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THE INFLUENCE OF LEARNING STRATEGIES AND PERFORMANCE STRATEGIES--ETC(U)

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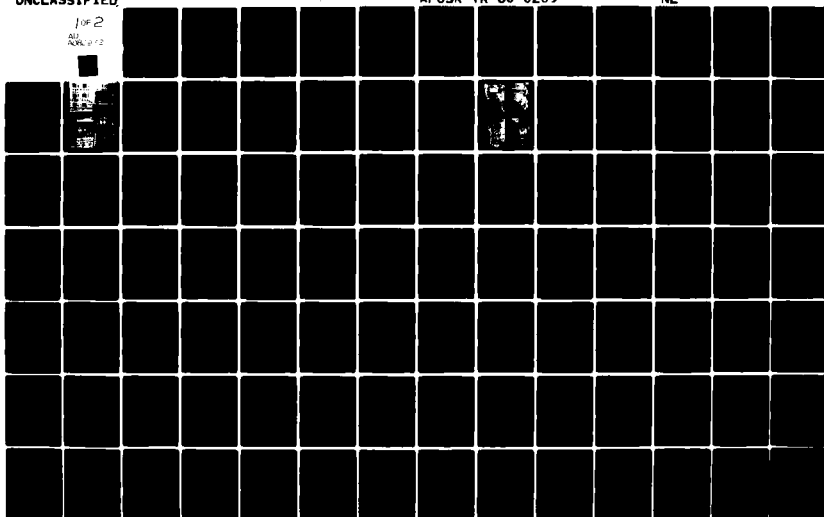
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The Influence of Learning Strategies and
Performance Strategies Upon Engineering
Design

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20. Abstract A study arising from previous work on electronic hardware design, is described. (a) Subjects from the previous study and a few others extended the original experiment; (b) A computer program linked to a display and control console through A/D and D/A convertors provided an alternative, though overall isomorphic, des- ign task; (c) Subjects performed in a controlled manner, a less restrictive des- ign task; to design intruder alarm systems; (d) A small group of subjects per- formed the intruder alarm system task, in less controlled conditions, but at leisure. In all cases, subjects were pretested for conceptual style. There are certain clear, but quite complex relations between the test profiles of conceptual style and the methods of design and one score variable is useful as a predictor of design ability. However, the connection is complex; for example, there is a different relation in the hardware and the software programming tasks (cont)		

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20. cont/ abstract:

((a) and (b)) . In the intruder alarm task ((c) and (d)) , versatile subjects adopt a diverse but systematic approach; the others may or may not have diversity, but are not systematic (they do not generate sensible design principles). If enough time is allowed versatile subjects and, in one sense, good designers will continue to produce essentially different designs over a time of several months, (study (d)) but this effect is not evident under more restrictive conditions (study (c)) ..

Throughout, there is a strong tendency for cognitive fixity, with respect to design principles, and the main mechanism of innovation is abduction, or the construction of valid analogies and their subsequent employment.

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1. Introduction

The research described in this report is a rational continuation of previous work upon design capability and conceptual style carried out as part of Contract F44620-76-C-0003 through the European Office.

In the previous studies, the subjects, some of them experienced designers, and some of them graduates in electronic engineering, designed an analogue electronic simulator for demonstrating the principles of reaction kinetics in physical chemistry; the progress and the energetics of a chemical reaction being simulated, as customary for the (United Kingdom) "A level" student, in terms of "activated complex" theory; a gross, but numerically sophisticated, approximation to reality. All subjects were tested for learning and conceptual style using the "Spy Ring History Test", and were required to justify their design by constructing a graph, which approximated an entailment mesh, indicating how and why they designed the simulator as they did. Further, all the designs "worked satisfactorily"; meeting the requirements of a design brief. But, given this much, the quality of designs (all of which satisfied the brief) was assessed according to stated criteria; namely, reliability, transparency, ruggedness (how fool proof the designed simulator is), and the extent to which a simulator can be used in a flexible manner for different demonstrations.

The results obtained in this previous study have been reported. Results include a significant positive correlation between the versatility score on the stylistic test and the rated quality of design; between versatility score and the tendency to use defensible analogies between the application domain, and the domain of electronic design, and in some respects, the superiority of the experienced designers who do, however, take longer to produce a design which satisfies the brief.

The studies covered by the present report are as follows:

- (a) Continued investigation, using recorded group and individual interviews, of subjects in the original pool, the intention being to provoke them, where necessary, by suggested deficiencies in the original brief, into innovative activity based upon a more widely useable simulator. Somewhat contrary to the pessimistic views I expressed, during discussions in Washington, this enquiry has yielded some useful data; chiefly, because it proved possible to retrieve "lost" subjects, more than 18 months after the first study was finished.
- (b) Experiments intended to indicate the difference between hardware designing and computer programming and the dependency between programming skill and the stylistic test scores. For this purpose A/D and D/A convertors were used to interface the computer with a replica of the display and control layout of the original reaction kinetics design task, and the brief presented was similar except for the criteria of design quality employed. Once again, all of the designs did as a minimal requirement, satisfy the design brief.
- (c) Fairly large scale, 4 session, experiments, in which less sophisticated designers, (26 subjects from teacher training college and from technical college), attempted the design of an intruder alarm system. Subjects were provided with details of how simple devices

function, how detectors could be wired together, etc., and they all had access to two differently located premises (presenting two, very different, kinds of protection problem). One goal of the study was to relate conceptual style, as determined by the tests, to design quality (all designs must satisfy a minimal brief), and another goal was to relate these indices to the number of other-than-trivially different designs produced. Subjects were encouraged to make and describe as many alternative designs as possible, and two designs (each bearing a different cost limit) were required, for each of the two premises.

(d) A small scale study, 11 subjects from one of my graduate classes (MSc in Cybernetics, at Chelsea College), carried out over 8 months in which the experiment of (c) was repeated in a more open-ended and leisurely manner. Serious comprehension of how the intruder detection and alarm devices work is unnecessary (and, as judged by a standard questionnaire, the knowledge of the function of each device, as a "black box", scarcely differed from the knowledge of the subjects in (c)). However, in this case, the design task gained "out of class" credit, and it was possible for the (d) subjects to think at leisure. Their gradings did not depend upon design quality, as such, rather, upon discussion of the task, comparison of designs, etc., in subsequent 1st year seminars.

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2. Follow up study of designers

I expressed some anxiety about this study when last in Washington because of corruption of the data.

Due to unavoidable circumstances, it turned out that all the individual and group sessions were (finally, and for some part of each person's history) conducted by one experimenter, myself. I had the strong impression at that stage (some year or more ago), that many of the innovations were due to the experimenter, even though accidentally introduced. On listening to sample tapes (all sessions were sound recorded and many video recorded) this pessimistic impression is false. The findings must of course, be qualified, regarded as "clinical type" data and no elaborate comparisons have been attempted. All the same the findings are of interest, particularly since members of our original subject pool of hardware designers who had left the neighbourhood returned to London and proved sufficiently interested to make contact and return for further discussions.

The prompting comments, used to elicit innovations, were as follows:

(a) Can you really amalgamate the designs into a potentially more powerful or accurate simulation (if so, show me, or us, as a group, how to do so).

(b) Is the complex amalgamated system chemically or physically meaningful (if not, say why not)

(c) What really is assumed about the kinetics of a reaction.

(d) What happens if the reactants are not stirred and mixed in the vessel. The Belousov Zhabotinski reaction was demonstrated i.e. the complex oscillatory reaction, involving HBrO_2 , Br , BrO_3 and a redox coupling (Ce III, Ce IV; or Mn II MnIII, (Field and Noyes, 1974, or Winfree 1974).

(e) How can you show what goes on in a chemical reaction, given an explanation (which was usually quite well understood) of relaxation time and transit time for an activated complex? (The subjects were encouraged to introduce more sophisticated models if they were familiar with them).

(f) Given excerpts from Prigogine's work, what do you think to the a ivated complex model? Is it at all possible to assume near to equilibrium thermodynamics. If not, how can you simulate or demonstrate what goes on? What is the price paid in "mathematical complication"?

Design a system which is intelligible to a non mathematician.

(g) What is a molecule? Which energy in the system is kinetic, and which is potential? What happens at really high or low temperatures?

(h) How would you have benefitted from having the original simulator when you were in high school? (all subjects have done some physical chemistry, all have done a good deal of physics). From having the advanced simulator you propose? Have you changed your views on science as a result of this design task?

Insofar as these comments, or questions, convey ideas, directly, the results must be deemed unoriginal, but to the best of my knowledge, and contrary to my original belief, these are the only substantial prompts originating solely in the experimenter.

The most obtrusive finding is a confirmation of the (earlier report) hypothesis that abduction or analogy construction is the dominant, if not the only, means of innovation. The proposed mechanism of abduction closely resembles the mechanism examined by Gordon (1968) and his colleagues which is encouraged in their "synectics method" for design and management-situation creativity-training. It is an initial juxtaposition of different perspectives on a problem, either by different people in a group or, more often, by one person. The perspectives appear, initially, as related but irreconcilable. The disparity may or may not be resolved. If not, then an inconsistency or incoherence is recognised (and, as the experimenter, I tried to make certain that the matter was not "simply dropped"). If coherence is obtained, then something has been discovered, though it may or may not have particular relevance as a solution to the problem.

For example, in the problem of coupling units of the original design together. "Look at the input to the Black Box", and "Look at the output from the Black Box" (which leads to an incoherency if the reaction is reversible, unless the temperature, or one of the other parameters is regarded as an input, which was not the intention).

Conversely, "Look at the environment of a molecule", and "Look at the molecule from its surroundings", led to a very ingenious colour television display design which, although rather too costly in practice is implementable (the design replaces relaxation times i.e. the times needed for energy transfer, by spatial contours in a neighbourhood map).

The next finding is confirmed by the study of Section 5; Designers who exhibit novelty can continue to design fresh designs but it takes many months to do so.

The designs produced are very varied and by any reasonable criterion should be judged as innovative (whether they are successful innovations or merely permissible inventions is an utterly different matter). At one extreme, there were complex simulations (like the case already cited, of the temporal contours). At the other extreme, there is a design containing a minimum of electronics or computation but students are instructed to enact reactions (lawfully, however) regarding pairs of students as molecules. This scheme, which struck me as particularly inventive was later elaborated to a low frequency loop radio system intended to detect rule disobedience.

As in other studies of problem formulation and problem solving, it was possible to observe a great deal of fixity with respect to principles or underlying themes. Six of these themes are obtrusive enough to be accounted (Table 1). They are

(A) Scaling, the representation of quantities so that, for example, plots of a 1st order and of a 2nd order reaction are visually distinct.

(B) Display complexity. If on its own, this feature is concerned with the elaborate presentation of either macro or micro level variates. If combined with (C), below, it represents a complex interaction at control as well as display points.

(C) The Interactionist position; to be effective the design must allow the student to modify parameters, initialise or otherwise vary the course of events.

A systematic attempt was made to shift adherents of "(B) alone" to "(B) and (C)" using the valid argument, that any "(B) alone" scheme could be implemented with comparable effectiveness, but lower cost, by a film or, at any rate, a library of video tapes. It is an interesting observation, which speaks more strongly than figures for the dominance of rigidity or fixity effects, that without exception, this argument was taken at face value, but sidestepped; these very intelligent design subjects doggedly pursue their theme and spend great trouble in fabricating (factually, untenable) reasons for why their equipment cannot really be replaced by film and tape. This is a clearcut issue on which it is possible to present a cogent and universal counter example, but to do so does not have an influence upon behaviour.

(D) Emphasis upon elaborated mathematical approaches; for example, the far from equilibrium thermodynamics of Prigogine, in which macro level variables are retained. Once again, there is fixity. These subjects do not contemplate (do not like, find sympathetic to their tastes), the microstructure of a reaction mechanism.

(E) Emphasis, often exclusive, upon the microstructure of reactions. The simulations highlight molecular level events, variables like concentration are relegated to irrelevance and the interpretation of the design is the concrete process.

(F) Belief that the original simulation units can be assembled together (on sensible, but often factually untenable, grounds). Once set on this orientation, subjects will not budge.

(G) A catch-all category containing the radical innovations by analogy-construction or abductive methods.

The stylistic profiles of the 17 subjects (conceptual style test results) are shown in Table 2 and there is a significant positive correlation between the versatility score and innovation.

Finally, the probing question (h) was used to obtain answers in as much detail as possible, to how, if at all, subjects' design experience had changed their views about reaction kinetics. There is no point in tabulating the results, for without exception, the subjects learned, at high school, nothing significant. They learned rules and formulae, but did not have the remotest idea of what the mumbo jumbo meant. Two subjects (two, that had used the formulae in practice, in industry) had individually come to grips with their meaning. With the (possible) exception of the cases noted all the subjects finished the design task, with a full comprehension, ie. they learned by learning to think, do, and design, in the area of reaction kinetics.

Although the finding is of peripheral relevance, to the immediate study, it does indicate the futility of most ritualistic learning; it equips people to pass examinations, but that is about all it does.

Tape from this study are preserved. Currently, there are no funds available for any really serious content analysis as this would, unavoidably, be a costly business compared to a gross and impressionistic overview of the type given in this report. Surely however, a systematic, and quantitative analysis is possible, and, in view of the earlier comments on the status of the data, is likely to be worth performing.

