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MEASURING BULK RECOMBINATION RATES AND BOUNDARY RECOMBINATION VELOCITIES

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Measurement of L (or τ) and s

I. ALL METHODS MEASURE SOME OTHER QUANTITY, DEDUCE L (OR τ) AND S.

II. IN MOST, THE MEASURED QUANTITY IS ALSO INFLUENCED BY OTHER PARAMETERS. THESE ARE SEPARATELY MEASURED, ASSUMED, OR NEGLECTED.

III. ALL METHODS HAVE RANGES OF L, S, OR THE OTHER PARAMETERS, WHERE THE DEPENDENCE OF THE MEASURED QUANTITY ON L AND/OR S IS WEAK.

IV. THERE ARE STEADY-STATE AND TIME-DEPENDENT MEASUREMENTS. SOME OF THE LATTER STILL DEPEND ON A TRANSPORT PROPERTY (L), NOT A TIME CONSTANT (τ).

V. SOME METHODS FIND A CONDITION WHERE THE MATHEMATICAL RELATIONSHIPS BECOME SIMPLE, E.G. REAL AND IMAGINARY PARTS OF A NUMBER BECOME EQUAL.

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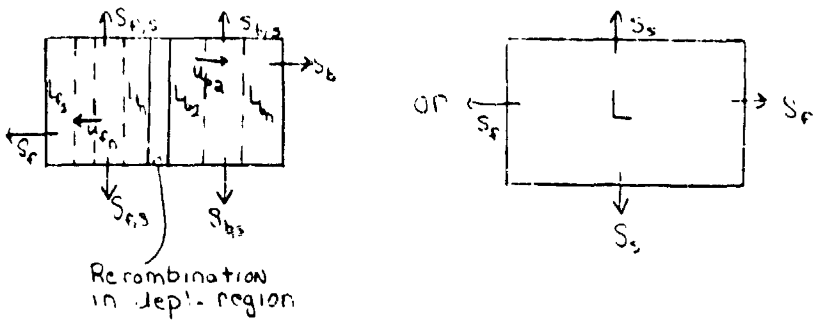

MEASURED QUANTITIY:

	$M = M(L_{WANTED},$	$u_{WANTED},$	$A_1 \ldots A_I,$	$B_1 \ldots B_J,$	$C_1 \ldots C_K,$	$D_1 \ldots D_K)$
MAY BE COMPLEX NUMBER			VARIABLE DEVICE PAPAMETERS	VARIABLE EXTERNAL PARAMETERS	CONSTANT DEVICE PARAMETERS	CONSTANT EXTERNAL PARAMETERS
EXAMPLE:	L_{FI}	$u_{FI} \div 1$	THICKNESSES S_{BJ}, S_{FJ}, L_{BJ}, L_{FJ}, u_{FJ}, u_{BJ}	T S-INFLUEN-CING ENV'T EXCITATION: LIGHT: λ, f VOLTAGE: V_1, f TERMINAL IMPEDANCE: S.C., O.C., ETC.	ANY OF A_I NOT VARIED; R IN DEPL'N REGION	ANY OF B_I NOT VARIED

Basic Requirement for Determination of Both L and u

AT LEAST 2 INDEPENDENT MEASURED DATA (M_1, M_2) NEEDED, WHICH ARE SENSITIVE TO U AND L IN THEIR RANGE OF INTEREST. (ONE MEASUREMENT MAY BE SENSITIVE TO ONLY L OR U, IF THE OTHER IS SENSITIVE TO BOTH.)

