Time
N
320
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
Observed Data
Theoretical Curve
t₀ = 16 hrs.
15
17
19
21
23
25
27
29
31
33
35
Elapsed Time (hrs.)

FIGURE 8


The Number of Grand Rapids Lettuce
Seeds Germinated @ 28.5 C.°
As a Function of Time
N
320
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
Observed Data
Theoretical Curve
t₀ = 19 hrs.
18
20
22
24
26
28
30
32
34
36
38
Elapsed Time (hrs.)

APPENDIX III

LINEAR REGRESSION TABLES FOR KINETIC AND THERMODYNAMIC PARAMETERS

TABLE 9

TABULATED EXPERIMENTAL RESULTS

Temp. (C.°)	Temp. (K.°)	1000/T (1/K.°)	t_o (hrs.)	ln t_o	$[F]_o$	ln $[F]_o$	$[A]_o$	ln $[A]_o$	$\frac{[F]_o}{[A]_o}$	ln $\frac{[F]_o}{[A]_o}$	$k_2 x 10^{-3}$	ln k_2	ΔG (kcal/mole)
28.5	301.5	3.316	19	2.94	0.30	-1.200	33	3.50	0.0090	-4.70	9.5387	-4.65	2.819
26.0	299.0	3.344	16	2.77	0.40	-0.916	282	5.64	0.0014	-6.56	2.4502	-6.03	3.903
22.5	295.5	3.384	16	2.77	1.25	0.223	341	5.83	0.0037	-5.61	1.3759	-6.59	3.299
19.2	292.2	3.422	19	2.94	6.08	1.800	371	5.92	0.0164	-4.11	0.9930	-6.91	2.390
17.3	290.3	3.445	21	3.04	2.55	0.936	348	5.85	0.0073	-4.92	1.2087	-6.72	2.842
14.5	287.5	3.478	26	3.26	0.44	-0.821	209	5.34	0.0021	-6.16	1.8586	-6.29	3.524
11.5	284.5	3.515	35	3.56	1.44	0.365	297	5.69	0.0048	-5.33	0.9043	-7.01	3.017
10.2	283.2	3.531	48	3.87	1.48	0.392	102	4.62	0.0145	-4.23	2.6087	-5.95	2.383

TABLE 10

TABULATED LINEAR REGRESSION RESULTS

	Obs. X	Obs. Y	Est. Y	Residual
	3.384	2.7700	2.6794	0.0906
	3.422	2.9400	2.9508	-0.0750
	3.445	3.0400	3.1150	-0.0750
ln t_o vs. 1000/T Fig. #9 (b)	3.478	3.2600	3.3507	-0.0907
	3.515	3.5600	3.6149	-0.0540
	3.531	3.8700	3.7292	0.1408
	3.316	-1.2000	-1.4734	0.2734
	3.344	-0.9160	-0.6693	-0.2467
ln $[F]_o$ vs. 1000/T Fig. #10 (a)	3.384	0.2230	0.4793	-0.2563
	3.422	1.8000	1.5704	0.2296
	3.422	1.8000	1.8826	-0.0826
ln $[F]_o$ vs. 1000/T Fig. #10 (b)	3.445	0.9360	0.7958	0.1402
	3.478	-0.8210	-0.7634	-0.0576
	3.478	-0.8210	-0.7610	-0.0649
ln $[F]_o$ vs. 1000/T Fig. #10 (c)	3.515	0.3650	0.1503	0.2149
	3.531	0.3920	0.5420	-0.1500
	3.344	5.6400	5.6854	-0.0454
	3.384	5.8300	5.7764	0.0536
ln $[A]_o$ vs. 1000/T Fig. #11 (a)	3.445	5.8500	5.9153	-0.0653
	3.422	5.9200	6.0219	-0.1019

TABULATED LINEAR REGRESSION RESULTS (CONTINUED)

	Obs. X	Obs. Y	Est. Y	Residual
ln $[A]_o$ vs. 1000/T Fig. #11 (b)	3.422	5.9200	6.0219	-0.1019
	3.445	5.8500	5.7334	0.1166
	3.478	5.3400	5.3196	0.0204
	3.531	5.6200	4.6551	-0.0351
ln k_2 vs. 1000/T Fig. #12 (a)	3.316	-4.6500	-5.0392	0.3892
	3.344	-6.0300	-5.5069	-0.4331
	3.384	-6.5900	-6.3939	-0.1964
	3.422	-6.9100	-7.1504	0.2404
ln k_2 vs. 1000/T Fig. #12 (b)	3.422	-6.9100	-6.8916	-0.0184
	3.445	-6.7200	-6.6840	-0.0360
	3.478	-6.2900	-6.3865	0.0963
	3.531	-5.9500	-5.9081	-0.0419
ln $[F]_o/[A]_o$ vs. 1000/T Fig. #13 (a)	3.344	-6.5600	-6.6795	0.0995
	3.384	-5.6100	-5.4058	-0.2042
	3.422	-4.1100	-4.2147	0.1047
ln $[F]_o/[A]_o$ vs. 1000/T Fig. #13 (b)	3.422	-4.1100	-4.0976	-0.0124
	3.445	-4.9200	-4.9411	0.0231
	3.478	-6.1600	-6.1513	-0.0870
ln $[F]_o/[A]_o$ vs. 1000/T Fig. #13 (c)	3.478	-6.1600	-6.2589	0.0989
	3.515	-5.3300	-5.0022	-0.3278
	3.531	-4.2300	-4.4588	0.2288

TABULATED LINEAR REGRESSION RESULTS (CONTINUED)

	Obs. X	Obs. Y	Est. Y	Residual
	283.2	2.3830	2.5108	-0.1278
ln ΔG vs. T Fig. #14 (a)	284.5	3.0170	2.8338	0.1832
	287.5	3.5240	3.5794	-0.0554
	287.5	3.5240	3.5223	0.0017
ln ΔG vs. T Fig. #14 (b)	290.3	2.8420	2.8462	-0.0042
	292.2	2.3900	2.3875	0.0025
	292.2	2.3900	2.4499	-0.0599
ln ΔG vs. T Fig. #14 (c)	295.5	3.2990	3.1825	0.1165
	299.0	3.9030	3.9595	-0.0565

TABLE 11

TABULATED LINEAR REGRESSION STATISTICS

Graph	Curve #	Slope $\pm \sigma_s$	y-Intercept $\pm \sigma_i$	PMCC	Confidence Level %	F-Statistic	Confidence Level %
$\ln t_o$	Fig. #9(b)	7.14 ± 0.84	-21.49 ± 2.92	0.973	99.7	71.57 on 1 & 2 deg. of freedom	99^+
$\ln [F]_o$	Fig.#10(a)	28.72 ± 4.44	-96.60 ±34.95	0.977	97.0	41.84 on 1 & 2 deg. of freedom	97
$\ln [F]_o$	Fig.#10(b)	-47.25 ± 4.34	163.57 ±14.95	-0.996	95.0	118.79 on 1 & 1 deg. of freedom	94
$\ln [F]_o$	Fig.#10(c)	24.49 ± 7.02	-85.94 ±20.63	0.961	85.0	12.17 on 1 & 1 deg. of freedom	82
$\ln [A]_o$	Fig.#11(a)	2.28 ± 1.03	-1.93 ± 3.49	0.843	80.0	4.91 on 1 & 2 deg. of freedom	80
$\ln [A]_o$	Fig.#11(b)	-12.54 ± 1.38	48.93 ± 4.79	-0.988	98.0	82.42 on 1 & 2 deg. of freedom	98
$\ln k_2$	Fig.#12(a)	-39.92 ± 5.81	61.61 ±19.57	-0.924	92.0	11.74 on 1 & 2 deg. of freedom	92