	Main Themes						
	A Scaling	B D play	C Interaction	D Math. macro	E Chem. Micro	F Parts	G Other
1 *	1	0	1	1	0	0	0
2	0	0	1	1	0	0	0
3	0	1	0		0	0	0
4	0	1	0	0	1	0	1
5 *	1	1	0	0	1	0	
6 *	1	0	1	0	1	1	0
7	0	0	0	1	0	1	0
8 *	1	1	0	1	0	1	0
9	1	1	0	0	0	0	1
10	0	0	1	1	0	1	0
11 *	1	0	1	0	1	1	0
12	0	0	0	1	0	1	1
13	0		1	1	0	0	0
14	1	0	1	0	1	0	0
15	1	0	0	1	0	1	0
16 *	0	0	1	0	0	1	0
17	1	0	1	0	1	0	1

Table 1. Distribution of main themes amongst subjects participating and considered to have adequately complete records. Any subject may contemplate several themes at once, or on different occasions. In all, 17 subject records proved complete enough to suffice. Subjects from the first study are marked by *

Original number (experts unmarked students marked by -)	Subject number (current series)	Conceptual Style Test Scores			
		N	O	C	V
6*	1	81	72	76	52
-	2	70	64	40	56
-	3	65	60	32	46
-	4	66	65	54	38
3	5	75	74	49	47
4	6	58	63	62	25
-	7	34	63	52	34
7	8	76	64	54	28
-	9	70	73	47	20
-	10	75	50	36	18
8	11	70	46	59	45
-	12	60	79	85	88
-	13	60	61	44	32
-	14	56	75	20	16
-	15	47	56	59	56
1*	16	72	57	67	47
-	17	32	34	78	49
Means		62.8	62.4	53.8	41
SDs		13.7	11.4	16.5	17.3

Table 2: Scores on test for conceptual style. Subjects from previous study are indicated at the left together with number and type given in Final Scientific Report on F44620-76 C-0003

3. Programming Task

The details of the task are outlined, comprehensively, in Annexe 1 and Annexe 2, (the design brief and the programming manual for the version of BASIC run on the LSI computer, together with the machine language routines required to operate the A/D and D/A convertors). Subjects could orient themselves more or less towards the computer, as such (for example, by obtaining program printout, numerical values of computed variables by trial execution), or towards the display and control console (Fig 1), which, apart from the "run" or "start" button, (here, initiated on the computer), is isomorphic to the original (hardware design study) simulator display (Fig 2).

All 22 subjects who started the task knew the outlines of BASIC, and all received the Spy Ring History Test for conceptual style. Partial results are available from most of these subjects but only 8 completed the task, over a period of between 5 weeks and a couple of months. Some of the "drop out" subjects were unable to visit the laboratory and lost interest, but three "drop outs", at least, can be ascribed to lack of reasonably convenient appointments when the equipment was available for use.

Because of these circumstances, the numerical results have less value than they might. There is a 1% level significant positive correlation between "rule inference" (the U score component of the operation learning score in the stylistic test), and an estimate of programming facility. There appears to be a strong relation between conceptual style and the type of programming used, in particular, the extent to which, in tackling the task, the subject did or did not translate the program operation into display and control variables. The Comprehension Learning Scores and Versatility Scores are both higher, for subjects who were display and control oriented, though the increment is greater on Comprehension Learning. The results are significant for the "Near Completing", subjects, at the 1% level. The same difference is characteristic of the "Completing" subjects but significance, in this case, is untestable.

In terms of (qualitative) observation, and scrutiny of the records, there are two dominant approaches to the design task. These interact with two kinds of programming, namely, "making the display and control system work", and "making an elegant, as well as brief program".

The approaches to the task are comparable to the results obtained in the design study, but it appears that the requirement for the computation converts the task, so far as several (at least 5) subjects are concerned, into a piece of mathematics. These subjects spent several weeks to select (in fact) arbitrary incrementation values, after which, they tried to interpret the operation of their program.

The mathematically oriented, or abstract, approach also characterised some (I suspect, a smaller proportion) of the hardware simulator designers. There is, however, one important difference. The programming subjects in this category did, without exception, find the design brief unsatisfactory.

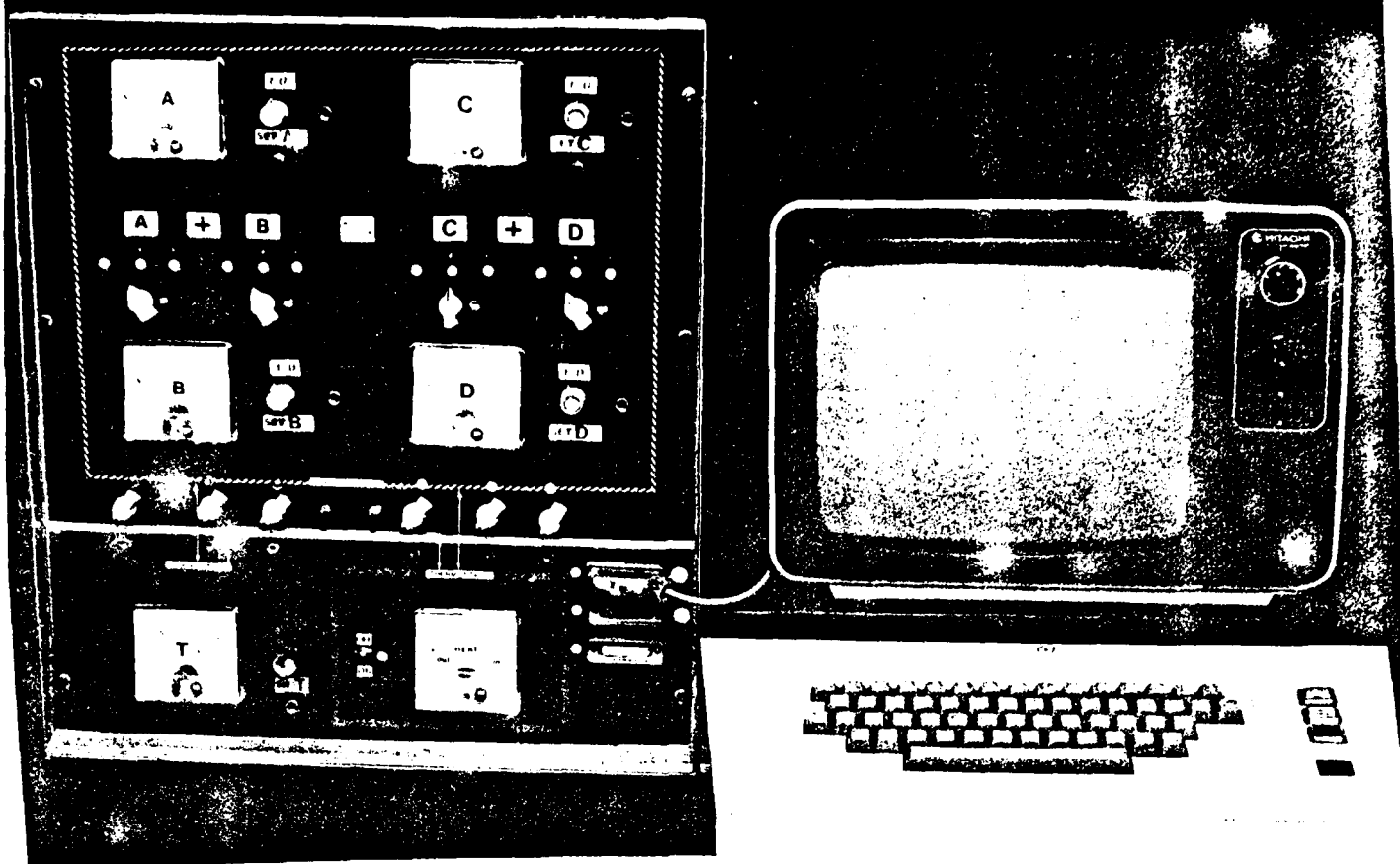


Fig 1: Display and control console

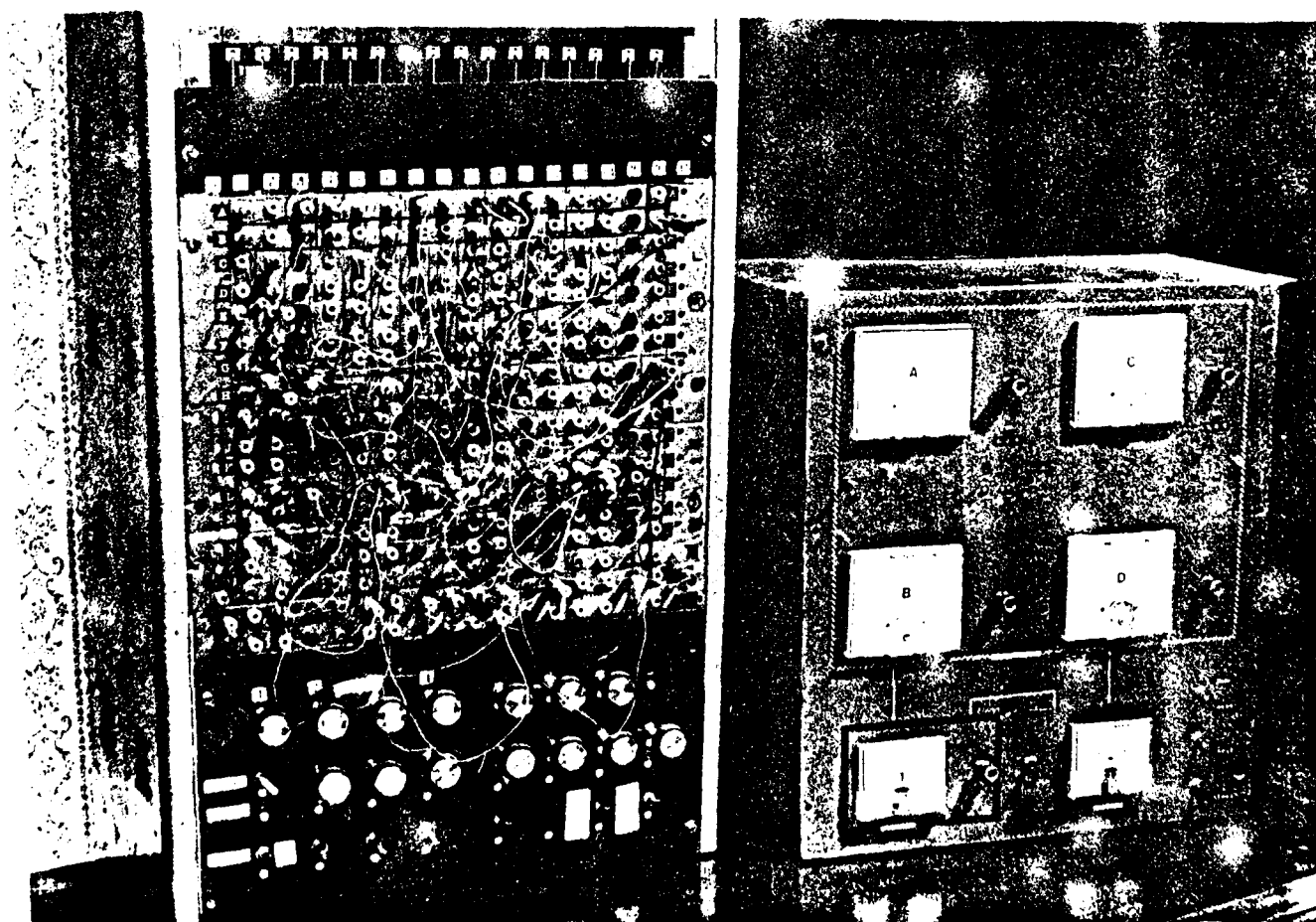


Fig 2: Original simulator display

The hardware designers did not criticise the design brief, and there is no reason to believe them at all unhappy with it. Possibly, the difference is due to programmers' expectations. For experienced programmers are accustomed to receive a much more process determining specification from a system analyst, and these subjects, at any rate, seemed to resent, or find alien, the requirement of thinking about a real, rather than an artificial, process.

Other subjects (certainly six of them, if near-to-completion subjects are counted) took the interpretation, in terms of reaction kinetics, as primary. In contrast to the others, they realised that incremental changes in heat are arbitrary provided that changes occur in the proper direction and the overall equation is satisfied. As a result, these subjects soon wrote programs to perform the (almost trivial) computations and devoted a good deal of effort to scaling. (Scaling also preoccupies some of the hardware designers).

Most of the program solutions to the design problem are disappointingly pedestrian, if compared with the solutions proposed by hardware designers, and the subjects seemed loath to exploit the innovative potential of a computer. For example, only one subject produced a successful stochastic program which is quite easy (further, quite appropriate) as the basis for a simulation and only one other subject tried to do so (but gave up the attempt and offered a trivial program in its place). No subjects tried another fairly obvious trick, namely, to simulate an ensemble of systems and to couple them together by a linking routine.

A pair of competent, but uninventive, program listings are shown in Fig 3 and in Fig 4.

Subject	Trial runs	Debugging Sessions	Radical Modifications	Stylistic Test			
				N	O	C	V
1	18	11	4	60	65	47	54
2	8	4	0	70	43	68	76
3	20	12	2	46	55	24	78
4	24	18	6	75	54	32	56
5	7	7	1	57	58	50	79
6	6	6	1	64	60	53	40
7	19	16	3	49	22	69	80
8	22	18	2	47	58	30	54
9 *	17	15	5	66	42	75	67
10 *	11	11	3	77	45	46	74
11 *	9	8	0	66	60	35	29
12 *	18	18	2	30	25	65	70
Means				58.9	48.9	49.5	63.1
SDs				13.2	13.3	16.3	15.9

Table 3: Overall Pattern of activity and test scores. Subjects marked * did not complete to their own satisfaction.