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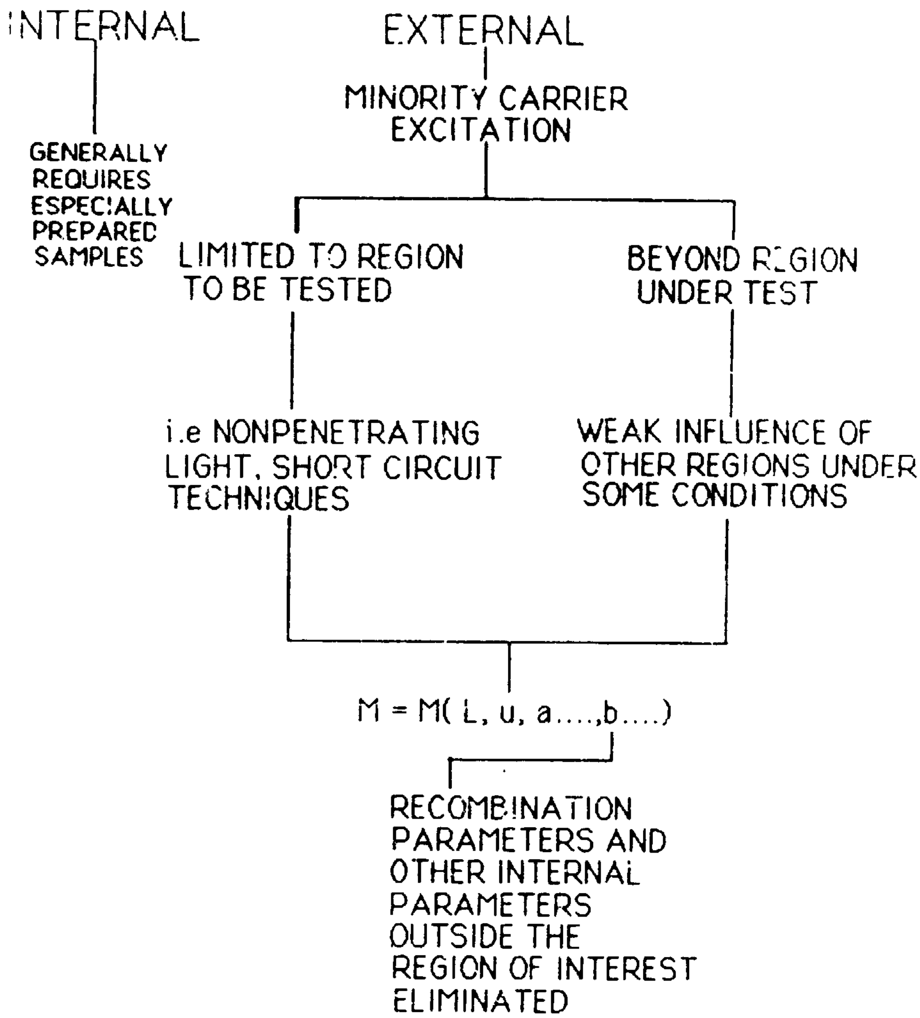
2 INDEPENDENT DATA ARE AVAILABLE FROM:

- COMPLEX NUMBERS (ONE OPTION)
- VARIATION OF A SUITABLE PARAMETER (EACH PARAMETER = ONE OPTION)

FINDING: A SENSITIVE DATA PAIR SEEMS THE MORE LIKELY, THE MORE OPTIONS FOR OBTAINING 2 DATA POINTS EXIST.

Type of Parameters Varied



Classification of Methods

TYPE	EXCITATION	M	VARIED EXTERNAL PARAMETERS	NUMBER OF OPTIONS
ASLBIC	LIMITABLE	REAL	λ	1
MODULATED LIGHT METHOD	LIMITABLE	COMPLEX	ω, λ	3
IMPEDANCE	DEVICE DEPENDENT	COMPLEX	ω	2
I_{sc}, V_{oc} PAIR	DEVICE DEPENDENT	COMPLEX	CIRCUIT IMPEDENCE	1
SCCD	DEVICE DEPENDENT	REAL	CIRCUIT IMPEDENCE	1

Goal: Reduce the Number of Variable or Constant Parameters (Requirements Listed in Order of Importance):

1. ELIMINATE INFLUENCE OF UNMEASURABLE PARAMETERS.
2. FIND SENSITIVE RELATIONSHIP BETWEEN L_{WANTED}, U_{WANTED}, AND M.
3. METHOD SHOULD BE APPLICABLE TO FINISHED, OR IN-PROCESS PRODUCT.
4. FIND EASILY MEASURABLE QUANTITY M, AND EASILY, REPEATABLY VARIABLE PARAMETERS.
5. REDUCE NUMBER OF INFLUENCING PARAMETERS.
6. FIND SIMPLE RELATIONSHIP.

