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Analog program for the Widdas model of sugar transport

In a recent paper LEFEVRE[1] developed two equations from the Widdas model for the transport of sugars to test STEIN's dimerizer hypothesis[2]. Solutions of the equations were generated by numerical analysis with a *digital* computer (Monrobot XI, Monroe International, Inc.). Since the two rate equations emerge in the form of:

$$\dot{F} = (a + bF_i + cG_i)/(u + vF_i + wG_i) \cdot zk$$

and

$$\dot{G} = (p + qF_i + rG_i)/(u + vF_i + wG_i) \cdot zk$$

they may be programmed with the analog computer quite readily. Since the coefficients are constant, potentiometer settings can replace $a, b, c \cdots u, v, w$; the remainder of the equations requires two dividers and ancillary amplifiers as summers and integrators. Much of this hardware is available in basic models of a number of commercial sources. In developing the program, I have used an EAI TR-20 (ref. 3).

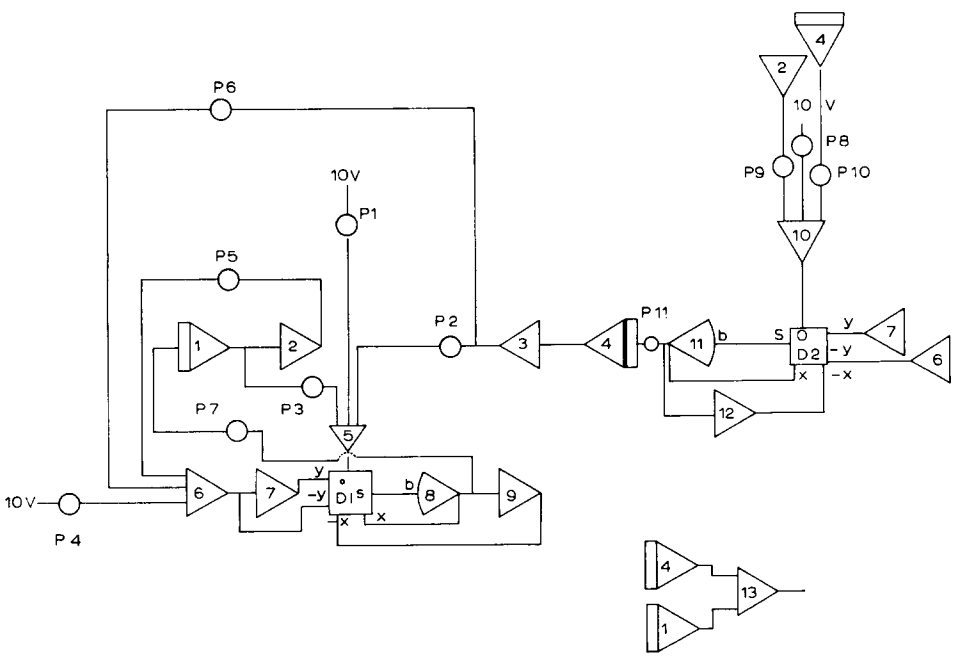

Fig. 1. Analog program for Eqns. 2a and 2b in the paper of LEFEVRE[1] describing the transport of two sugars by a common carrier across the membrane of the human erythrocyte.

Since these equations describe the transport of pairs of sugars across the membrane of the human erythrocyte, any simple solution will help workers in the field of membrane transport to apply the equations with ease and versatility to their own experimental data. For this reason I have summarized in the figures and tables below a program which any laboratory with minimal analog equipment can duplicate and apply.

TABLE I

TABLE OF POTENTIOMETERS

Scale factors: m',m: to scale variables F_i and G_i; N: to assure a ratio into Dividers 1 and 2 less than 1; p, q: to prevent overloading at summing amplifiers A5 and A6.

Potentiometer No.	*Coefficient*
1	$\{[F]_m K_g I/10\}/q$
2	$(M_t + K_g)\, F_m/mq$
3	$\{(M_t + K_g)\,[G]_m + MK_g\}/mq$
4	$\{K_f K_g I/10\} N/pq$
5	$\{(M_t + K_f)\, K_g\}\, N/mpq$
6	$\{(M_t + K_g)\, K_f\}\, N/mpq$
7	$\{z\, k_f/10\} Nm'/p$
8	$[G]_m\, K_f\, I/10$
9	$(M_t + K_f)\,[G]_m/m$
10	$\{(M_t + K_f)\,[F]_m + M\, K_f\}/m$
11	$\{z\, k_g/10\} Nm'/pq$

TABLE II

TABLE OF AMPLIFIERS

Scaling factors have been omitted from the table of amplifiers for purposes of clarity. They are included in the table of potentiometers. Outputs from amplifiers 8, 9, 11, 12 are increased by a gain of 10, as a characteristic of dividers manufactured by EAI.