To find values of change in concentrations I didn't integrate. Instead, I used the approx $\delta A_t = a^* / A^a / B^b / C^c \delta t$ and, $\delta A_t = a^* / C^c / D^d \delta t$ (the same δt in both cases)

$$\text{then } \Delta A = -\delta A_t + \delta A_t$$

in δt
at $t + \delta t$

To calculate energetic changes I have used the following notions

$$\delta A/a \text{ no. of elementary reactions}$$

$$(\delta A/a) (Q_F - Q_R) \text{ Total heat generated in } \delta t$$

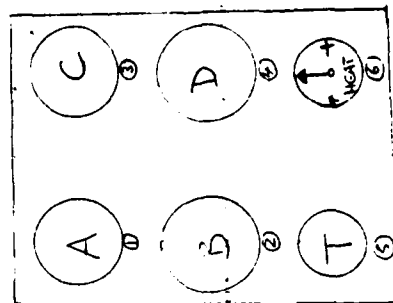
$$\delta T = [(\delta A/a) (Q_F - Q_R) / m_1 + m_2 + m_3 + m_4]$$

Temp. increase/decrease when this heat is dissipated. Throughout the mass of reactants and products.

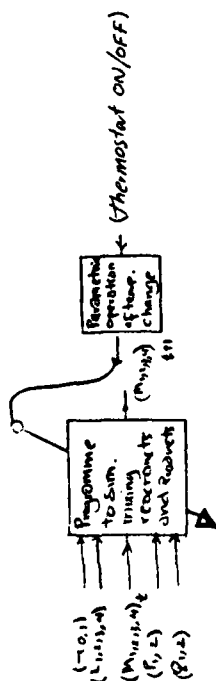
One of the strangest possibilities I have come to realise is that a reaction might be pre-ordained to be "Two-way" and yet be "one-way". When simulated through by virtue of one of the reactants drying up. So what are our criteria for one-wayness/two-wayness? (postulate) mechanism or end results? In any case one of the reactants drying up.)

Another interesting finding is that this whole program of simulating reaction kinetics is a digital fraud for it is in principal impossible to do a perfect simulation.

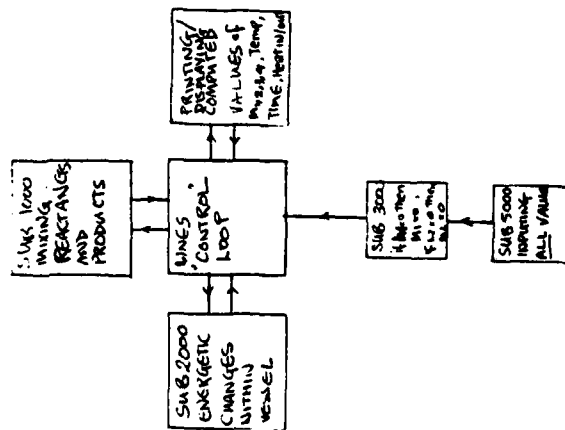
CALL(6,M1,1)
ASSIGNS VALUE M1 TO
METER 1.



Meters lay out



* Concise Scheme *



* Actual Scheme in Prog. Form *

Fig 4: Subject who is display and response, or process oriented (cont over)

SIMPOYNS

```

3 IF RS="0" THEN 6
4 PRINT "TWO WAY REACTION"
5 GOTO 11
6 PRINT "ONE WAY REACTION"
7 LET H0=255*0.5
22 LET J0=0.001
40 GOSUB 5000
50 GOSUB 3000
55 PRINT "SET INITIAL TEMP"
56 INPUT T0
57 LET T1=T0
60 PRINT "M1=",M1,"T0=",T0,"TIME=",0
102 FOR I=1 TO 10000
105 LET C=M1+M2
110 GOSUB 1000
120 GOSUB 100
130 IF (M1<0)*(M2<0) THEN 240
190 PRINT "END OF ONE WAY REACTION?"
200 STOP
240 REM PRINTING CURRENT VALUES OF CONCENTRATIONS, TIME
241 REM , REACTION RATE, EQUILLIBRIUM CONSTANT
244 PRINT "M1=",M1,"TEMP=",T1,"TIME=",I
245 PRINT "M2=",M2
246 PRINT "M3=",M3
247 PRINT "M4=",M4
248 PRINT "OBSERVED KEQ",M1*M2/(M3*M4)
249 PRINT "EXPECTED KEQ",K1/K2
250 PRINT "EXPECTED REACTION RATE",ABS(S-Z)
251 PRINT "-----"
252 CALL(6,M1,1)
253 CALL(6,M2,2)
254 CALL(6,M3,3)
255 CALL(6,M4,4)
256 CALL(6,T1,5)
257 CALL(6,H0,6)
258 NEXT I
259 PRINT "END OF ITERATION"
260 STOP
599 REM INITIALIZING ALL METERS
1000 LET S=K1*(M1*L1)*(M2*L2)*J0
1001 IF (M1<255)*(M2<255) THEN 1020
1002 PRINT "CONCENTS A,B TOO LARGE"
1003 STOP
1020 LET D1=L1*S
1021 LET D2=L2*S
1040 LET M1=M1-D1
1060 LET M2=M2-D2
1070 LET D3=L3*S
1080 LET M3=M3+D3
1090 LET D4=L4*S
1100 LET M4=M4+D4
1105 IF RS="0" THEN 1220
1110 LET Z=L3*L3*(M4*L4)+J0
1115 IF (M3<255)*(M4<255) THEN 1120
1116 PRINT "CONCENTRATION OF C,D TOO LARGE"
1120 LET E4=L4*Z
1122 LET E3=L3*Z
1130 LET M4=M4-E4
1150 LET M3=M3-E3
1160 LET E2=L2*Z
1170 LET M2=M2+E2
1180 LET E1=L1*Z
1190 LET M1=M1+E1
1220 RETURN
2000 IF RS="0" THEN 2050
2010 IF RS="0" THEN 2030
2020 LET Q2=0
2025 IF (C-(M1+M2))>1 THEN 2030
2027 PRINT "STABILITY ERROR"
2028 STOP
2029 LET H0=H0+S*(Q1-Q2)
2030 LET G0=S*(Q1-Q2)/(M1+M2+M3+M4)
2040 LET T1=T1+G0
2050 LET K2=P2*EXP(-Q2/(8.314*T1))
2060 LET K1=P1*EXP(-Q1/(8.314*T1))
2065 REM ASSIGNING VALUE OF HEAT IN/OUT TO METER NO.6
2066 CALL(6,H0,6)
2070 RETURN
3000 IF L1<>0 THEN 3002
3001 LET M1=0
3002 IF L2<>0 THEN 3004
3003 LET M2=0
3004 IF L3<>0 THEN 3006
3005 LET M3=0
3006 IF L4<>0 THEN 3008
3007 LET M4=0
3008 RETURN
5000 PRINT "P1,P2"
5001 INPUT P1,P2
5002 PRINT "Q1,Q2,T2"
5003 INPUT Q1,Q2,T2
5004 PRINT "L1,L2,L3,L4"
5005 INPUT L1,L2,L3,L4
5006 PRINT "M1,M2,M3,M4"
5007 INPUT M1,M2,M3,M4
5008 GOSUB 6000
5009 RETURN
6000 FOR I=1 TO 5
6005 CALL(6,0,1)
6010 CALL(6,0,2)

```

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FROM COPY FURNISHED TO BDC

Control Loop

displaying
concentrations,
current Temp.,
heat in/out.

mixing sub.

energetic changes
sub.

input sub.
initialization
typed in.

4. Design of an Intruder Alarm System

Can a good designer produce more essentially different designs than a bad or mediocre designer? It is reasonable to imagine that he might do so, given a reference task admitting (as most tasks and non trivial problems do), a diversity of possible solutions. The conjecture was voiced at Wright Field, and had some support from experiments carried out in an adjacent campus of the State University of Ohio. An ability to produce different but workable designs might even be used as a sensible criterion of whether a design is "good" or "bad".

Design of an intruder alarm system was chosen, after some preliminary experimentation, as a task which permits a great deal of variation; a problem with virtually unlimited solutions. The task also has the advantage of providing an interesting job, which can be done by any intelligent person without much dependence upon prior knowledge (for example, of electronics or computer programming). The sensors, detectors, etc., used to protect a premises are commonly put together by security firm "engineers", whose primary expertise is not so much "engineering" (in the usual sense) as an appreciation of architecture, the requirements of a client, the habits of vandals, criminals, or other intruders, and the hazards likely to be encountered. The particular devices that may be connected together to form an alarm system are, for the most part, compatible and they need only be known as "Black Boxes" which perform a given function.

There is no need to know how these devices work provided some critical characteristics are given (for example, false alarm rate, reliability, and sensitivity to irrelevant changes in the environment). Such data is readily assimilated or referenced in a manual, and the ingenuity of the designer is (at any rate under the experimental conditions employed) dependent upon how a system is put together and whether or not it fits the requirements and cost limitations of a client, given, as a prerequisite, that the system satisfies a functional design brief.

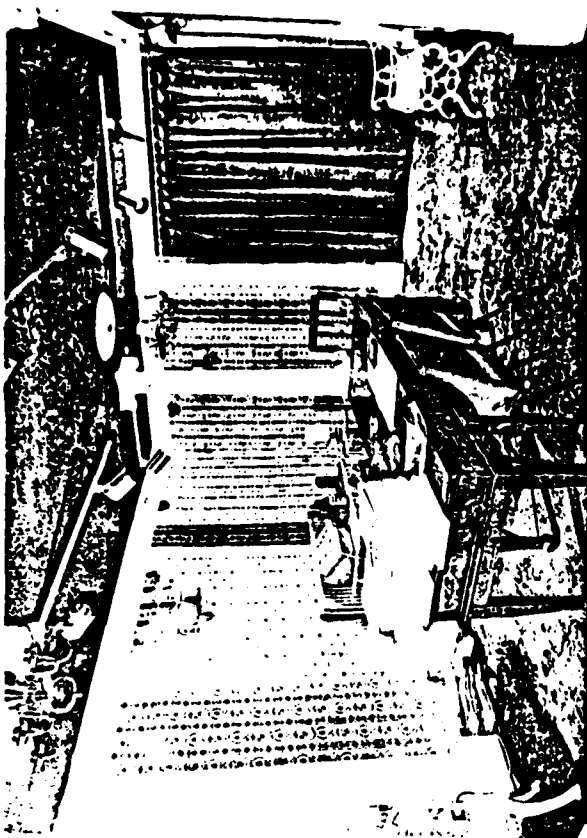
A manual containing terse descriptions and characteristics of the 23 devices in Table A (detectors, such as magnet and reed-relay sensor, capacity sensors, infra-red-beam sensors, together with alarm devices such as phone activating equipment, external bells) are placed at the disposal of all subjects. The same 23 devices were used in each experiment, none of them being inapplicable, (ie. no deliberately misleading or necessarily irrelevant "devices" were included).

Two experiments were carried out. In each case, all the subjects were pretested to obtain a score profile on the stylistic test, the mean scores being operation learning (rule application or serial recall, with a subscore for rule application only), comprehension learning (global recall and reconstruction), versatility (ability to predict beyond the information provided), and a neutral score (overall fact retention, achieved by any means).

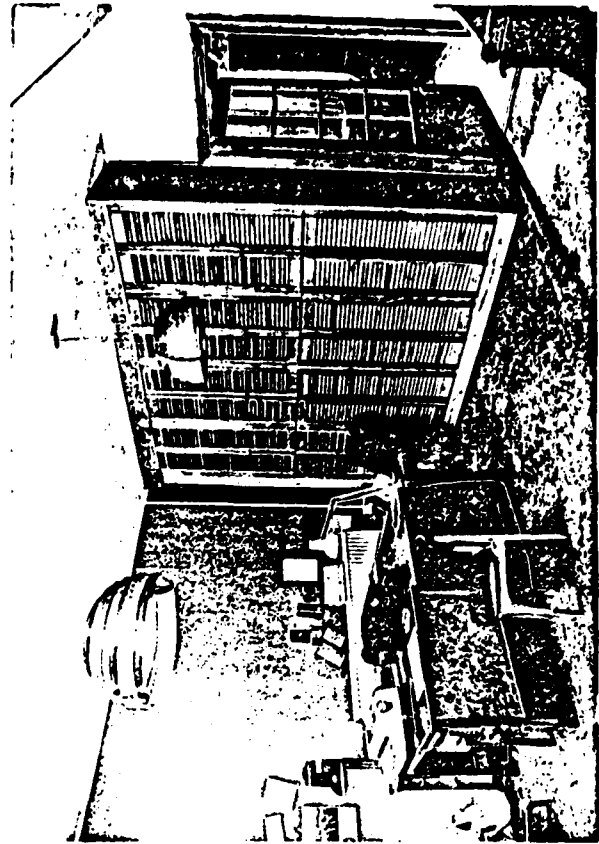
In the first of the two experiments twenty six subjects, (given the design brief) examined one premises at Sheen Road) in Session 1, occupying (about) 2½ hours. In Session 2, some days later, the subjects construct intruder alarm designs to a high cost and

Miniature radio modulator	Inertia switches
Smoke Sensor	Vibration contacts
Radio frequency responder (power input and transmitter and band sampling receiver)	Magnetic switches
Protected audio tape recorder (voice key or signal to start)	Mortise deadlocks
Protected video tape recorder (signal to start)	Indoor microwave intrusion sensors
Alarm bell	Capacity sensors
Magnetic sensors	Control Box (may contain <u>and</u> , <u>not</u> , <u>or</u> , <u>delay</u> , <u>count</u> devices as required and is one setting unit with key and lamp indicat- ing activation of system)
Pass Key switch	Microswitch contacts, for doors and windows
Pressure mats	Infra red directional sensor
Vibration contacts	Directional microphone, tuned to ultrasonic region or not
Window Foil	Directional infra red source
Passive infra red detectors	Image convertor and lens equipment
Breaking glass detector	
Solid state 999 dialler	
Untrasonic intruder detector	
Surveillance TV cameras	
Outdoor microwave intrusion sensor	
Untrasonic directional beam module	
Actuation buzzer	

Table A: List of devices available to subjects in the context of the intruder alarm task. Subjects are told that they can request (as a manufactured product) any other device they know of or any device that is physically realisable for production at a cost within the limits set by these devices (for example, a solid state special number dialling equipment has been requested).