The Basic Carrier Diffusion Expression

AN EXAMPLE FOR M: (ASLBIC):

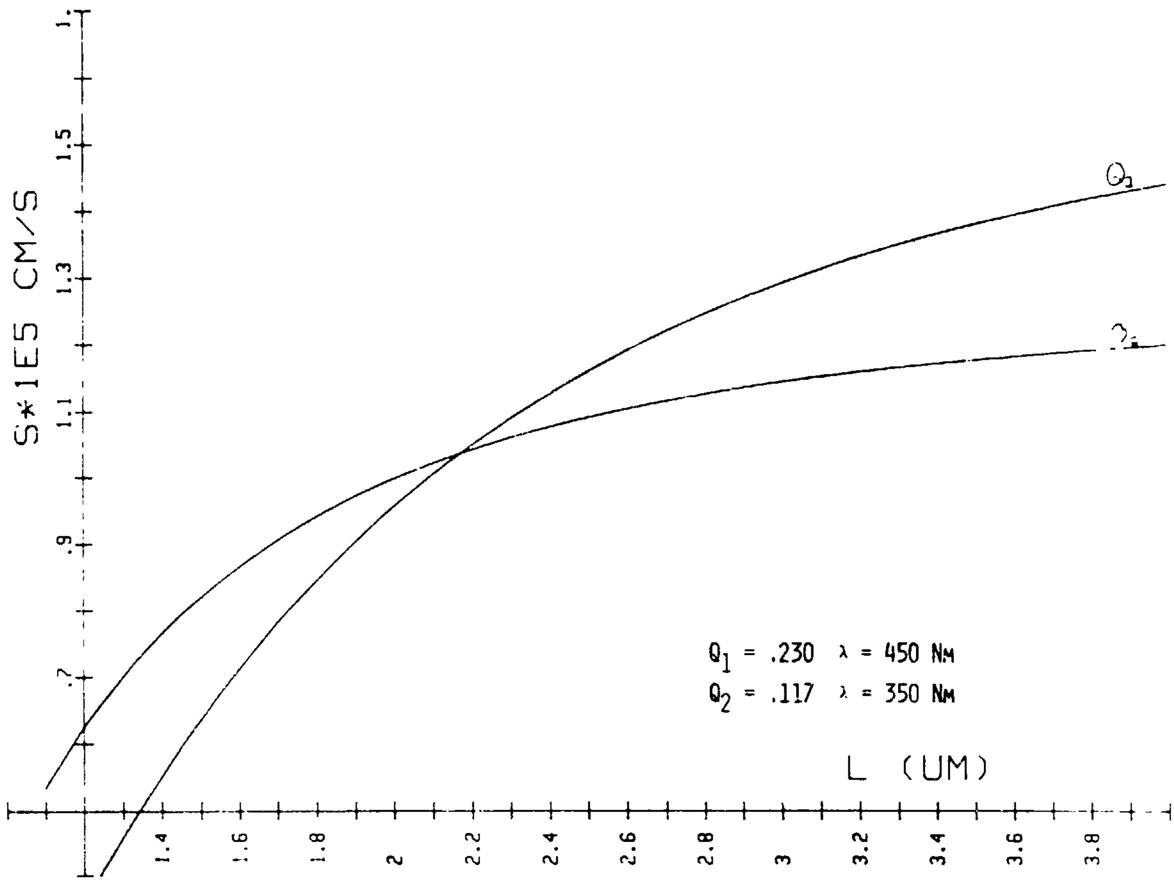
$$M = \eta_{COLL} = \frac{B}{B+Y} E^{-B} \left\{ 1 + \frac{1}{B-Y} \; \frac{(1+A)\, YE^{-Y} - (B+A)E^{B}}{COSH\, Y + A\, SINH} \right\}$$

(SIMPLEST FORM FOR SINGLE-LAYER FRONT REGION)