TABULATED LINEAR REGRESSION STATISTICS (CONTINUED)

Graph	Curve #	Slope $\pm \sigma_s$	y-Intercept $\pm \sigma_i$	PMCC	Confidence Level %	F-Statistic	Confidence Level %
$\ln k_2$	Fig.#12(b)	9.02 ± 0.97	-37.77 ± 3.37	0.989	99.99^+	86.28 on 1 & 2 deg. of freedom	99.99^+
$\ln \frac{[F]_o}{[A]_o}$	Fig.#13(a)	31.34 ± 4.54	-111.47 ± 15.34	0.990	90.0	47.77 on 1 & 1 deg. of freedom	92
$\ln \frac{[F]_o}{[A]_o}$	Fig.#13(b)	-36.67 ± 0.67	121.40 ± 2.25	0.999	99.99^+	3162.4 on 1 & 1 deg. of freedom	99.99^+
$\ln \frac{[F]_o}{[A]_o}$	Fig.#13(c)	33.96 ±10.71	-124.39 ± 35.58	0.954	80.0	10.06 on 1 & 1 deg. of freedom	80
ΔG	Fig.#14(a)	0.249 ± 0.074	-67.87 ± 21.03	0.959	80.0	11.35 on 1 & 1 deg. of freedom	80
ΔG	Fig.#14(b)	-0.242 ± 0.002	72.94 ± 0.45	0.999	99.99^+	23968.6 on 1 & 1 deg. of freedom	99.99^+
ΔG	Fig.#14(c)	0.222 ± 0.030	-62.42 ± 8.77	0.991	92	56.0 on 1 & 1 deg. of freedom	92

APPENDIX IV

LINEAR REGRESSIONS AND GRAPHS

FOR DETERMINING KINETIC AND THERMODYNAMIC PARAMETERS

The straight lines are theoretical curves based on the model. The points are the observed data points.

FIGURE 9

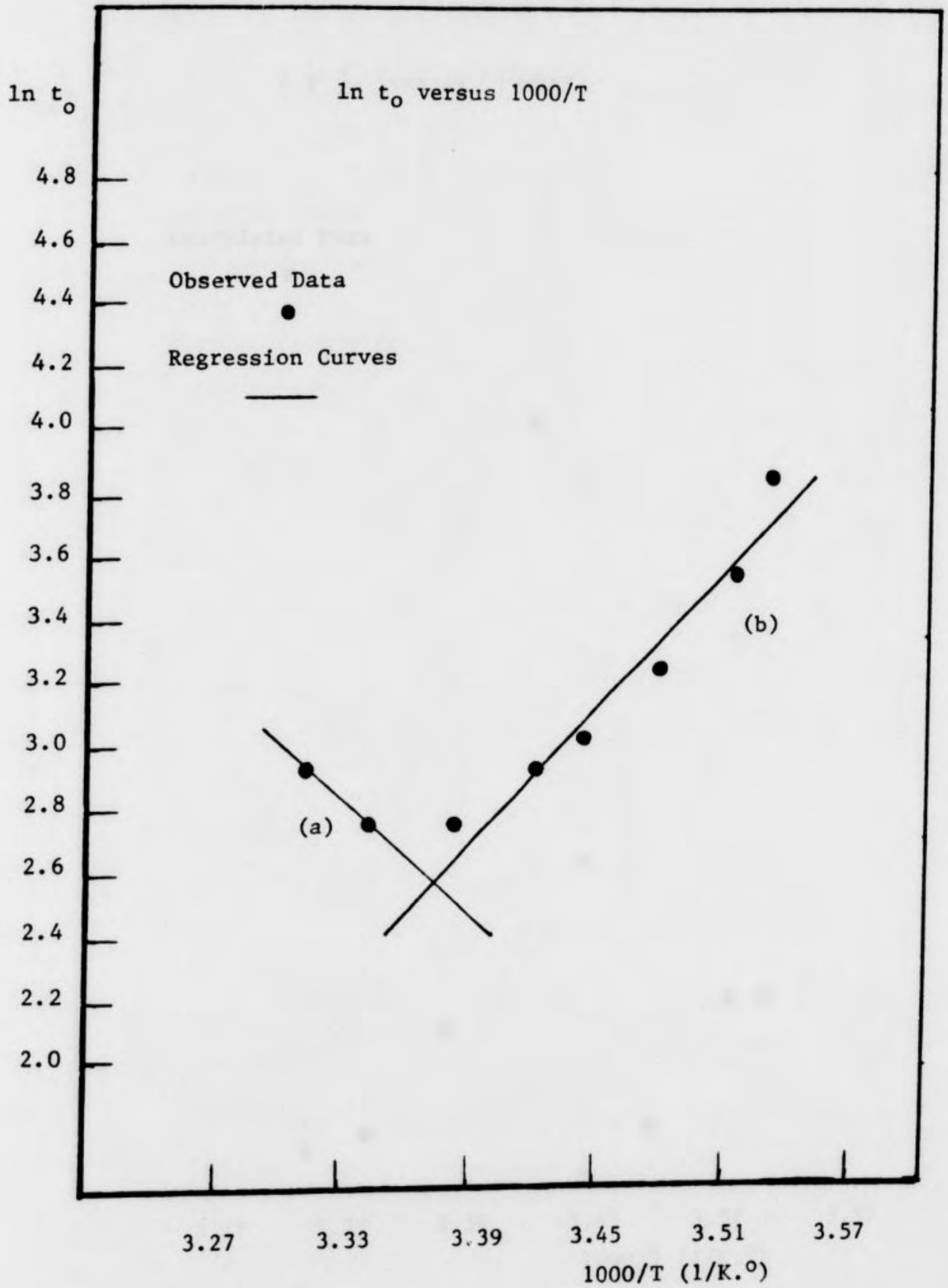

ln t_o
ln t_o versus 1000/T
4.8
4.6
4.4
4.2
4.0
3.8
3.6
3.4
3.2
3.0
2.8
2.6
2.4
2.2
2.0
Observed Data
Regression Curves
(a)
(b)
3.27
3.33
3.39
3.45
3.51
3.57
1000/T (1/K.°)