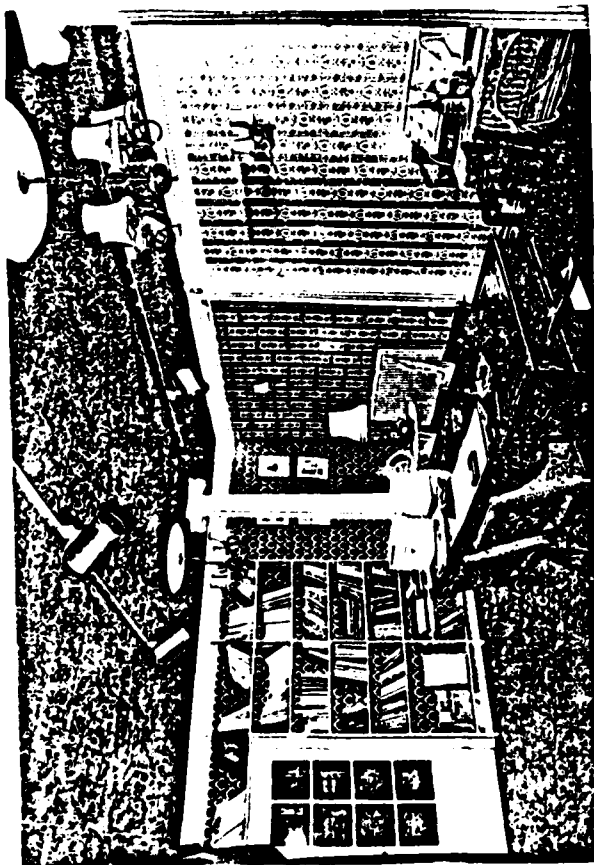


Board and meeting room

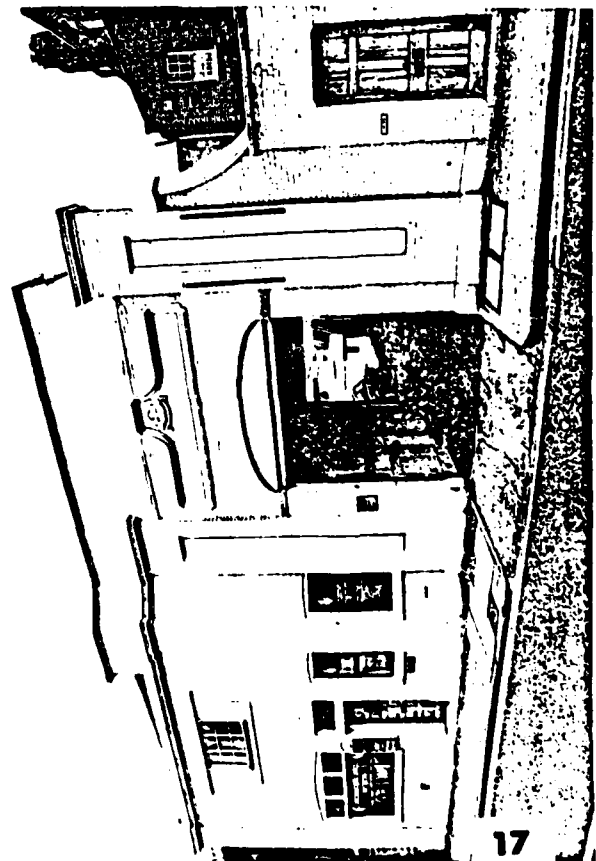


General Office

9



Board and meeting room



Offices and courtyard from outside

17

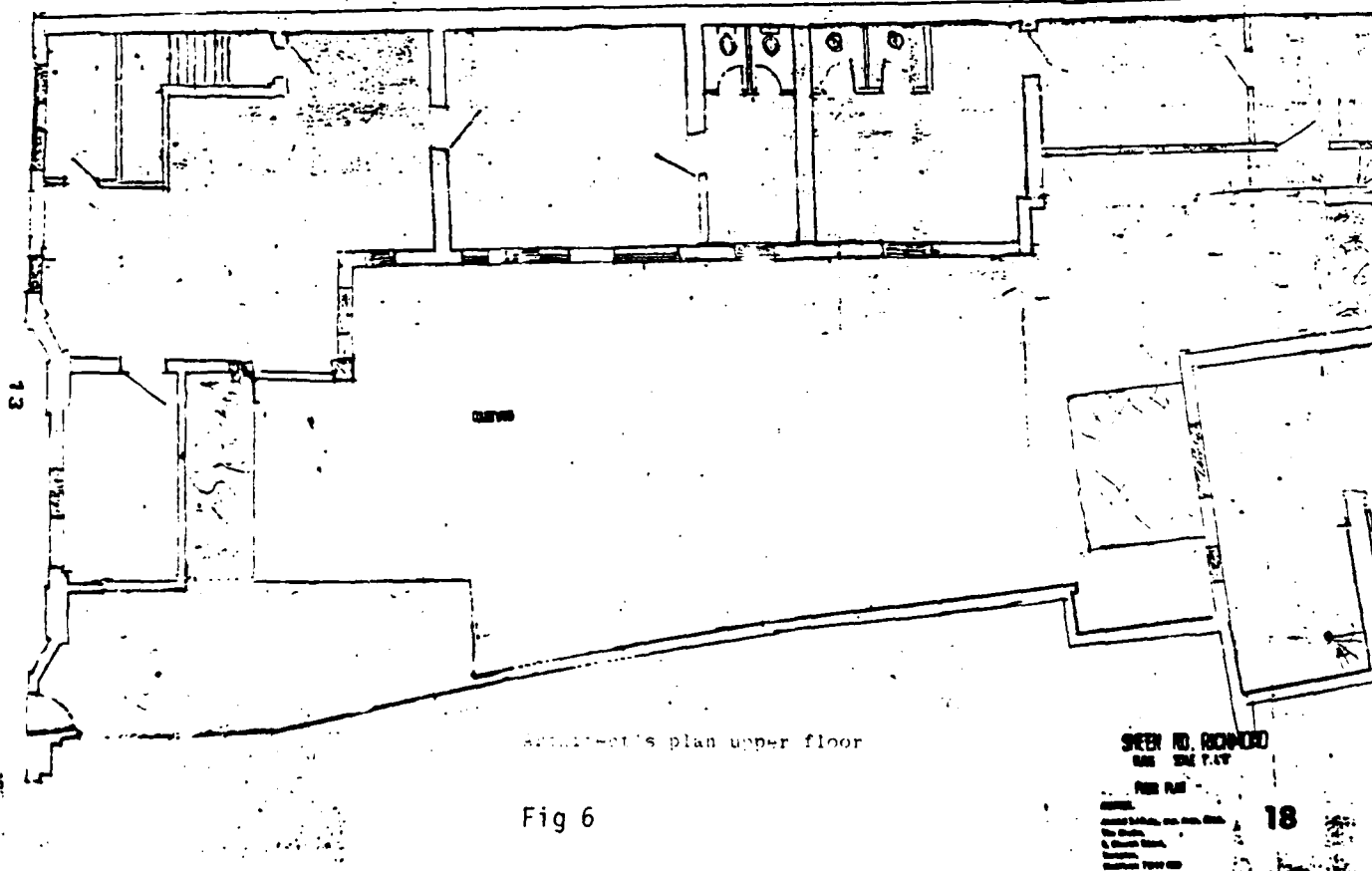
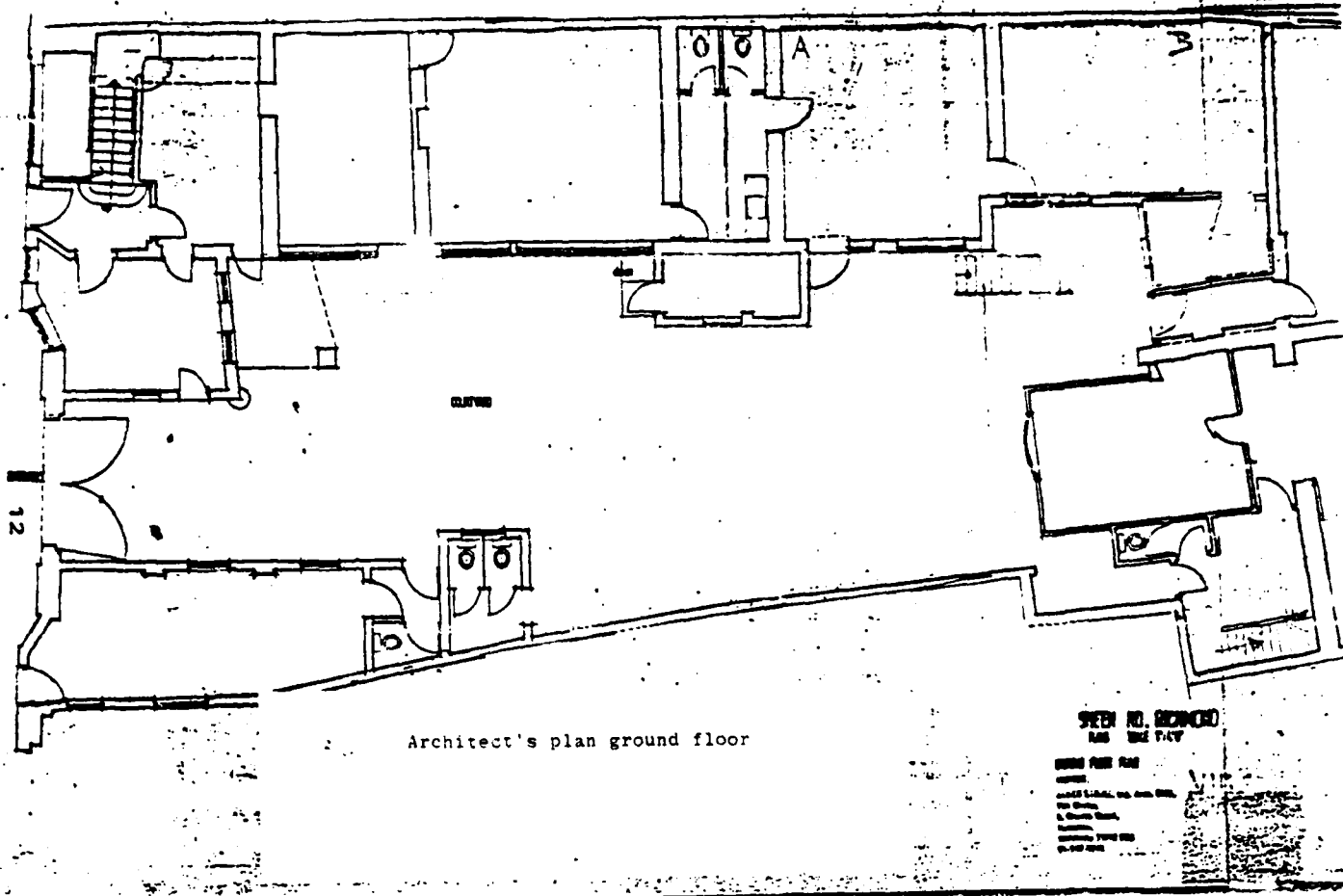


Fig 6

a low cost criterion, as specified in the brief. At the end of Session 1, they receive photographs (greatly reduced in Fig 5), to act as a recall cue from their experience in concrete reality, of the premises; together with layout plans, on which their design is charted (Fig 6, again greatly reduced in size). At the end of Session 2 these products are collected. The next Session, 3, is devoted to examination of a geographically distinct premises but essentially the same design requirements, the cost limits being scaled to minimise the difference (it was not practicable to balance the subtasks engendered by different premises by reversing this presentation order but, if anything, the premises viewed in Session 3 is more difficult to protect, adequately). At the end of the session, layout plans are distributed and completed for delivery in Section 4, which includes a recall test and questionnaire.

The main variables, in the first experiment, are an index of design quality, obtained by rating the properties of Table B, an index of design similarity based upon objectively determined use of similar /different devices for similar /different purposes in the configuration: The score profiles for conceptual style and the designs as such. The rationale behind the similarity measure is that although subjects in Experiment 1 (from a training college) can hardly be expected to continue thinking about a design over (say) several weeks, we can elicit 2 cost different design for 2 different premises and discover the amount of variation between them. There is certainly a strong tendency to stereotype, even though there are different situations and costs; as a result, an index of similarity should be high-valued (a repetition of methods) and we can be reasonably confident that variations shown up by a low-valued similarity index reflect a real tendency to diversity in design. Recalling that all designs submitted must (and are prompted to) satisfy the minimal brief, it is evident that such a tendency is not due to haphazard products.

Of the 26 subjects 23 completed all the sessions but only 18 of these are included in the sample because it later turned out that transgressions of the minimal brief had remained undetected in the case of 5 subjects.

The other study, Experiment 2, employed the same briefing materials and device list but only one premises (Sheen Road), was involved. However, in Experiment 2 the 11 subjects were graduate students and had an opportunity to design at leisure and literally to produce as many alternative designs as they could. They were encouraged in this pursuit by presenting, as part of their Seminar series, the solutions, (if reasonable) offered by other students in the class. Here, in other words, it was possible to examine the number of sensibly different designs provided at leisure, directly.

The results of these experiments are interesting, and often contrary to expectation.

Experiment 1: The original hypotheses can be concisely stated. It was predicted that good designers as judged by design quality, are also versatile. As a further hypothesis, that "good" (perhaps versatile) or versatile (perhaps "good") designers would have more varied designs.

Both of these plausible-by-previous work conjectures are unsupported, if not denied, by the data.

The quality of designs, taken as a summation over the desirable properties in Table 8, has no statistically significant connection to any of the stylistic test scores, except fact retention where there is a marginally significant correlation (nor, as a matter of peripheral interest to scores on either the "embedded figures" test or the quite different "AH5 test"). Nevertheless, there is a positive correlation, significant at or above the 5% level, between one judge's scoring, from low cost to low cost design, and from high cost to high cost design, (over the 4 designs) and between the judges. Hence, there are no grounds for supposing that the value scoring of designs fails to do what it was intended to do.