Amplifier No.	*Function*	*Output*
1	Integrator	$-F_i$
2	Inverter	$+F_i$
3	Inverter	$+G_i$
4	Integrator	$-G_i$
5	Summer	$-\{(F_m K_g I) + (M_t + K_g) F_m G_i - [(M_t + K_g)\, G_m + MK_g]\, F_i\}$
6	Summer	$-\{(K_f K_g I) + (M_t + K_f)\, K_g\, F_i + (M_t + K_g)\, K_f\, G_i\}$
7	Inverter	$+\{(K_f K_g I) + (M_t + K_f)\, K_g F_i + (M_t + K_g)\, K_f\, G_i\}$
8	Divider	$+\left[\dfrac{\{(F_m K_g I) + (M_t + K_g) F_m G_i - [(M_t + K_g)\, G_m + MK_g]\, F_i\}}{\{(K_f K_g I) + (M_t + K_f)\, K_g\, F_i + (M_t + K_g)\, K_f\, G_i\}}\right] \cdot 10$
9	Inverter	$-$ [output of amplifier 8]
10	Summer	$-\{(G_m K_f I) + (M_t + K_f)\, G_m F_i - \{(M_t + K_f)\, F_m + MK_f\}\, G_i\}$
11	Divider	$\left[\dfrac{\{(G_m K_f I) + (M_t + K_f)\, G_m F_i - [(M_t + K_f)\, F_m + MK_f]\, G_i\}}{\{(K_f K_g I) + (M_t + K_f)\, K_g\, F_i + (M_t + K_g)\, K_f\, G_i\}}\right] \cdot 10$
12	Inverter	$-$ [output of amplifier 11]
13	Summer	$+ (F_i + G_i)$

Fig. 1 is a diagram of the program written for the EAI analog computer (TR 20, Electronic Associates, Inc., Princeton, N.J.), for Eqns. 2a and 2b in the paper of LEFEVRE[1]. Table I lists the potentiometer settings. Table II is a table of

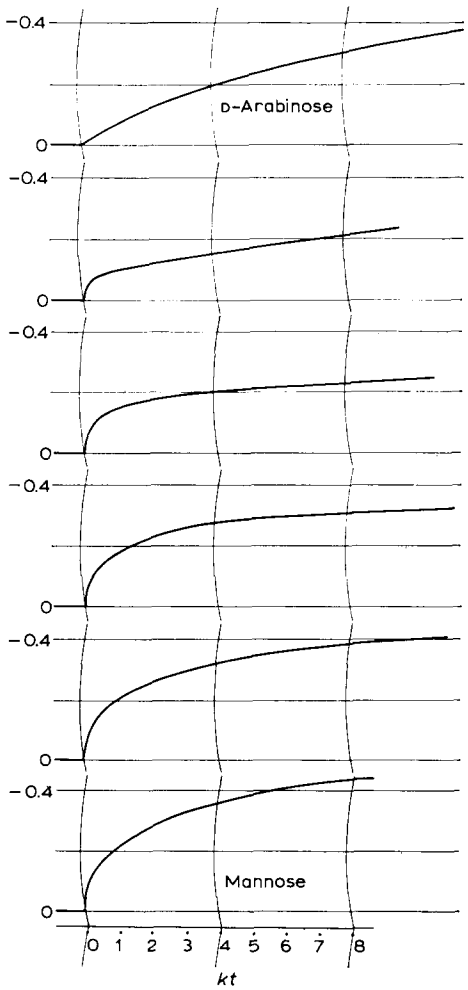

Fig. 2. Analog solution for the transport of D-arabinose (top) and mannose (bottom). Concentrations of mannose in the mixture of two sugars increase from top to bottom in the order of 0.0, 0.2, 0.4, 0.6, 0.8, and 1.00 of the total concentration of 190 mM (0.63 isosmolar).

amplifiers. The two variables, F_i and G_i require scaling to avoid amplifier overloading and the scale factors vary according to the particular combinations of the two sugars used.

The success of the program is evident from Fig. 2 which duplicates one of the more striking solutions illustrated in Fig. 2 of LEFEVRE's paper[1]. By way of example, Table III lists the potentiometer settings for this set.

I hope the program will help other workers in this area of membrane physiology

TABLE III

POTENTIOMETER SETTINGS TO DESCRIBE THE ENTRANCE OF D-ARABINOSE, MANNOSE, OR MIXTURES OF THE TWO SUGARS INTO THE HUMAN ERYTHROCYTE

Based on data from Fig. 2 (ref. 1).

Potentiometer No.	D-*Arabinose*					*Mannose*
	0.00	*0.20*	*0.40*	*0.60*	*0.80*	*1.00*
1	—	0.1260	0.0252	0.0378	0.0540	0.0630
2	—	0.1465	0.0293	0.0440	0.0586	—
3	—	1.586	0.1439	0.1293	0.1146	0.1000
4	0.0600	0.2400	0.0281	0.0400	0.0523	0.0675
5	—	6.760	0.7805	1.132	1.472	1.901
6	0.6978	0.2791	0.0327	0.0468	0.0608	—
7	—	0.1269	0.0895	0.0914	0.0925	0.0978
8	0.0037	0.0030	0.0022	0.0015	0.00070	—
9	—	0.0852	0.0639	0.0426	0.0213	—
10	0.0600	0.0273	0.0486	0.0699	0.0912	—
11	0.0094	0.1269	0.00895	0.00914	0.00925	—
m	1	10.0	10.0	10.0	10.0	10.0
m'	0.1	1	1	1	1	1
N	1	4	7	10	13	15
p	1	1	1.5	1.5	1.5	1.33
q	1	1	10.0	10.0	10.0	10.0

to use these valuable equations of competitive transport not only in sugar transport but in other transport systems as well.

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3 A. CARLSON AND G. HANNAUER, *Handbook of Analog Computation*, Electronic Associates, Inc., Princeton, N.J., 1964.

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Purification and properties of protein phosphokinase from bovine red blood cell membranes

Phosphoproteins are ubiquitous in nature, but their synthesis and metabolic role have not yet been well established. Phosphoprotein phosphorylation has been studied by several investigators[1–3] and its "reverse" reaction has been discovered by RABINOWITZ AND LIPMANN[2].

$$\text{ATP} + \text{dephosphoprotein} \rightleftharpoons \text{ADP} + \text{phosphoprotein}$$