FIGURE 10

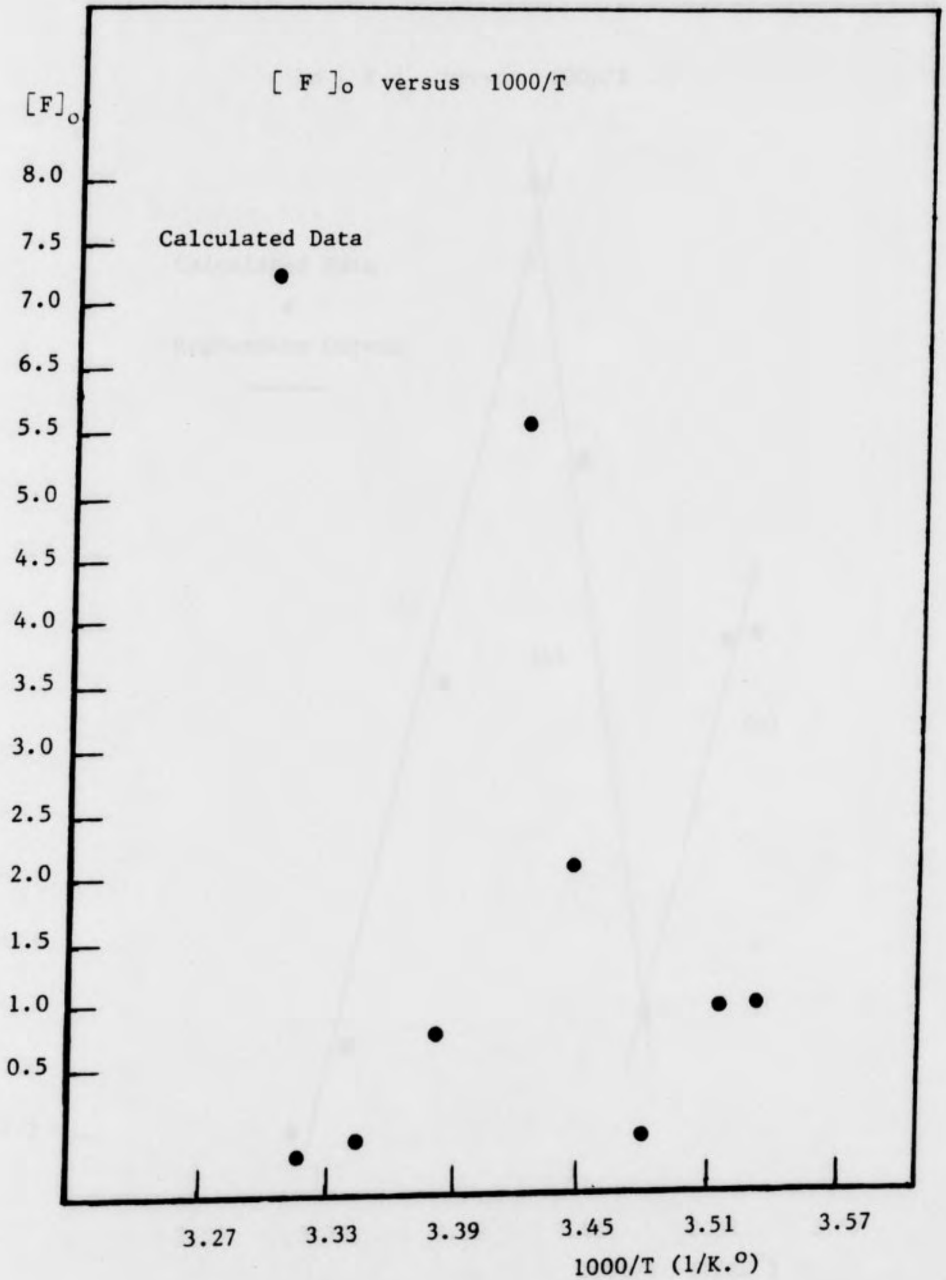

[F]o versus 1000/T
[F]o
8.0
7.5
7.0
6.5
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
Calculated Data
3.27
3.33
3.39
3.45
3.51
3.57
1000/T (1/K.o)

FIGURE 11

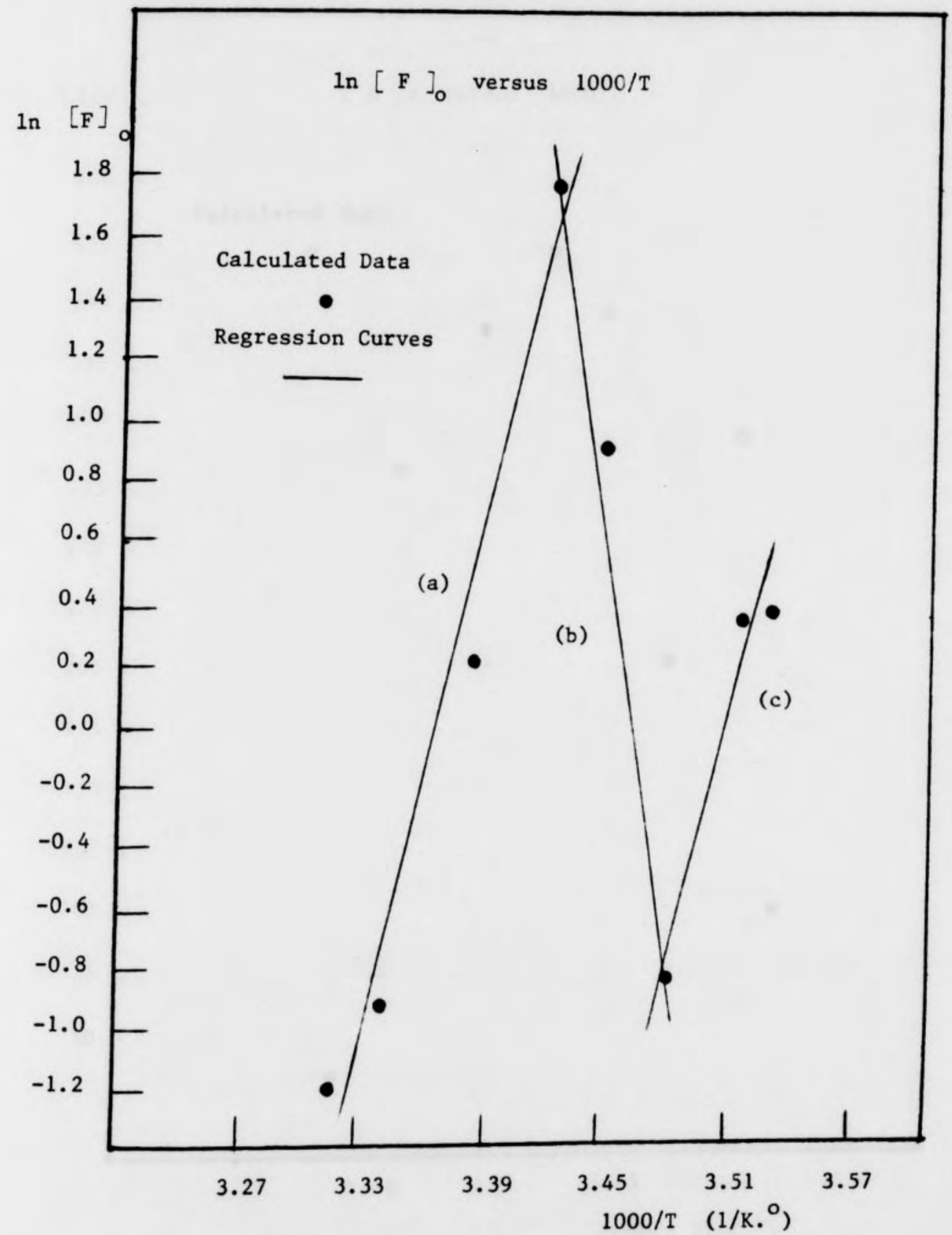

ln [F]$_o$ versus 1000/T
ln [F]$_o$
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
-1.2
Calculated Data
Regression Curves
(a)
(b)
(c)
3.27
3.33
3.39
3.45
3.51
3.57
1000/T (1/K.°)