Again, contrary to expectation, there is a strong positive correlation between versatility score and design similarity, which is the reverse of the predicted outcome. On the other hand, there is a strong positive correlation between the overall number of devices (those listed in Table A), and the versatility score of a subject. Similarly, there is a strong positive correlation between design similarity and the comprehension learning score, on the stylistic test.

Dr Robinson and I were surprised by these results, particularly since Robinson's observation of the subjects' behaviours appeared to be in line with the original and quite different hypotheses. Further, in the context of other tasks, involving planning and design, the versatility score is an accurate and reliable (though far from complete), indicator of general inferential ability. Its inadequacies are known; for example, it does not discriminate between abduction/valid-analogy construction and other kinds of inductive/deductive reasoning. It is surely desirable to make finer discriminations of this kind, but, it is also true that intruder alarm design could and probably does depend upon any or all of these different inferential skills.

Scrutiny of the records and behaviour in greater detail supports the following hypotheses (which are not the simple ones posited at the outset but are much more complex postulates compatible with the original view).

Versatile subjects formulate and test their solution methods to the design problem (use a consistent design philosophy), when designing intruder alarm systems and this is best done, during a limited interval, at any rate, by using a large number of devices to perform similar functions. The devices employed are changed from design to design but there is a coherent plan (usually, only one) which is employed in each design and which accounts for the similarity of designs, even though many different devices are used or tried out. It is the common principle or type of solution to the design problem. (not the type of device employed) which accounts for the fixity manifest in the behaviours and similarity indices of these subjects. Within this group of subjects, those with a high comprehension learning score as well as high versatility, try or use most devices (Table 4). Those with high operation learning score and high versatility produce more similar designs. (Table 4).

Vandalism /Petty theft :	intruder captured
Vandalism/Petty theft :	intruder detected (and assumed to be halted as a result of alarm signal)
Major theft:	intruder apprehended by system and intrusion halted
Espionage:	intruder apprehended by system
Espionage:	intruder detected by system and intrusion halted
False alarm probability calculated from "and" or else "or" connection of devices with known false alarm signal frequency	
Ease of access and priming	system (from outside, given that it is turned on)
Reliability or elegance (redundancy permitted but irrelevancy is discounted)	
Cost margin approximation to cost level).	

Table B : The criteria employed in evaluating
designs

Minor correlations, showing consistency of scoring scheme, are:

Marks for designs on same premises

D1/D2 $r_s = .429$ sig. at .05

D3/D4 $r_s = .560$ sig at .05

D (Max)/D (Min) $r_s = .539$ sig. at .05

Design quality vs.

LS Component	r_s	Sig. level
O	0.22	NS
V	0.1	NS
C	0.32	NS
N	0.35	NS

Design Similarity vs

LS Component	r_s	Sig. level
O	.704	.01
V	.562	.05
C	.407	n.s.
N	.213	n.s.

No. of Devices Used vs

LS Component	r_s	Sig. Level
C	.621	.01
V	.610	.05
N	.491	.05
O	.421	n.s.

O = Operation Learning, C = Comprehension Learning, N = Neutral Retention, V = Versatility score, LS = Learning Style.

(Thus versatile operation learners produce similar designs; versatile comprehension learners use more devices).

In contrast, another group of subjects is characterised by apparently unplanned problem solving and do not seem to have an appreciation of the issues involved in protecting a premises. Subjects in this group have low versatility scores, and come up with context specific designs, which differ a great deal from subtask to subtask. There is a tendency, which is most prominent amongst subjects with low comprehension learning scores, to employ the same devices throughout; for example, reed-relays and magnets, even in the high cost-limit design, or UHF devices in the low cost schemes, whatever, in fact, they have focussed attention upon, and become familiar with at the outset. The designs hang together (insofar as they are at all similar), chiefly because there are devices common to each one.

To check these hypotheses a Q Analysis (Atkin 1977a, 1977b) has been carried out to determine how, for each subject, devices are related by designers and designs are related by devices (ie. a structural Q analysis on the relation induced by designers upon the Cartesian Product Device X Design, and the conjugate relation on Designs X Devices).

Typical data are shown in Table 5, where, for reference in the computer program which performs the Q analysis, 4 devices common to each design have been omitted and the designs are coded as N10, N20, N30, N40. The statistical data is summarised in Table 6.

According to the revised hypothesis the value of the dimension of a design simplex in the simplicial complex of the relation induced on devices when a subject makes any design should correlate positively, at least with the versatility score and the comprehension learning score, (the dimension number "Top q" may either depend upon global appreciation or effective innovation or both). This should also be true of the mean value of "Top q" as shown in Table 6. This hypothesis is generally supported, although the correlations are not significant for versatility score over the designs at Sheen Road or for comprehension learning score for the Sheen Road high cost design.

Similarly, Eccentricity (which is Atkin's index of topological irregularity) should, for each design, correlate negatively with the operation learning score (a rule application skill) and to a lesser extent, under the revised hypothesis, with comprehension learning score and the versatility score. Again, this is generally true (Table 5) but the high cost design at Sheen Road and the other low cost design, are exceptional. However, the mean eccentricity does behave as predicted.

There is no obvious reason why these design subtasks are exceptional. From inspection of the data it looks as though there is a beginning and ending type of Hawthorne Effect, which may be responsible for the peculiarities.

5 An Investigation of Individual Design

Several outstanding questions remain to be answered.

Subject	Ecc 10	Dim 10	Dim 20	Ecc 20	Dim 30	Dim 40	Ecc 30	ΣQ_{max}	Ecc 40	Q_{max}
1	0.25	4	7	0.33	6	6	0.4	28	0.17	1.33
2	0.25	9	6	0	8	7	0.29	30	0	0.43
3	0.5	5	4	0.25	6	2	0.75	17	0	1.33
4	0.4	8	3	0.33	4	6	0	19	0.4	1.33
5	0.67	4	3	0.33	3	2	0.33	12	0.5	1.50
6	0.5	8	4		4	5	0.25	21	0	1.25
7	0.75	6	5	0.5	4	3	0.25	18	1	2.5
8	1.0	5	4	0.67	3	4	0	16	0.25	1.00
9	0.25	4	4	0	5	6	0.2	19	0.4	0.75
10	1	7	3	0	3	3	0.33	16	0	1.66
11	0.2	5	4	0.67	4	5	0	18	0.2	1.00
12	0.2	5	3	0.33	4	5	0	19	0.2	1.00
13	0.5	5	3	0	3	3	0	14	0.33	1.00
14	0	4	5	0.2	4	3	0.25	16	3	5.00
15	0.25	4	3	0	3	4	0	14	0.25	0.25

Table 5

(a)

	Ecc 10	Ecc 20	Ecc 30	Ecc 40	Mean Ecc
N	0.155	0.203	-0.132	-0.388	-0.269
O	-0.403	-0.128	-0.146	-0.569	-0.585
C	-0.146	0.107	0.064	-0.49	-0.129
V	-0.419	0.218	0.069	-0.395	-0.446

(b)

	N	O	C	V
Means	56.47	51.53	69.40	39.47
SDs	24.54	14.75	16.14	21.14

(c)

	Dim 10	Dim 20	Dim 30	Dim 40	Q	Over Ec	Qmax
N	0.382	-0.095	0.156	0.273	0.287	-0.269	0.196
O	0.043	-0.030	0.346	0.375	0.353	-0.585	0.132
C	0.558	0.177	0.504	0.386	0.475	-0.129	0.462
V	0.106	0.171	0.627	0.507	0.518	-0.441	0.159

(d)

	N	O	C	V	Dim 10	Dim 20	Dim 30	Dim 40	Q	Ecc	Q max
Means	56.467	51.533	69.4	39.47	5.53	4.07	4.27	4.27	18.13	1.42	5.87
SDs	24.54	14.75	16.14	21.17	1.68	1.73	1.44	1.62	4.32	1.17	1.47

Table 6: (a) Rank correlations between scores on Test and the "eccentricity" values as well as the mean eccentricity.
 (b) Means and standard deviations for test scores
 (c) Rank correlation of divisions "Top Q"
 (d) Means and standard deviations.

First of all, since there is every indication that the weighted mean quality index is consistent, why does it not correlate with conceptual style, or an informed, but intuitive, judgement of excellence in design behaviour.

Next, do designers rated either "good" or "versatile" (and, if "good", then by what criterion) make more significantly different designs or not, since the modification in the hypotheses proposed for experiment 1 (just described) precludes any direct determination of whether or not subjects with a high versatility score do produce more designs.

Experiment 2: Eleven subjects (a graduate class at Chelsea College and a few unregistered students), were presented with the design brief and the Sheen Road specifications. At some stage, early in the series, each subject inspected the Sheen Road premises, in fact. All subjects were provided with 25 copies of the layout charts and asked to produce as many, non trivially different, designs as possible, for both of the cost limits, to record under what circumstances and when they did so and roughly how long it took to complete a satisfactory design.

All subjects had fairly high versatility scores but quite varied operation learning scores and comprehension learning scores on the test for conceptual style which had been administered (as a routine part of the seminar series) before the design task was introduced. Sensible designs were compared and contrasted at the seminars and criticised by the students and myself in terms of whether or not it was possible to break in and whether or not they were worth purchasing as real systems.

From the debate it soon became evident that given that the design satisfies a brief the weighted mean of design quality is neither a very sensitive or an appropriate criterion to employ; a comment that applies to any index of the weighted mean type. A design that satisfies a brief is judged according to varied criteria all of which may belong to the original set and that are, in context, of equal legitimacy. Under a cost constraint, generally, under the acceptance of the principle that an absolutely fool-proof system is impossible, all the desirable property values cannot be maximised and the subset employed depends upon the design presented, as well as the purchaser's view of the hazards (vandalism, theft, and confidentiality loss, for example). Any "good" design ("good" that is, by judgement), will have a fairly high quality value, but this value cannot be significantly incremented provided that only some of the properties are highlighted in its theme. Notably, judging by 32 designs rated excellent, and 25 rated more-than-brief-satisfying, there is no significant difference in the quality assigned to the excellent designs and the acceptable designs.

Above a certain standard, which is approached but not reached, by satisfying the requirements of a brief, designs are judged, in practice, by agreement between designer/user, or user/other user, and not by consensus. In this respect, the quality index is quite insensitive.

Further, it looks as though some designers can find an unlimited number of solutions to the high cost design problem (the low cost problem is much more restrictive). There are seldom more than two low cost designs and two are required). This probably reflects only concentration upon the more interesting and innovative task, so, as such, a result to be anticipated. There are many ways of making a really elegant or really creative design unless the device costs are modified and this study did not (at any rate explicitly) focus upon novel devices although a few were suggested.

It was possible, in seminar discussion, to refer back to specific designs and roughly categorise the types of thinking employed to devise them .

As might be expected, given the commentary upon leisurely simulation design in Section 2, the dominant mode of innovation involves a juxtaposition of perspectives . By far the most common juxtaposition is a perspective of an intruder and either the owner or designer (ie. breaking ~~into~~ ^{into} your own or some other person's system is an obvious expedient used by all subjects).

Another clearcut juxtaposition is the perspective of a staff member and either the police or the owner (relevant to how easy it is to price the system). These categories of juxtaposed perspectives are counted as "Juxt" in Table 7 which shows , also, the scores for each subject on the test for conceptual style. The category "Compare design" may also include the juxtaposition of perspectives which, if anything , strengthens the case in favour of juxtaposition of perspectives and design by abductive reasoning. "Hunch" is less determined; thinking described as "out of the blue" or "insight taking place suddenly when thinking of a different topic" The category "Perseveration" amounts to logical thinking, to working out the consequences, or possible consequences, of an idea.

In all, 102 designs were produced. The number of designs produced by any one subject varies greatly but one subject in the group provided 20 designs and several subjects provided more than 10 of them.

A cognitive fixity effect, also noted, in the context of simulator design, in Section 2, is most readily exhibited by examining the number of devices that are used and the temporal progress of thinking (deemed, by the subjects, relevant thinking) . An attempt is made to show this in Table 8 which indicates also the temporal distribution of submitted designs. There are quite large individual differences between the subjects but the most obtrusive feature of Table 8 is a marked clustering of designs into periods of fruitful creativity interspersed by periods of inactivity. This clustering may to some extent , be an artifact of the seminars, but that is certainly not the whole story and the subjects generally agreed to intermittency upon one or a few design principles.

Subject	N	O	C	V	Juxt.	Huch.	Compare design	Per	Number Designs
1	35	60	34	55	1	6	1	1	8
2	27	40	80	79	12	1	4	2	18
3	52	53	77	56	15	5	0	7	20
4	60	18	84	78	10	8	0	0	16
5	26	22	90	27	0	4	4	0	4
6	51	31	83	35	11	5	1	1	17
7	37	69	15	74	10	7	5	2	15
8	61	75	18	85	6	1	1	1	9
9	19	40	88	91	16	0	1	5	10
10	30	78	30	67	10	9	8	1	18
11	54	82	64	59	5	0	1	0	6
Mean	41.1	51.6	60.3	64.2	96	45	26	20	102
SD	14.2	21.8	28.4	19.3					
Total	452	568	663	706	column sums				

Table 7: Conceptual style test scores and categories of thinking reported by subjects (and referred to a particular design as an illustration which is discussed). The various categories are not exclusive (that is, several kinds of thinking may be used in one design) but some of the subjects are inclined to regard them as though they were exclusive.