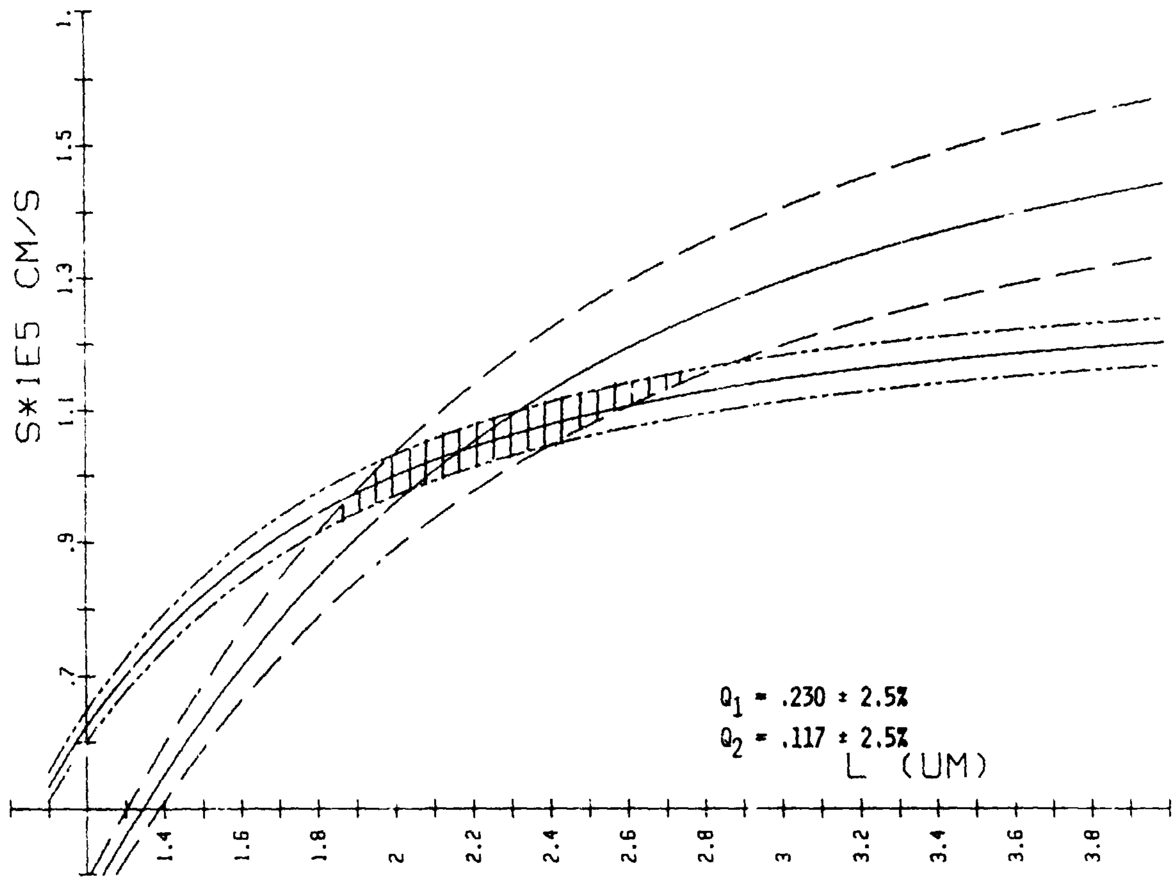
WITH THE BASIC VARIABLES:

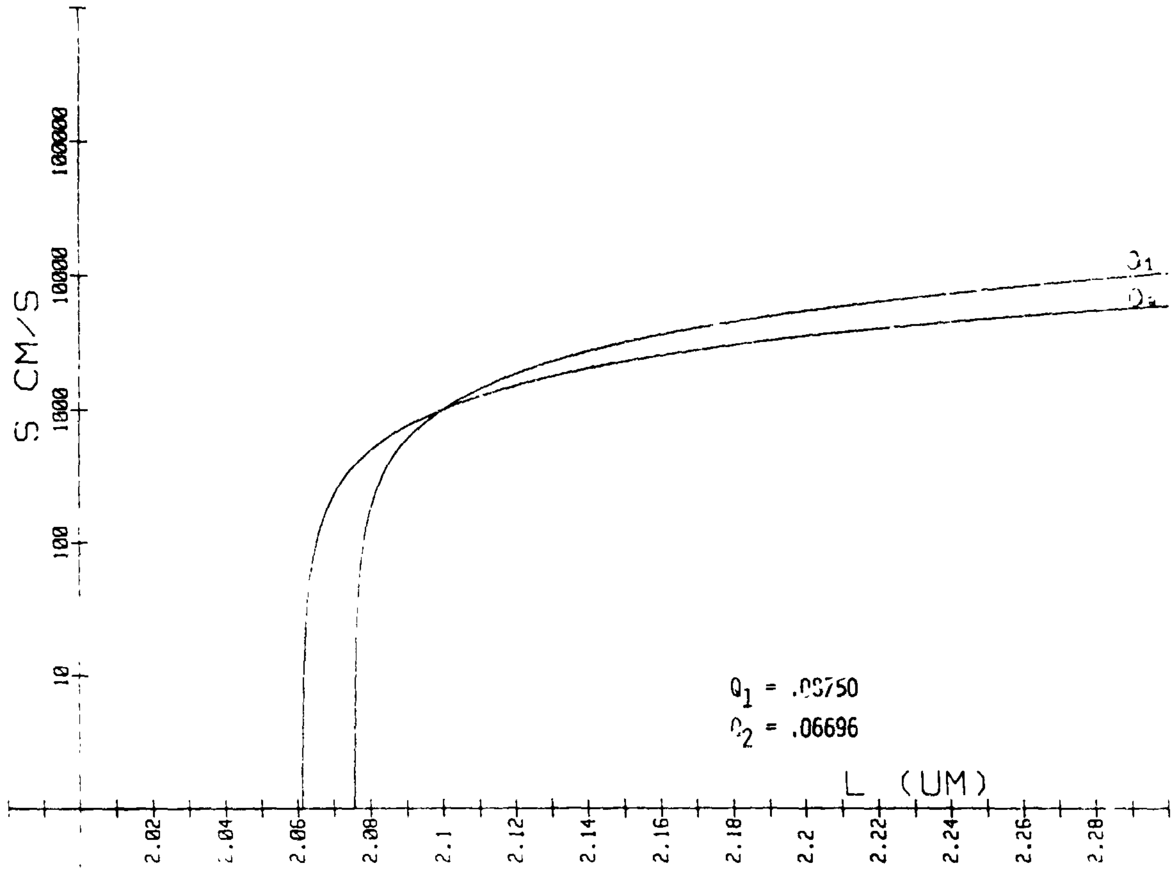
$$Y = \frac{X_{J,F}}{L}; \qquad A = \frac{SL}{D}; \qquad B = \alpha(\lambda) . X_{J,F}$$