FIGURE 12

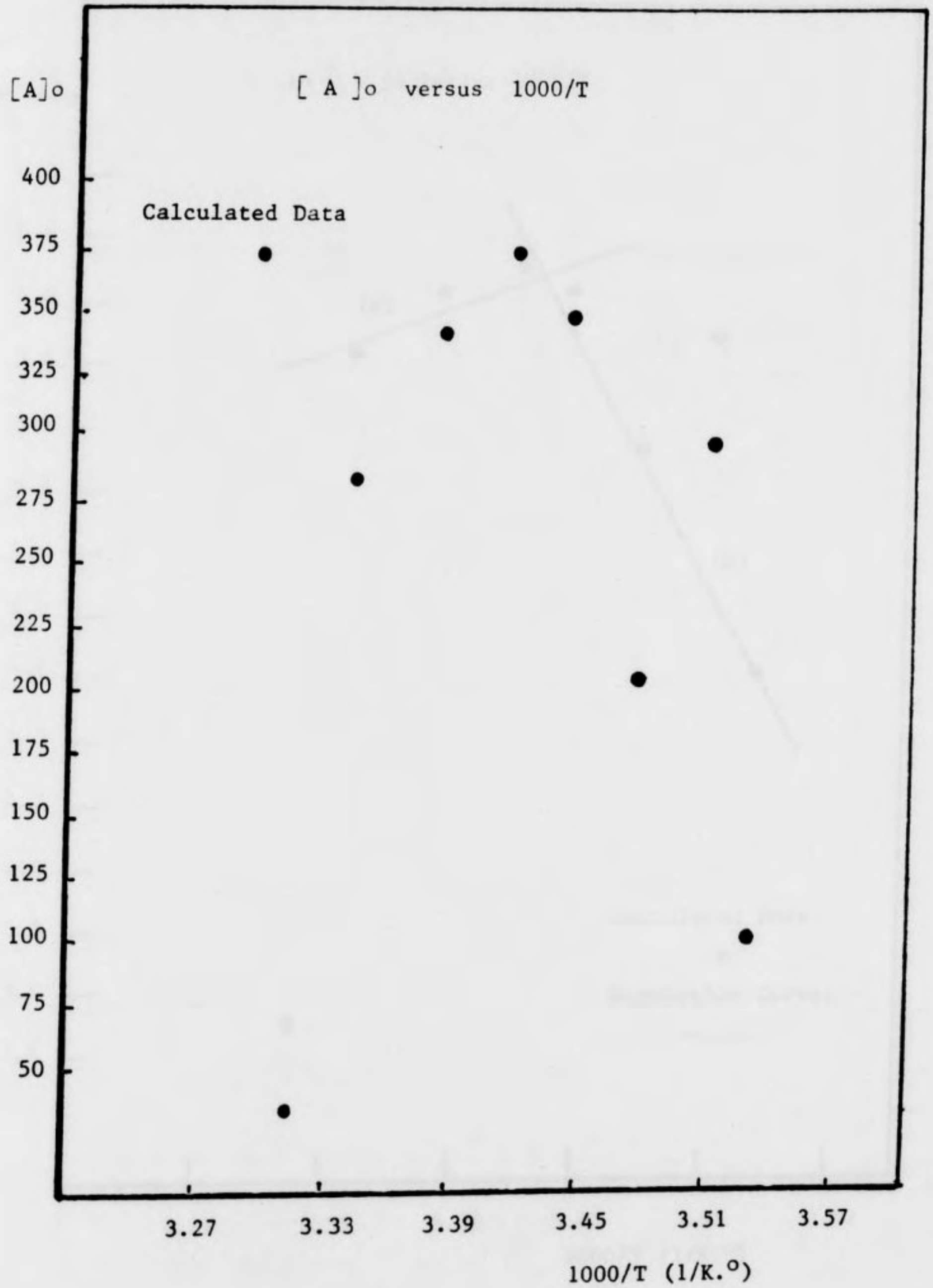

[A]o
[A]o versus 1000/T
400
375
350
325
300
275
250
225
200
175
150
125
100
75
50
Calculated Data
3.27
3.33
3.39
3.45
3.51
3.57
1000/T (1/K.°)