Estimate of relevant thinking interval	Subject	Seminar Sessions							
		1	2	3	4	5	6	7	8
15	1	2 10 10	2 11 12				4 11 18		
24	2	3 12 11	2 10 15		5 16 18			1 10 20	7 11 20
40	3	2 15 10	4 16 14			5 12 16	5 10 17		4 12 18
40	4	1 12 8	2 12 9	7 12 11			3 10 20	3 15 20	
19	5	2 17 10	2 18 12						
27	6	3 10 8		3 7 8	4 13 16			5 11 18	2 11 18
18	7	2 9 9	6 11 7		4 16 16		3 15 16		
6	8	5 12 7		4 13 20					
55	9	2 9 6	3 10 7			4 14 17		5 9 18	5 9 20
46	10	1 10 7	5 19 9	5 11 20					6 10 20
32	11	1 12 8	2 15 9				1 16 17	1 16 17	1 16 17

Key to table:

Number Designs		
	Mean Devices	
		Number different devices

Table 8: A representation of progress in terms of cumulative designs presented, mean number of devices in any batch of designs presented at a given occasion, the cumulative number of different devices employed in all previous designs, and the subject's estimated hours of relevant thinking necessary. Four devices are, as before, excluded.

Another feature of Table 8 is that subjects who produced many designs did eventually use nearly all of the devices in one way or another. However, the periodic fixation on a group of devices does support the hypothesis of the earlier study (Section 4), that in systematic design devices are rearranged to typify a principle, until there is a radical change in principle, bringing fresh devices into the picture in an organised manner.

Finally, Fig 7 and Fig 8 jointly support the hypothesis that good designers can produce many different kinds of design, given the opportunity to do so systematically, rather than haphazardly and that subjects with high versatility scores are likely to do so, (my own conviction is possibly greater than the figures warrant; but, for example, Subject 8 stopped designing quite early in the study, because of commitment to other matters).

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INTRUDER ALARM SYSTEM

(1)	Introduction
(2)	Specifications
(3)	Intruder Alarm Devices
(4)	Initial Design Considerations
(5)	Design 1 (a/b)
(6)	Design 2 (a/b)
(7)	Variety of Designs
(8)	Conclusion
(9)	Entailment Meshes(and pocket)

(1) (2) and (3) materials given to subjects as part of brief

(9) comprises figures as entailment mesh

9-4-79

F.A. ROGATI

(1) INTRODUCTION

This project concerns the design of an intruder alarm system for System Research Ltd.. Several designs are submitted, together with their representation in entailment meshes and also the strategies employed.

Contents:

Alarm bell
Anti-Clash Paint
Breaking Glass Detector
Control Unit
Door
Door Locks
Infrared Directional Sensor
Infrared Intruder Detector
Magnetic Contacts
Microswitches
Microwave Intruder Detector (Outdoor)
Microwave Intruder Detector (Indoor)
Pass Key Switch
Power Supplies
Pressure Mats
Telephone Alarms (999 only & Multi-message)
TV Surveillance Camera
Ultrasonic Intruder Detector
Vibration Contacts
Window Bars & Grilles
Window Locks
Wireless Alarm Systems
Warning Notice
Dummy Television Camera
Powerful Lamp
Dummy Guard Dog
Dummy Night-watchman
Latticed Screen

} Subject's additions to list

Fig 7 Subject design materials

(4.1) General Protection of Woodville House

For the sake of convenience, it will be assumed that the cost of the general alarm system (Spec. 1b, Sect. 2.2) will be shared by System Research Ltd. and two other occupiers (TUV Ltd. & XYZ Ltd.) only. Consequently, it seems reasonable that the general alarm system should not only provide special protection for System Research Ltd., but also that TUV Ltd. and XYZ Ltd. should be favoured to some extent with respect to the remaining occupiers. Furthermore, this could prove a useful strategy in order to obtain the participation of TUV Ltd. and XYZ Ltd. in the first place.

(4.2) False Alarms

False alarms fall into basic categories — "unacceptable" and "acceptable". The unacceptable type can best be described as a false alarm that inconveniences or annoys unnecessarily either the police or the neighbours. The number of such false alarms can be minimised quite easily by making it a necessary condition that at least two intruder detector devices be activated in order to raise an otherwise unacceptable alarm.

The acceptable type can be best described as a false alarm that neither inconveniences nor annoys anybody. For example, suddenly illuminating the courtyard with a powerful lamp should cause the neighbours little or no disturbance. Hence the activation of only one intruder detector device should be a sufficient condition for raising an acceptable alarm.

(5) DESIGN 1 (a/b)

(4.3) Night/Day Operation

The combination of pass key switch and entry timer allows an authorised person to enter or leave a protected premises without setting off the corresponding intruder alarm system. Also, the action of the pass key switches the intruder alarm system from night-time to day-time operation and vice-versa.

(4.4) Graphical Representation

The graphical representation adopted in Fig.14,15,27,28 is:

- (i) 29 = item no. 29, 1 off
29 x 5 = " " " 5 "
- (ii) 25 x 1/2 = " " 25, one half of a pair
- (iii) 35T = " " 35, transmitter
35R = " " " receiver
- (iii) → = direction of lamp/camera/microwave detector
- (iv)  = lattice screen, plan view

(5.1) Design 1(a/b) --- Basic Strategy

In this design, the problem is approached from an overall point of view with respect to the intruders. On the one hand, an entailment mesh is developed of the total natural threat posed by the intruders to:

- (i) the offices of System Research Ltd.
(Design 1a --- Fig.9, 1st half)
- (ii) Woodville House in general
(Design 1b --- Fig.12, left half)

This can be further expanded from the generalised entailment mesh (Fig.11) for each class of intruder.

On the other hand, another entailment mesh is developed of the overall counter-threat directed at the intruders by the personnel and/or the intruder alarm system of:

- (i) the offices of System Research Ltd.
(Design 1a --- Fig.9, right half)
- (ii) Woodville House in general
(Design 1b --- Fig.12, right half)

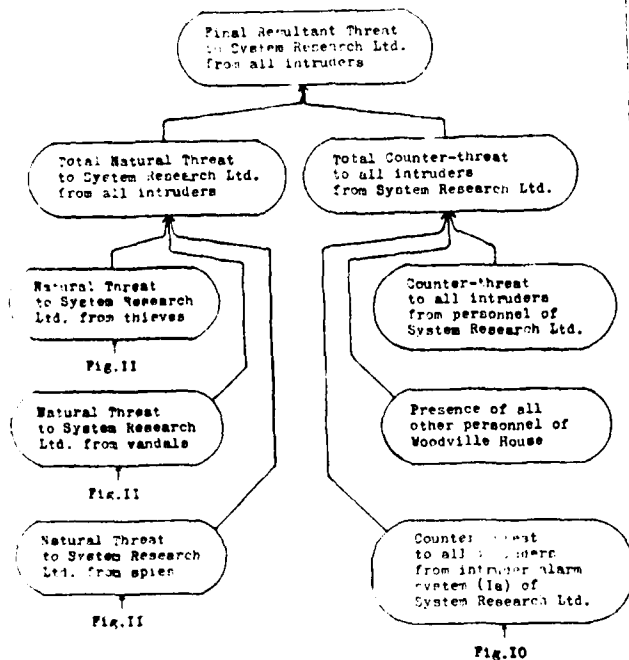
The counter-threat can be subdivided into:

- (i) the threat of physical violence
e.g. an attack by guard dogs
- (ii) the threat of arrest
e.g. alerting the police before ringing alarm bell.

Finally, the required alarm system (Design 1a - Fig.10, Design 1b - Fig.13) can be designed by attempting to equate or match the overall counter-threat to the corresponding total natural threat (Design 1a - Fig.9 / Design 1b - Fig.12). In this way, it is hoped to reduce the final resultant threat to a minimum approaching zero.

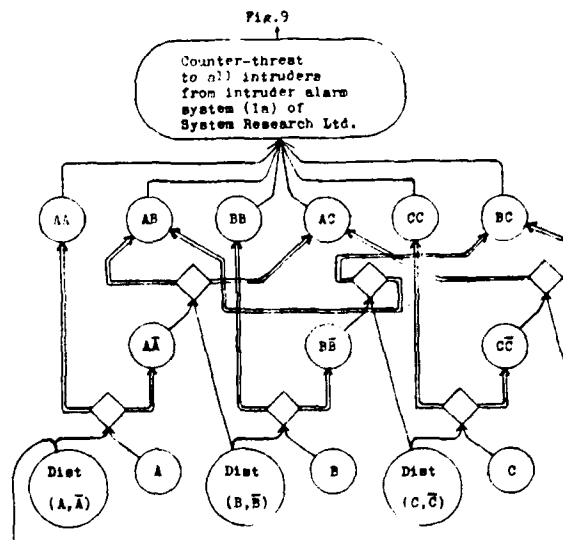
(Design 1a)

FIG. 9



(Design 1a)

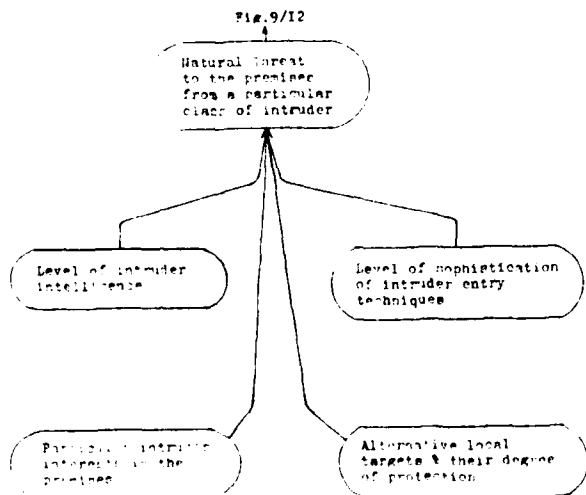
FIG. 10



A = all items listed in Sect. 5. $d(i)$
 B = " " " " " " $d(ii)$
 C = " " " " " " a, b, c
 $A+B+C$ = " " " " " " 5.3
 $\bar{A} = B+C$ $\bar{B} = A+C$ $\bar{C} = A+B$
 AA = items A when co-operating amongst themselves
 BB = " " " " " " " "
 CC = " " " " " " " "
 AB = " " A, B " " " "
 AC = " " A, C " " " "
 BC = " " B, C " " " "
 AA = AB and/or AC BB = AB and/or BC
 CC = AC and/or BC

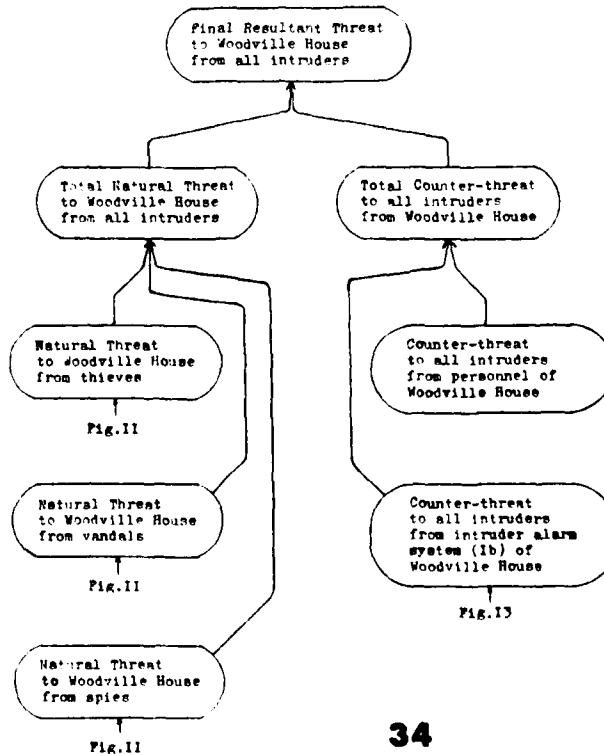
(Design 1a & 1b)

FIG. 11



(Design 1b)

FIG. 12



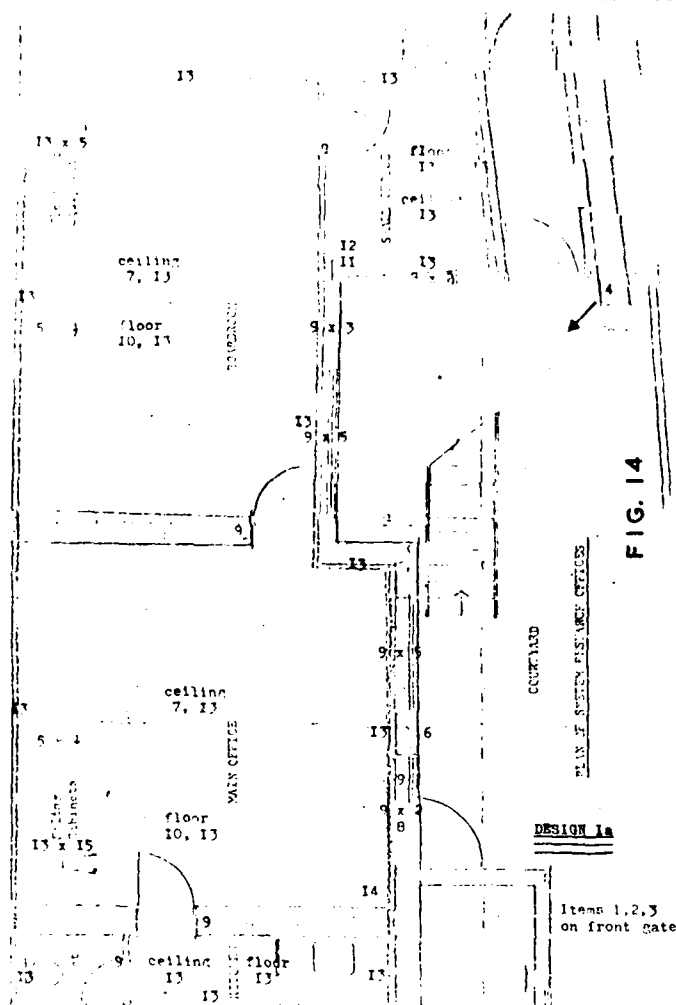


FIG. 14

(5.4) Design 1b --- Description

The basic layout for Design 1b is shown in Fig. 15 and itemised in Sect. 5.5. The special protection for System Research Ltd. is basically the same as Design 1a. Thus, for example, the separate pass key switch and entry timer allow the personnel of System Research Ltd. to enter and leave their offices independently of all the other occupiers of Woodville House. Now, the personnel of TUV Ltd. and XYZ Ltd. are each provided with similar independence - items 28 x 2, 36.