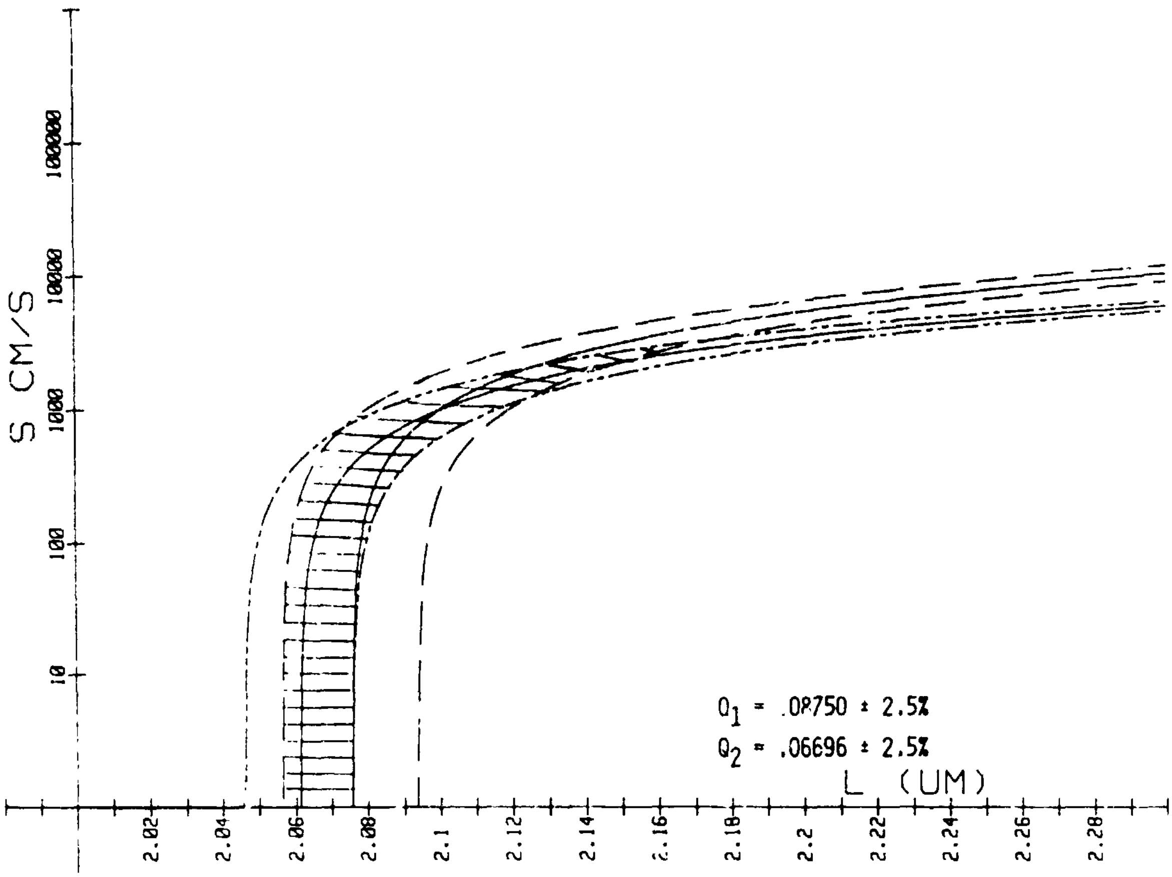
VERY SIMILAR RELATIONSHIPS FOR OTHER METHODS.