FIGURE 13

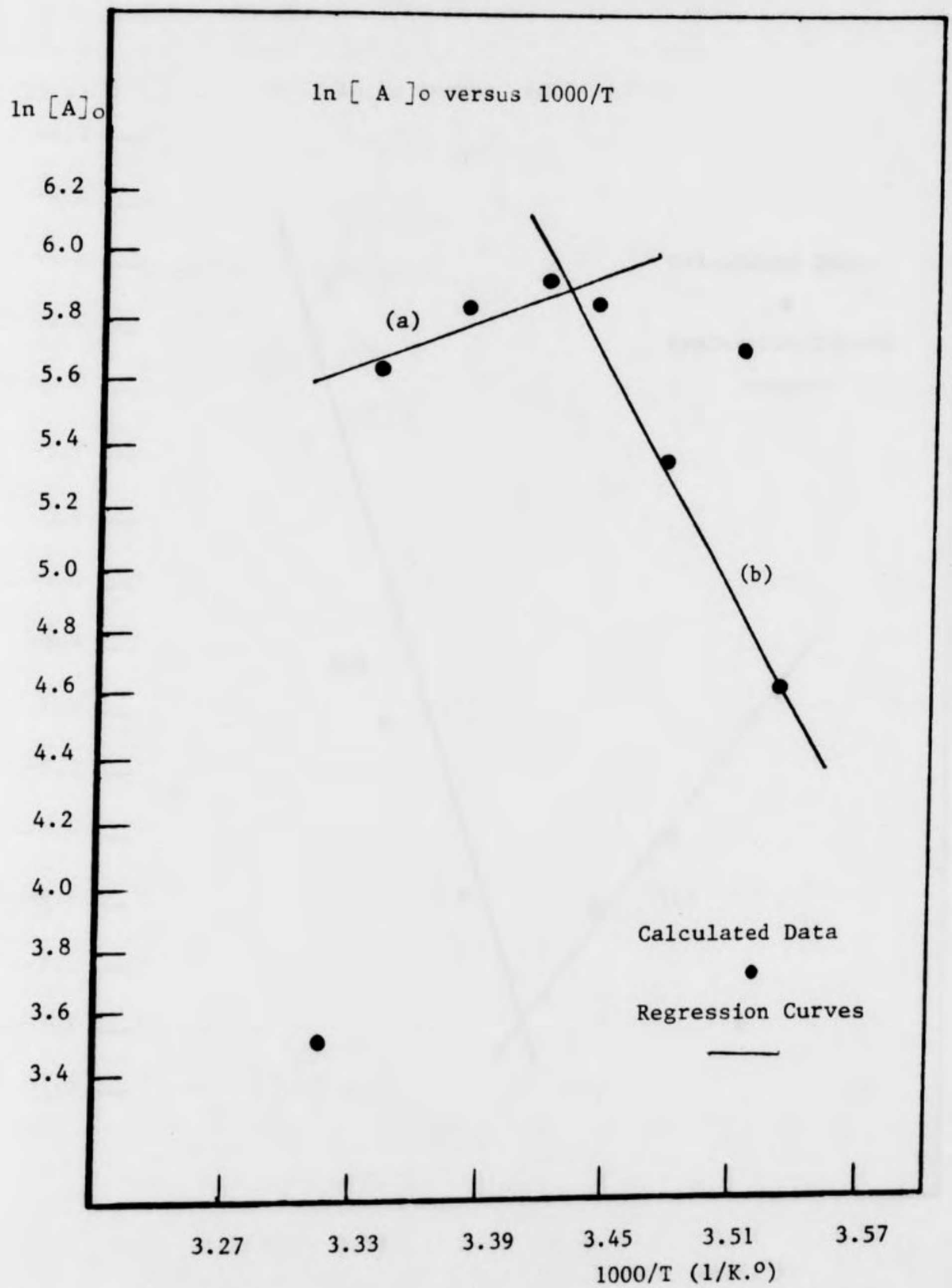

ln [A]o
ln [A]o versus 1000/T
6.2
6.0
5.8
5.6
5.4
5.2
5.0
4.8
4.6
4.4
4.2
4.0
3.8
3.6
3.4
(a)
(b)
Calculated Data
Regression Curves
3.27
3.33
3.39
3.45
3.51
3.57
1000/T (1/K.°)

FIGURE 14

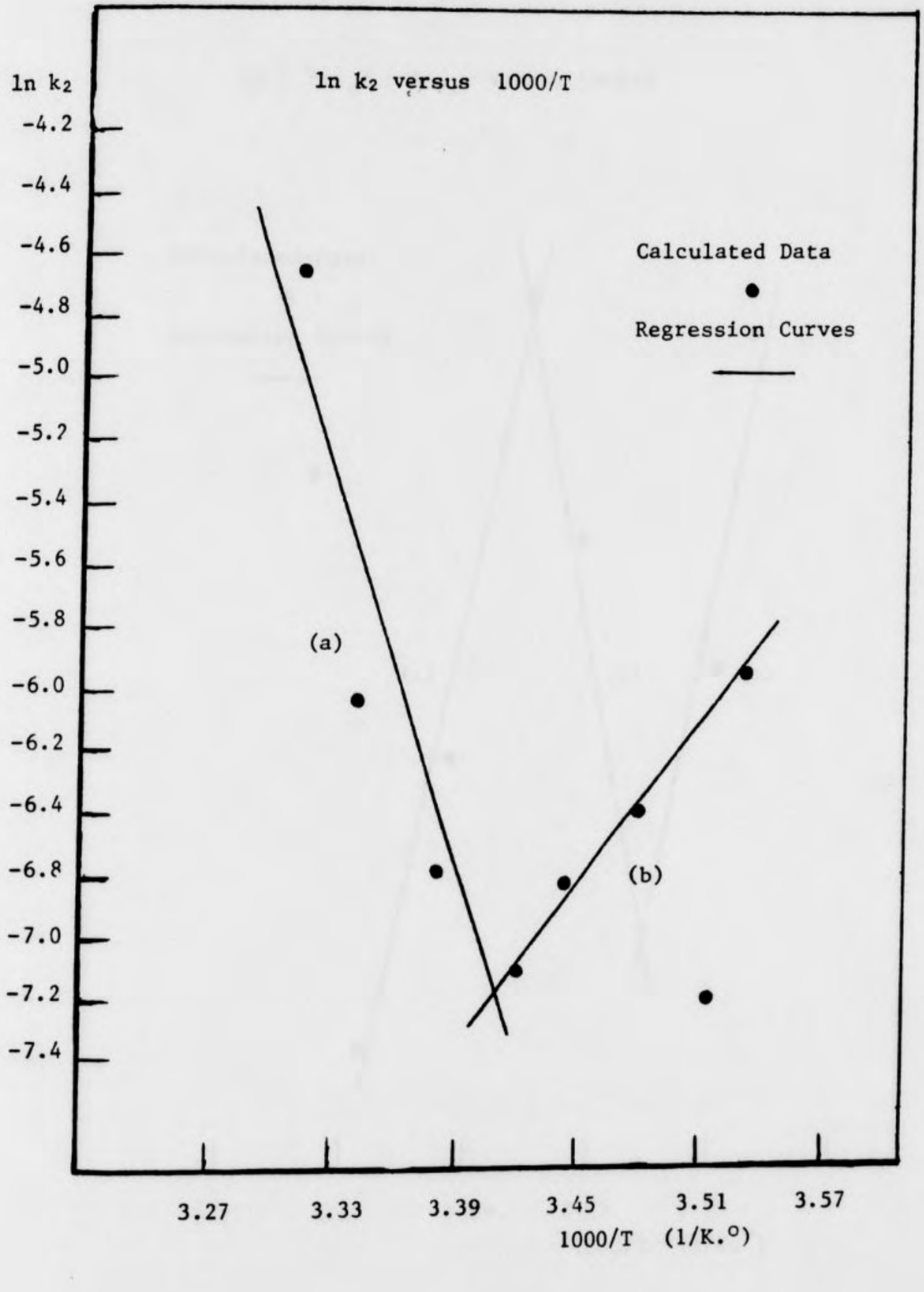

ln k2
ln k2 versus 1000/T
-4.2
-4.4
-4.6
-4.8
-5.0
-5.2
-5.4
-5.6
-5.8
-6.0
-6.2
-6.4
-6.8
-7.0
-7.2
-7.4
Calculated Data
Regression Curves
(a)
(b)
3.27
3.33
3.39
3.45
3.51
3.57
1000/T (1/K.°)