Furthermore, a fourth pass key switch is fitted to the front gate of Woodville House, and every occupier is issued with a suitable pass key. This pass key activates / deactivates those intruder alarm devices which protect Woodville House in general, including the courtyard. The end result is that Design 1b has three individual alarm subsystems as well as a common or general alarm subsystem. The whole system can be regarded as a hierarchical structure composed of the following lines of deterrent :

- (a) the first line of deterrent is situated externally - items 21, 22, 23
- (b) the second line of deterrent monitors the front of Woodville House - items 29 x 5, 27 x 2, 24
- (c) the third line of deterrent monitors the courtyard of Woodville House - items 24, 34, 35 x 2
- (d) the fourth line of deterrent monitors the outer shells of the offices of :
 - (i) System Research Ltd. - items 27 x 2, 24, 29 x 18, 33 x 20
 - (ii) TUV Ltd. - items 27, 29 x 4,

(iii) XYZ Ltd. - items 27, 29 x 5

- (e) the fifth line of deterrent monitors the interior of the latter three offices :

(i) System Research Ltd. - items 30 x 2, 29 x 4

(ii) TUV Ltd. - items 30, 29 x 2

(iii) XYZ Ltd. - items 30, 29

- (f) the sixth line of deterrent provides System Research Ltd. with the special monitoring required for :

(i) the filing cabinets - items 33 x 15

(ii) the electronic equipment - items 33 x 5

If any two of the above intruder detector devices should be disturbed, the dummy guard dogs would be brought into action immediately. Simultaneously, the police would be alerted via item 32. However, the two alarm bells would not be rung until 20 minutes later in order to allow the police sufficient time to surprise the intruder. The only exception to the above rule is that the disturbance of any one microwave intruder detector would be a sufficient condition for raising the alarm. Otherwise, an intruder could safely enter the courtyard from over the roof-tops.

Furthermore, the mutual help obtained by the total interconnection of all the intruder detector devices (Fig. 13) provides a total deterrent which can be considerably greater than the basic deterrent provided merely by each alarm system acting alone :

$$\text{basic deterrent} = SS + FF + C + TT + XI \quad \dots (1)$$

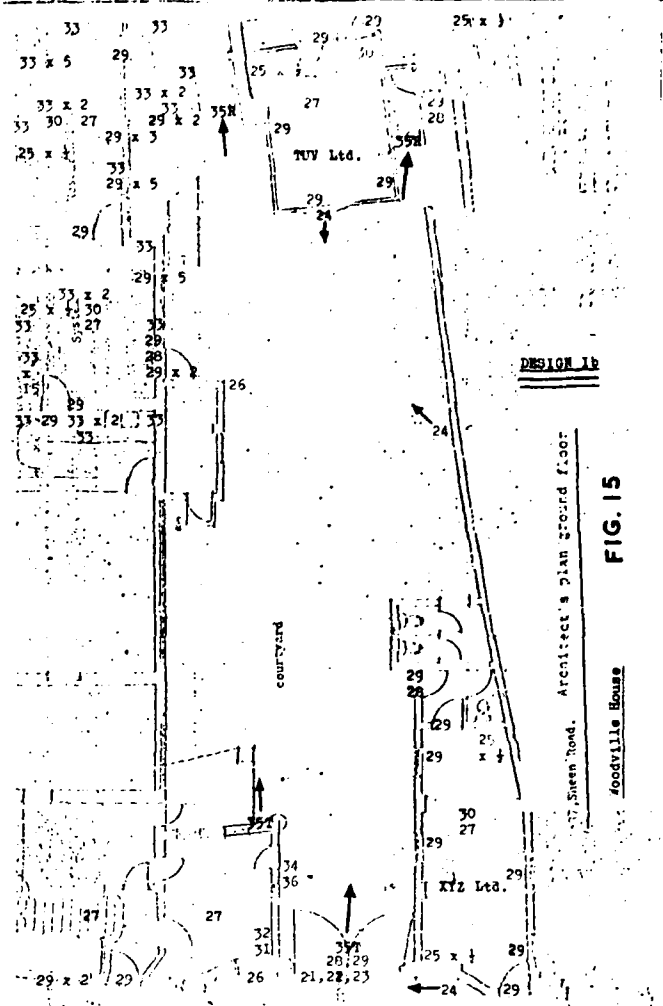
$$\text{total deterrent} = SS + FF + C + TT + XI +$$

$$PS + ST + SX + PT + PX + TX \quad \dots (2)$$

The whole system described above is in operation when the whole of Woodville House is closed. During normal business hours, only items 21, 22, 23, 24 x 3, are employed. Then, the only other deterrent is the presence of the personnel of Woodville House.

5.5) Security Parts List:

Item No.	Quantity	Description	Cost
21	1	Warning Notice (Sect. 3.23a)	£ 5.00
22	1	" (Sect. 3.23b)	£ 5.00
23	1	" (Sect. 3.23c)	£ 5.00
24	3	Dummy TV Camera (+anti-tamper dev.)	£ 21.00
25	3	A Pair of Dummy Guard Dogs	£ 90.00
26	2	External Alarm Bell (+ 11 lit & anti-tamper switch)	£ 70.00
27	6	Pressing Glass Detector (+ extras)	£156.00
28	4	Pass Key Switch	£ 52.00
29	39	Magnetic Contacts	£ 39.00
30	4	Ultrasonic Intruder Detector (range set at 3.5 metres approx.)	£160.00
31	1	Power Supply	£ 35.00
32	1	Telephone Alarm-1 (Sect. 3.16) (+ independent power supply)	£ 50.00
33	40	Vibration Contact	£ 60.00
34	1	Dummy Night-watchman	£ 25.00
35	2	Microwave Intruder Detector (outdoor, range 20m, beam width 6m, extras)	£150.00
36	1	Control Unit (+ extras & logic: Voltage Check & Test Facilities 4 Entry Timers & Dummy Night-watchman DELAY (20 minutes for alarm bell) OR (unacceptable/false alarms) AND ("unacceptable" false alarm, Solar between 2.1 unit & 1 hour)	£ 50.00
TOTAL			£553.00



(6.1) Design 2(a/b) — Basic Strategy

In this design, the problem is approached in a piecewise manner from the point of view of the property that has to be protected. An entailment mesh is developed of the total danger to each class of property and the individual protection required to reduce this danger to a minimum approaching zero for the following premises :

- (i) the offices of System Research Ltd.
(Design 2a - Fig 16.17,18)
- (ii) Woodville House in general
(Design 2b - Fig.21,22,23,24)

The protection provided (Design 2a - Fig.20 / Design 2b - Fig.26) prevents the intruder from reaching his goal by :

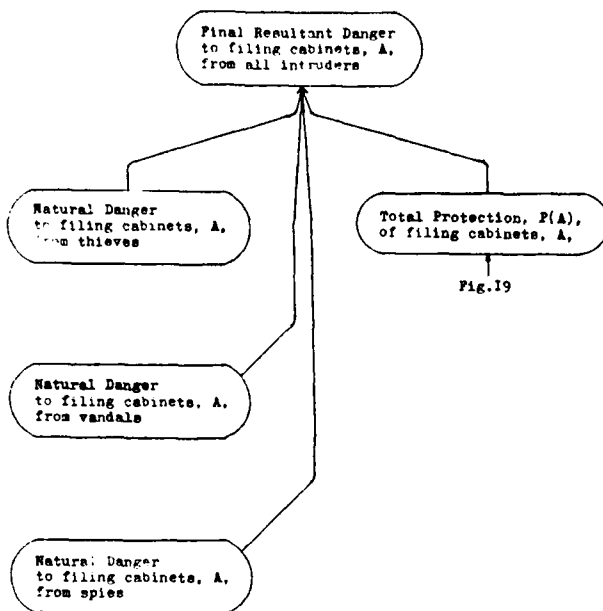
- (i) either physically preventing his passage
e.g. window bars/grilles
- (ii) or immediately alarming him into instant flight
e.g. suddenly being spot-lighted by a lamp.

Finally, the required alarm system (Design 2a - Fig.19 / Design 2b - Fig.25) can be designed by summing up the number of devices required to satisfy the individual protection for each class of property. It should be noted that there may be considerable overlap between any two groups of individual protection. This should be exploited in order to reduce system redundancy and system cost.

(6) DESIGN 2 (a/b)

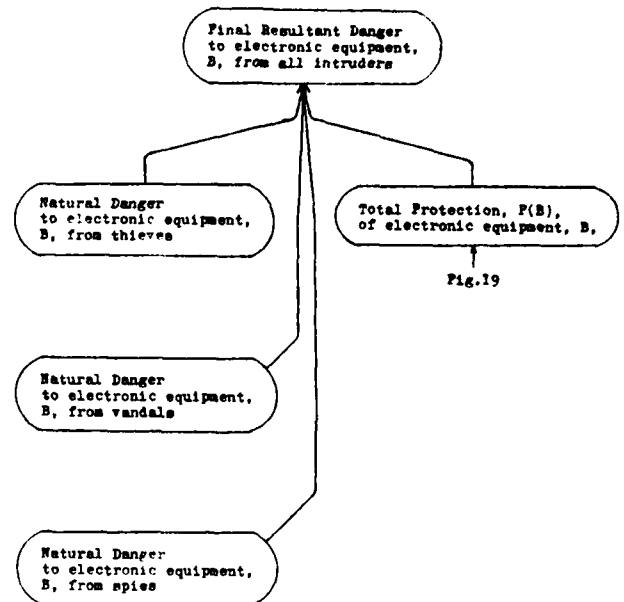
(Design 2a)

FIG. 16



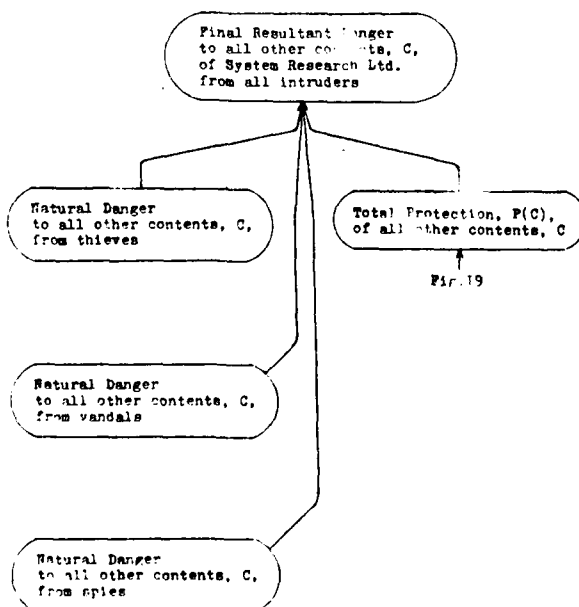
(Design 2a)

FIG. 17



(Design 2a)

FIG. 18



(Design 2a)

FIG. 19

Symbols

$P(A)$ = total protection of filing cabinets A
 $P(B)$ = " " " electronic equipment B
 $P(C)$ = " " " all other contents C

pb = protection (total) by police alert & alarm bell, Fig.20(i)
 $pbAB$ = " of A+B " " " "
 pbA = " of A " " " "
 pbB = " of B " " " "
 pbC = " of C " " " "

pp = protection (total) by physical prevention, Fig.20(ii)
 $ppAB$ = " of A+B " " " "
 ppA = " of A " " " "
 ppB = " of B " " " "
 ppC = " of C " " " "

im = protection (total) by illumination, Fig.20(iii)
 $imAB$ = " of A+B " " " "
 imA = " of A " " " "
 imB = " of B " " " "
 imC = " of C " " " "

pe = protection (total) by personnel, Fig.20(iv)
 $peAB$ = " of A+B " " " "
 peA = " of A " " " "
 peB = " of B " " " "
 peC = " of C " " " "

FIG. 19

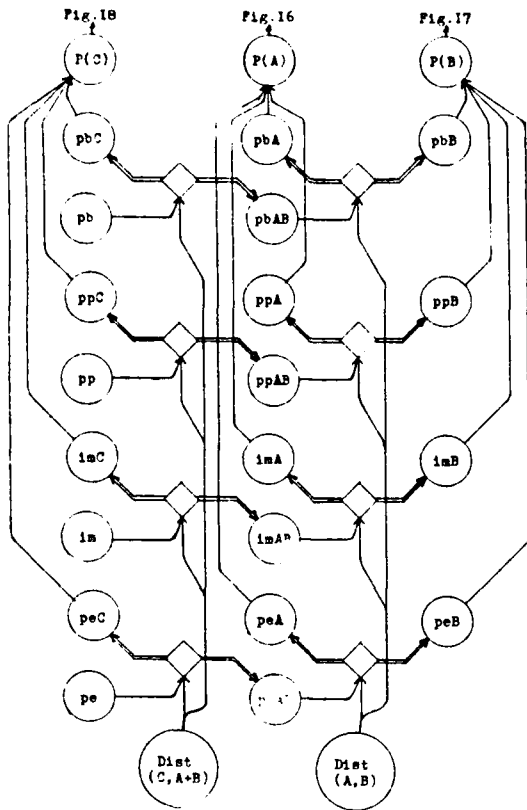


FIG. 20

Symbols

a = all items listed in Sect. 6.2a
 b = " " " " " " 6.2b
 c = " " " " " " 6.2c
 d = " " " " " " 6.2d
 e = " " " " " " 6.2e
 f = " " " " " " 6.2f

bb = items b when co-operating amongst themselves

cc = " c " " " "
 dd = " d " " " "
 ee = " e " " " "
 ff = " f " " " "
 bc = " b,c " " jointly
 bd = " b,d " " "
 be = " b,e " " "
 bf = " b,f " " "
 cd = " c,d " " "
 ce = " c,e " " "
 cf = " c,f " " "
 de = " d,e " " "
 df = " d,f " " "
 ef = " e,f " " "