S*1E5 CM/S
1.
1.5
1.3
1.1
.9
.7
Q1
Q2
Q1 = .230 λ = 450 NM
Q2 = .117 λ = 350 NM
L (UM)
1.4
1.6
1.8
2
2.2
2.4
2.6
2.8
3
3.2
3.4
3.6
3.8


S*1E5 CM/S
.7
.9
1.1
1.3
1.5
1.4
1.6
1.8
2
2.2
2.4
2.6
2.8
3
3.2
3.4
3.6
3.8
L (UM)
Q1 = .230 ± 2.5%
Q2 = .117 ± 2.5%


S CM/S
100000
10000
1000
100
10
Q_1
Q_2
Q_1 = .08750
Q_2 = .06696
L (UM)
2.02
2.04
2.06
2.08
2.1
2.12
2.14
2.16
2.18
2.2
2.22
2.24
2.26
2.28


S CM/S
100000
10000
1000
100
10
Q1 = .08750 ± 2.5%
Q2 = .06696 ± 2.5%
L (UM)
2.02
2.04
2.06
2.08
2.1
2.12
2.14
2.16
2.18
2.2
2.22
2.24
2.26
2.28

Measurement Comparison Criterion

SE..SITIVITY ANALYSIS DETERMINES THE ERRORS IN CONSEQUENCE OF INACCURACIES IN THE MEASURED DATA AND THE PARAMETERS.

EXAMPL.. ASLBIC:

$$M_1 = M\ (L,\ S,\ \lambda_1,\ A_2\ .\ .\ .) \qquad (1)$$

$$M_2 = M\ (L,\ S,\ \lambda_2,\ A_2\ .\ .\ .) \qquad (2)$$

IDEALLY, THESE EQUATIONS WOULD BE ANALYTICALLY INVERIABLE TO:

$$S = S\ (M_1,\ M_2,\ \lambda_1,\ \lambda_2,\ A_2\ .\ .\ .\ .,\ B_1\ .\ .\ .) \qquad (3)$$

$$L = L\ (M_1,\ M_2,\ \lambda_1,\ \lambda_2,\ A_2\ .\ .\ .\ .,\ B_1\ .\ .\ .) \qquad (4)$$

AND THEN PERMIT A SENSITIVITY ANALYSIS SUCH AS:

$$\Delta S = \frac{\partial S}{\partial M_1}\bigg|_{M_2} \cdot \Delta M_1 + \frac{\partial S}{\partial M_2}\bigg|_{M_1} \cdot \Delta M_2 \qquad (5)$$

$$\Delta L = \frac{\partial L}{\partial M_1}\bigg|_{M_2} \cdot \Delta M_1 + \frac{\partial L}{\partial M}\bigg|_{M_1} \cdot \Delta M_2 \qquad (6)$$

AS EQ. (1), (2) ARE TRANSCENDENTAL (3), (4) ARE NOT ANALYTICALLY EXPRESSABLE.
HOWEVER:

$$S = S\ (L,\ M,\ \lambda,\ A_2\ .\ .\ .\ .,\ B_1\ .\ .\ .)$$

IS AVAILABLE, AND CONSEQUENTLY (6). FOR (5), NOTE

$$\frac{\partial S}{\partial M_1}\bigg|_{M_1} \neq \frac{1}{\frac{\partial M}{\partial S}}\bigg|_{L}$$

WHERE ANALYTICAL TREATMENT NOT POSSIBLE, LINEAR APPROXIMATIONS:

$$M_1 \quad M_0\ (S_F,\ L_F,\ A_1)\ .\ .\ .\ .) + \frac{\partial M}{\partial A_1}\bigg|_{S_F,\ L_F,\ .\ .\ .} \cdot \Delta A_{1,\ 1}$$

$$M_2 \quad M_0\ (S_F,\ L_F,\ A_1,\ .\ .\ .\ .) + \frac{\partial M}{\partial A_1}\bigg|_{S_F,\ L_F,\ .\ .\ .} \cdot \Delta A_{1,\ 2}$$

$$M_3 \quad M_1 + \frac{\partial M}{\partial S_F}\bigg|_{L_F,\ A_1 + \Delta A_{1,\ 1},\ .\ .\ .\ .}$$

MAY YIELD <u>SOME</u> INFORMATION ON SENSITIVE RANGES.