FIGURE 15

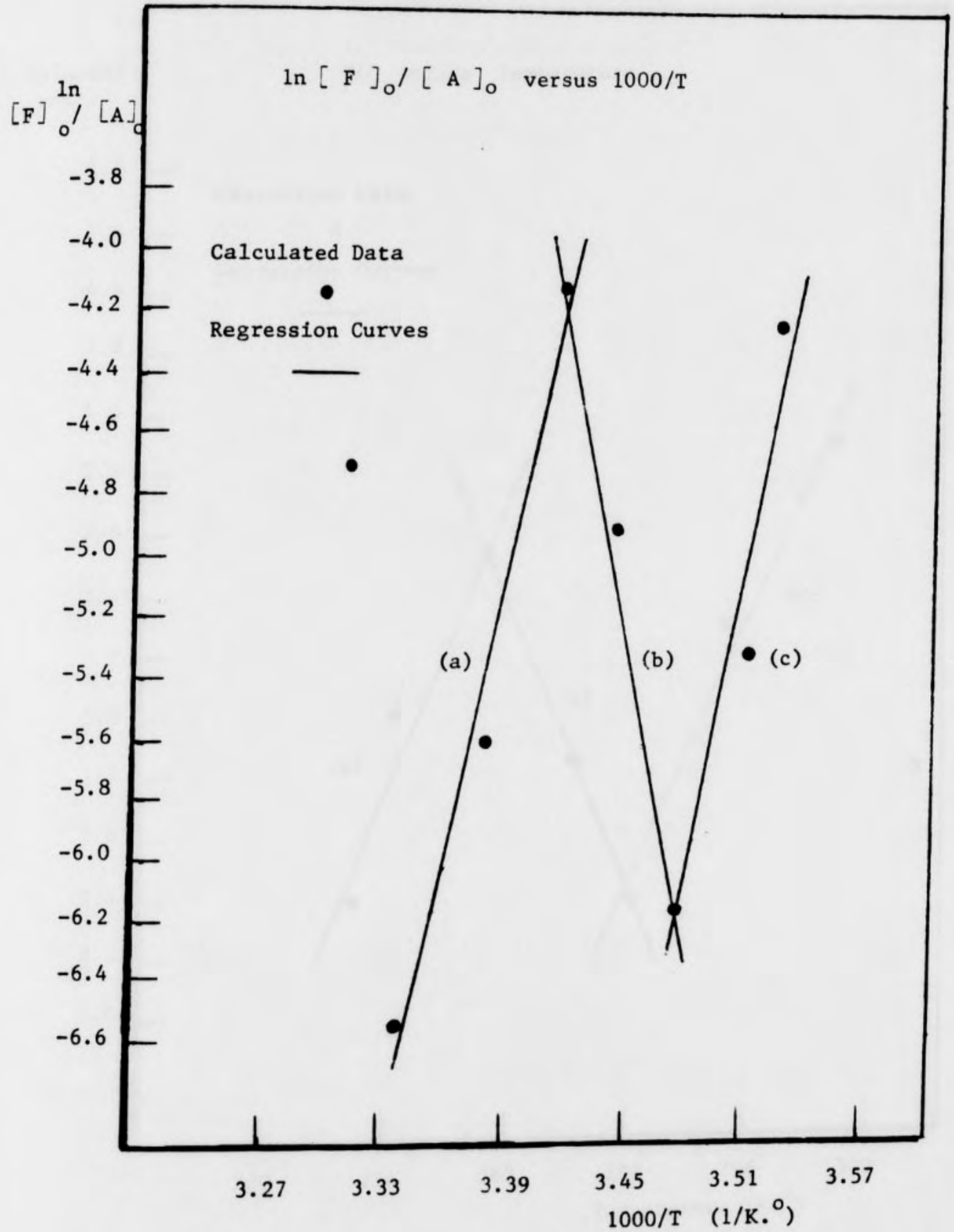
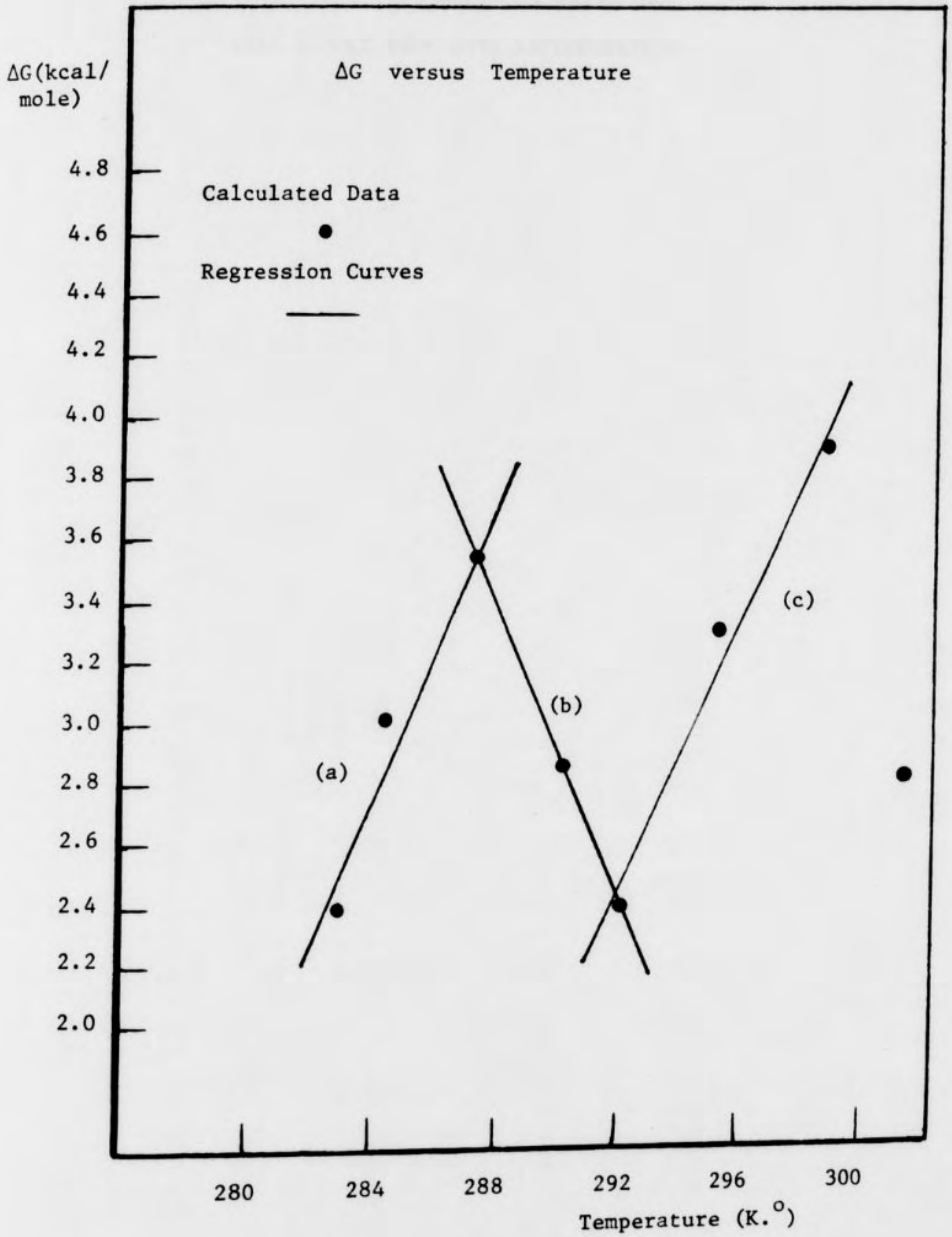

ln [F]o/ [A]o versus 1000/T
ln
[F]o/ [A]o
-3.8
-4.0
-4.2
-4.4
-4.6
-4.8
-5.0
-5.2
-5.4
-5.6
-5.8
-6.0
-6.2
-6.4
-6.6
Calculated Data
Regression Curves
(a)
(b)
(c)
3.27
3.33
3.39
3.45
3.51
3.57
1000/T (1/K.°)

FIGURE 16


ΔG(kcal/
mole)
ΔG versus Temperature
4.8
4.6
4.4
4.2
4.0
3.8
3.6
3.4
3.2
3.0
2.8
2.6
2.4
2.2
2.0
Calculated Data
Regression Curves
(a)
(b)
(c)
280
284
288
292
296
300
Temperature (K.°)

APPENDIX V

KINETIC AND THERMODYNAMIC PARAMETERS THAT RESULT FROM DATA SUPERPOSITION

TABLE 12

CALCULATED THERMODYNAMIC PARAMETERS

INCLUDING CALCULATED RESULTS FOR TURNIP SEEDS

	Ea for [F]o (kcal/mole)	Ea for [A]o (kcal/mole)	Ea for the Autocatalytic Reaction (kcal/mole)	Temp. Range (C.°)	ΔH (Det. by Plot of ΔG) (kcal/mole)	ΔH (Det. by Plot of ln [F]o) (kcal/mole)	ΔS (Det. by Plot of ΔG) (kcal/-mole-K.°)	ΔS (Det. by Plot of ln [F]o/[A]o) (kcal/mole-K.°)
				10.2-14.5	-67.87 ±21.03	-67.24 ±21.21	+0.249 ±0.074	+0.246 ±0.070
Lettuce	+94.0 ± 8.6	+24.9 ± 2.7	+79.0 +11.5	14.5-19.2	+72.94 ± 0.45	+72.61 ± 1.33	-0.242 ±0.002	-0.240 ±0.004
				19.2-26.0	-62.42 ± 8.77	-62.05 ± 8.99	+0.222 ±0.030	+0.221 ±0.030
Turnips*	+52.67 ±8.87	+ 8.30 ± 0.98	+71.4 ±11.6	below 33	+67.2 ± 2.5	+68.4 ± 2.1	+0.219 ±0.008	--

* Joyner, op. cit., p. 37.

TABLE 13

CALCULATION FOR THE ACTIVATION ENERGY

OF [F]o FOR TURNIPS

Temp. (C.°)	Obs. X 1000/T (1/K.°)	Obs. Y** ln [F]o	Est. Y ln [F]o	Residual
33	3.27	6.8000	6.1112	0.6888
31	3.29	5.9200	5.5792	0.3408
27	3.33	4.2100	4.5153	-0.3053
23	3.38	2.2200	3.1855	-0.9655
21	3.40	1.9300	2.6535	-0.7235
18	3.44	1.3600	1.5896	-0.2296
14	3.48	1.7200	0.5257	1.1943

The PMCC is -0.936, giving a confidence level of 99.8%.

The F-Statistic is 35.19 on 1 and 5 degrees of freedom, giving a confidence level of 99.8%.

The slope is -26.60 ± 4.48, and intercept, +93.08 ± 15.11.

The activation energy is +52.67 ± 8.87 kcal/mole for [F]o.

** G. T. Hageseth and R. D. Joyner, *op. cit.*, p. 58.

TABLE 14

TABULATED RESULTS FOR QUIET AND NOISE DATA

Temp. ($C.^{o}$)	1000/T ($1/K.^{o}$)	[F]o Quiet	[F]o Noise***	ln [F]o Quiet	ln [F]o Noise***	[A]o Quiet	[A]o Noise***	ln [A]o Quiet	ln [A]o Noise***	ln [F]o/[A]o Quiet	ln [F]o/[A]o Noise***	ln k_2 Quiet	ln k_2 Noise***
28.5	3.316	0.30	0.50***	-1.200	-0.690***	33	58***	3.50	4.06***	-4.70	-4.70	-4.65	-5.12***
26.0	3.344	0.40	0.44***	-0.916	-0.820***	282	227***	5.64	5.42***	-6.56	-6.24***	-6.03	-6.02***
22.5	3.384	1.25	1.05***	+0.223	-0.049***	341	291***	5.83	5.67***	-5.61	-5.62***	-6.59	-6.27***
19.2	3.422	6.08	6.20***	+1.800	-1.820***	371	360***	5.92	5.89***	-4.11	-4.06***	-6.92	-6.90***
17.3	3.445	2.55	2.03***	+0.936	-0.708***	348	279***	5.85	5.63***	-4.92	-4.92***	-6.72	-6.46***
14.5	3.478	0.44	1.00***	-0.821	0.000***	209	400***	5.34	5.99***	-6.16	-5.99***	-6.29	-7.05***
11.5	3.515	1.44	1.06***	+0.365	0.0583***	297	220***	5.69	5.39***	-5.33	-5.33***	-7.01	-6.69***
10.2	3.531	1.48	2.20***	+0.392	0.788***	102	189***	4.62	5.24***	-4.23	-4.45***	-5.95	-5.79***

***

Horton, Sherry Jean, (Data was obtained by cooperative consultation), Master Thesis (To be published), Greensboro, 1976.

TABLE 15

COMPOSITE LINEAR REGRESSION RESULTS

Obs. X 1000/T (1/K.°)	Obs. Y ln [F]o	Est. Y ln [F]o	Residual	Statistics Item	Statistics Value
3.316	-0.6900***	-1.2999	0.6099		
3.316	-1.2000	-1.2999	0.0999	PMCC	0.947
3.344	-0.8200***	-0.5607	-0.2593	Confidence level	99.9^{+}%
3.344	-0.9160	-0.5607	-0.3553	F-Statistic	51.66 on 1&6 deg. of freedom
3.384	-0.0490***	+0.4952	0.4462	Confidence level	99^{+}%
3.384	+0.2230	+0.4952	-0.2722	Slope	26.40 ±3.67
3.422	+1.8200***	+1.4984	0.3216	Intercept	-88.84 ±12.37
3.422	+1.8000	+1.4984	0.3016		
3.422	+1.8200***	+1.7805	0.0395	PMCC	-0.964
3.422	+1.8000	+1.7805	0.0195	Confidence level	99.8%
3.445	+0.7080***	+0.8721	-0.1641	F-Statistic	53.32 on 1&4 deg. of freedom
3.445	+0.9360	+0.8721	0.0639	Confidence level	99.9%
3.478	+0.0000***	-0.4311	0.4311	Slope	-39.49 ±5.41
3.478	-0.8210	-0.4311	-0.3899	Intercept	136.92 ±18.65
3.478	0.0000***	-0.4251	0.4251	PMCC	0.827
3.478	-0.8210	-0.4251	0.3959	Confidence level	99%
3.515	+0.0583***	+0.2600	-0.2017	F-Statistic	8.63 on 1&4 deg. of freedom
3.515	+0.3650	+0.2600	0.1050	Confidence level	96%
3.531	+0.7880***	+0.5562	0.2318	Slope	18.52 ±6.30
3.531	0.3920	+0.5562	-0.1642	Intercept	-64.83 ±22.11

COMPOSITE LINEAR REGRESSION RESULTS (CONTINUED)

Obs. X 1000/T (1/K.°)	Obs. Y ln [A]o	Est. Y ln [A]o	Residual	Statistics Item	Value
3.316	4.0600***	4.3553	-0.2953	PMCC	0.811
3.316	3.5000	4.3553	-0.8553		
3.344	5.4200***	4.8465	0.5735	Confidence level	99%
3.344	5.6400	4.8465	0.7935		
3.384	5.6700***	5.5483	0.1217	F-Statistic	11.53 on 1&6 deg. of freedom
3.384	5.8300	5.5483	0.2817	Confidence level	98%
3.422	5.8900***	6.2150	-0.3250	Slope	17.54 ± 7.17
3.422	5.9200	6.2150	-0.2950	Intercept	-53.82 ±17.40
3.422	5.8900***	5.9532	-0.0632		
3.422	5.9200	5.9532	-0.0332	PMCC	-0.726
3.445	5.6300***	5.7906	-0.1606	Confidence level	99%
3.445	5,8500	5.7906	0.0594		
3.478	5.9900***	5.5574	0.4326	F-Statistic	8.92 on 1&8 deg. of freedom
3.478	5.3400	5.5574	-0.2174	Confidence level	98%
3.515	5.3900***	5.2959	0.0941		
3.515	5.6900	5.2959	0.3941	Slope	-7.07 ± 2.37
3.531	5.2400***	5.1828	0.0572	Intercept	30.14 ± 8.23
3.531	4.6200	5.1828	-0.5628		

COMPOSITE LINEAR REGRESSION RESULTS (CONTINUED)

Obs. X 1000/T (1/K.°)	Obs. Y ln [F]o/[A]o	Est. Y ln [F]o/[A]o	Residual	Statistics Item	Value
3.344	-6.5600	-6.5306	-0.0294	PMCC	0.976
3.344	-6.2400***	-6.5306	0.2906	Confidence level	99.9^{+}%
3.384	-5.6100	-5.3469	-0.2631	F-Statistic	79.50 on 1&4 deg. of freedom
3.384	-5.6200***	-5.3469	-0.2731	Confidence level	99.9^{+}%
3.422	-4.1100	-4.225	0.1125		
3.422	-4.0600***	-4.225	0.1626	Slope	29.59 ± 3.32
				Intercept	-105.48 ±11.23
3.422	-4.1100	-4.0919	-0.0181	PMCC	-0.998
3.422	-4.0600***	-4.0919	0.0319	Confidence level	99.99^{+}%
3.445	-4.9200	-4.9083	-0.0117	F-Statistic	99.49 on 1&4 deg. of freedom
3.445	-4.9200***	-4.9083	-0.0117		
3.478	-6.1600	-6.0798	-0.0802	Confidence level	99.99^{+}%
3.478	-5.9800***	-6.0798	0.0898	Slope	-35.50 ±1.13
				Intercept	117.38 ±3.89
3.478	-6.1600	-6.1642	0.0042	PMCC	0.947
3.478	-5.9900***	-6.1642	0.1742	Confidence level	95.5 %

COMPOSITE LINEAR REGRESSION RESULTS (CONTINUED)

Obs. X 1000/T (1/K.°)	Obs. Y ln [F]o/[A]o	Est. Y ln [F]o/[A]o	Residual	Item	Value
3.515	-5.3300	-5.0346	-0.2954	F-Statistic	35.09 on 1&4 deg. of freedom
3.515	-5.3300***	-5.0346	-0.2954		
3.531	-4.2300	-4.5462	0.3162	Confidence level	99.5%
3.531	-4.4500***	-4.5462	0.0962	Slope	30.53 ±5.15
				Intercept	-112.34 ±18.08

COMPOSITE LINEAR REGRESSION RESULTS (CONTINUED)

Obs. X 1000/T (1/K.°)	Obs. Y ln k_2	Est. Y ln k_2	Residual	Statistics Item	Value
3.316	-4.6500	-5.1717	0.5217	PMCC	-0.930
3.316	-5.1200***	-5.1717	0.0511	Confidence level	99.9^{+}%
3.344	-6.0300	-5.6649	-0.3651		
3.344	-6.0300***	-5.6649	-0.3551	F-Statistic	38.17 on 1&6 deg. of freedom
3.384	-6.5900	-6.3695	-0.2205		
3.384	-6.2700***	-6.3695	0.0995	Confidence level	99.9^{+}%
3.422	-6.9100	-7.0389	0.1289	Slope	-17.62 ±2.55
3.422	-6.9000***	-7.0389	0.1389	Intercept	53.24 ±9.60
3.422	-6.9100	-6.6862	-0.2238	PMCC	0.443
3.422	-6.9000***	-6.6862	-0.2138	Confidence level	80%
3.445	-6.7200	-6.6168	-0.1032		
3.445	-6.4600***	-6.6168	0.1568	F-Statistic	1.95 on 1&8 deg. of freedom
3.478	-6.2900	-6.5172	0.2272		
3.478	-7.0500***	-6.5172	-0.5328	Confidence level	80%
3.515	-7.0100	-6.4056	-0.6044		
3.515	-6.6900***	-7.0091	0.3191		
3.531	-5.9500	-6.3573	0.4073	Slope	3.02 ±2.16
3.531	-5.7900***	-6.3573	0.5673	Intercept	-17.01 ±7.47

TABLE 16

CALCULATED COMPOSITE THERMODYNAMIC PARAMETERS

INCLUDING RESULTS FOR TURNIP SEEDS

Curve	Lettuce Composite Group	Lettuce Quiet Group	Turnips Quiet Group
	Activation Energy (kcal/mole)	Activation Energy (kcal/mole)	Activation Energy (kcal/mole)
ln [F]o (14.5--19.2) C.°	78.19 ± 10.71	94.0 ± 8.6	52.67 ± 8.87 below 33 C.°
ln [A]o (10.2--19.2) C.°	14.00 ± 4.69	24.9 ± 2.7	8.30 ± 0.98 below 33 C.°
ln k_2 (19.2--28.5) C.°	34.89 ± 5.05	79.0 ±11.5	71.4 ±11.6 below 33 C.°
	ΔH (kcal/mole)	ΔH (kcal/mole)	ΔH (kcal/mole)
ln [F]o/[A]o (10.2--14.5) C.°	-58.59± 3.32	-67.24 ±21.21	+68.4 ± 2.1 below 33 C.°
ln [F]o/[A]o (14.5--19.2) C.°	+70.29± 2.24	+72.61 ± 1.33	-
ln [F]o/[A]o (19.2--26.0) C.°	-60.45±10.28	-62.05 ± 8.99	-
	ΔS (kcal/mole-K.°)	ΔS (kcal/mole-K.°)	ΔS (kcal/mole-K.°)
ln [F]o/[A]o (10.2--14.5) C.°	0.209 ±0.022	0.246 ±0.070	0.219 ±0.008 below 33 C.°
ln [F]o/ [A]o (14.5--19.2) C.°	-0.232 ±0.008	-0.240 ±0.004	-
ln [F]o/[A]o (19.2--26.0) C.°	0.222 ±0.036	0.221 ±0.030	-