FIG. 20

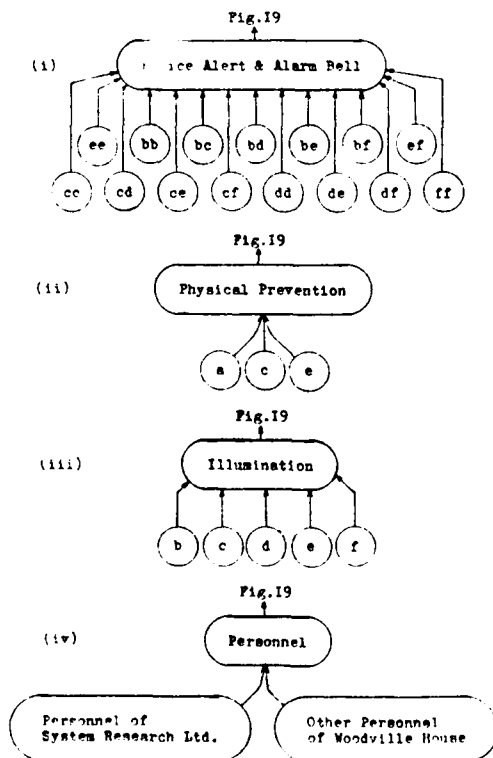
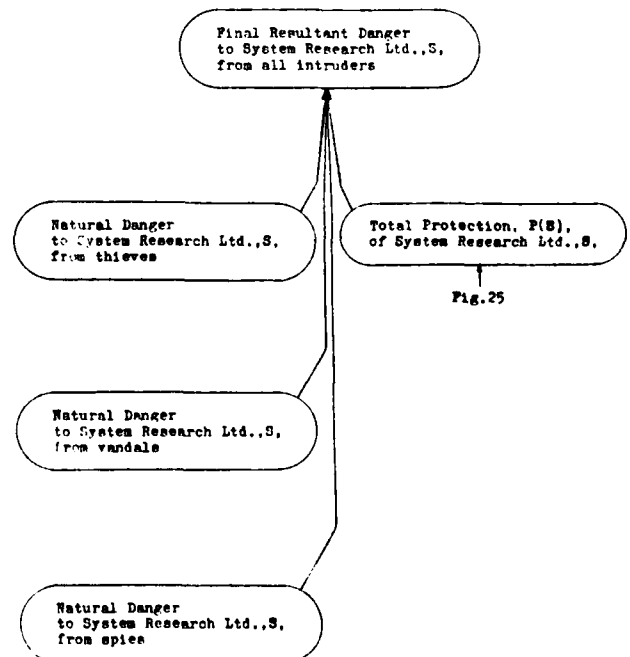
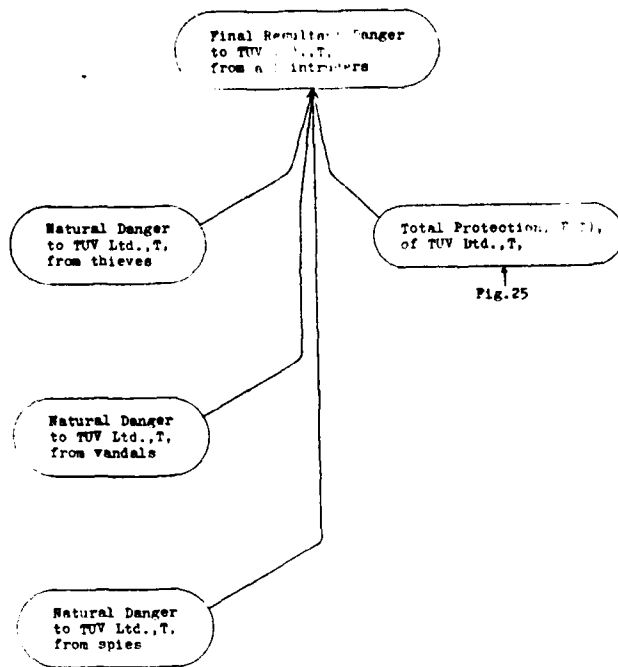


FIG. 21



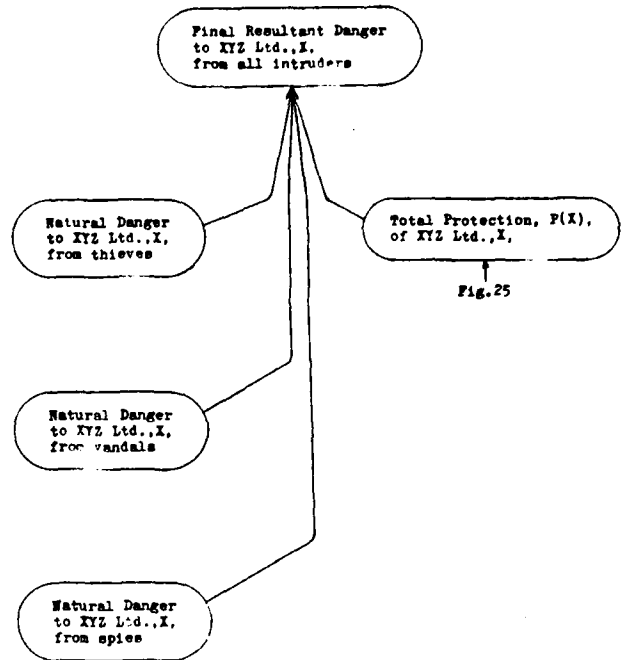
(Design 2b)

FIG.22



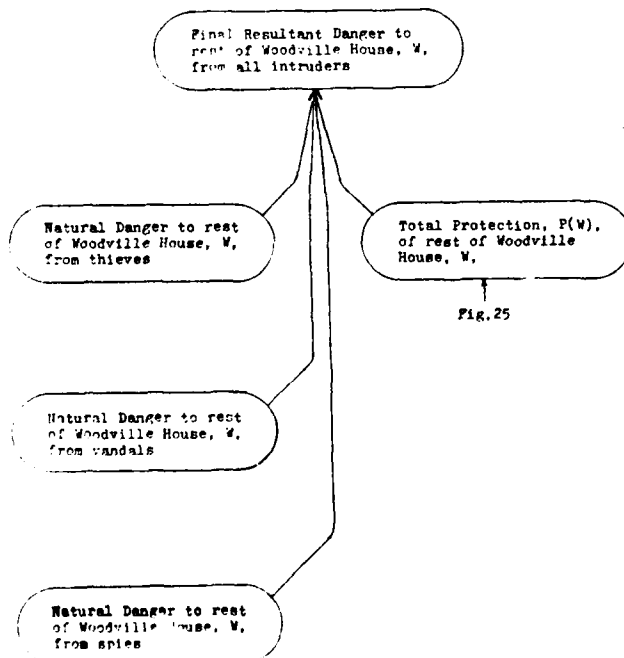
(Design 2b)

FIG.23



(Design 2b)

FIG.24



(Design 2b)

FIG.25

Symbols

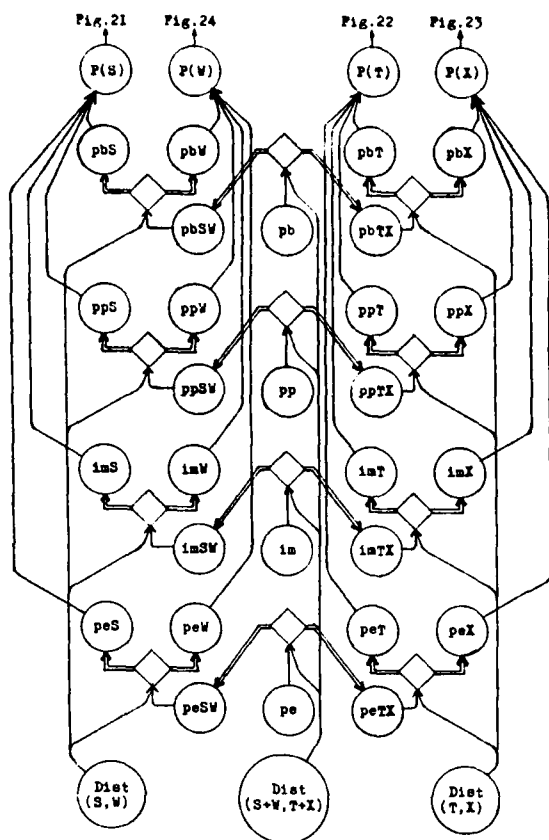
P(S) = total protection of System Research Ltd., S
 P(T) = " " " TUV Ltd., T
 P(X) = " " " XYZ Ltd., X
 P(W) = " " " the rest of Woodville House, W

pb = protection (total) by police alert & alarm bells, Fig.26(i)
 pbSW = " of S+W " " " " "
 pbTX = " of T+X " " " " "
 pbS = " of S " " " " "
 pbT = " of T " " " " "
 pbX = " of X " " " " "
 pbW = " of W " " " " "

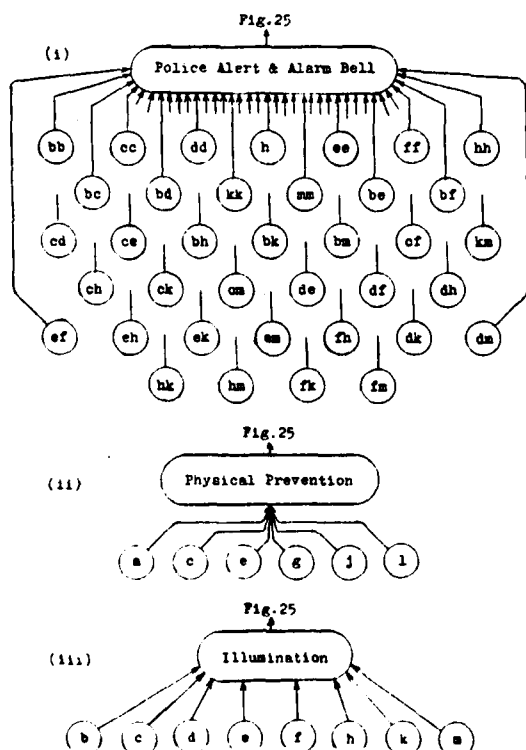
pp = protection (total) by physical prevention, Fig.26(ii)
 ppSW = " of S+W " " " " "
 ppTX = " of T+X " " " " "
 ppS = " of S " " " " "
 ppT = " of T " " " " "
 ppX = " of X " " " " "
 ppW = " of W " " " " "

im = protection (total) by illumination, Fig.26(iii)
 imSW = " of S+W " " " " "
 imTX = " of T+X " " " " "
 imS = " of S " " " " "
 imT = " of T " " " " "
 imX = " of X " " " " "
 imW = " of W " " " " "

pe = protection (total) by personnel of Woodville House
 peSW = " of S+W " " " " "
 peTX = " of T+X " " " " "
 peS = " of S " " " " "
 peT = " of T " " " " "
 peX = " of X " " " " "
 peW = " of W " " " " "



a	=	all items listed in Sect.	6.4a
b	=	"	6.4b
c	=	"	6.4c
d	=	"	6.4d
e	=	"	6.4e
f	=	"	6.4f
g	=	"	6.4g
h	=	"	6.4h
j	=	"	6.4j
k	=	"	6.4k
l	=	"	6.4l
m	=	"	6.4m
bb	=	items b when co-operating amongst themselves	
cc	=	c	
dd	=	d	
ee	=	e	
ff	=	f	
gg	=	g	
hh	=	h	
jj	=	j	
kk	=	k	
ll	=	l	
mm	=	m	
bc	=	b,c	jointly
bd	=	b,d	
be	=	b,e	
bf	=	b,f	
bh	=	b,h	
bk	=	b,k	
bm	=	b,m	
cd	=	c,d	
ce	=	c,e	
cf	=	c,f	
ch	=	c,h	
ck	=	c,k	
cm	=	c,m	
de	=	d,e	
df	=	d,f	
dh	=	d,h	
dk	=	d,k	
dm	=	d,m	
ef	=	e,f	
eh	=	e,h	
ek	=	e,k	
em	=	e,m	
fh	=	f,h	
fk	=	f,k	
fm	=	f,m	
hk	=	h,k	
hm	=	h,m	
km	=	k,m	



The basic layout for Design 2a is shown in Fig.27 and itemised in Sect. 6.3. The intruder alarm system commences with two lines of defence which are common to all the contents of the System Research offices :

- (a) the first line of defence physically prevents entry - items 42,50
- (b) the second line of defence detects intrusion into the general interior of the System Research offices - items 45 x 22, 46 x 2, 49 x 8

The filing cabinets are protected by two more lines of defence :

- (c) the third line of defence physically prevents passage to filing cabinets - items 43, 49 x 2
- (d) the fourth line of defence detects any unauthorised tampering with the filing cabinets - items 49 x 15.

The electronic equipment is protected by two similar lines of defence :

- (e) the third line of defence physically prevents passage to the electronic equipment - items 43, 49 x 2
- (f) the fourth line of defence detects any unauthorised tampering with the electronic equipment - items 49 x 5

Equating the above with Fig.19.20, it can be seen that :

$$P(A) \geq a + b + bb + c + cc + cb + cd + bd + dd \dots\dots(3)$$

$$r(B) \geq a + b + bb + e + ee + eb + ed + bf + ff \dots (4)$$

$$P(C) \geq a + b + bb \dots\dots(5)$$

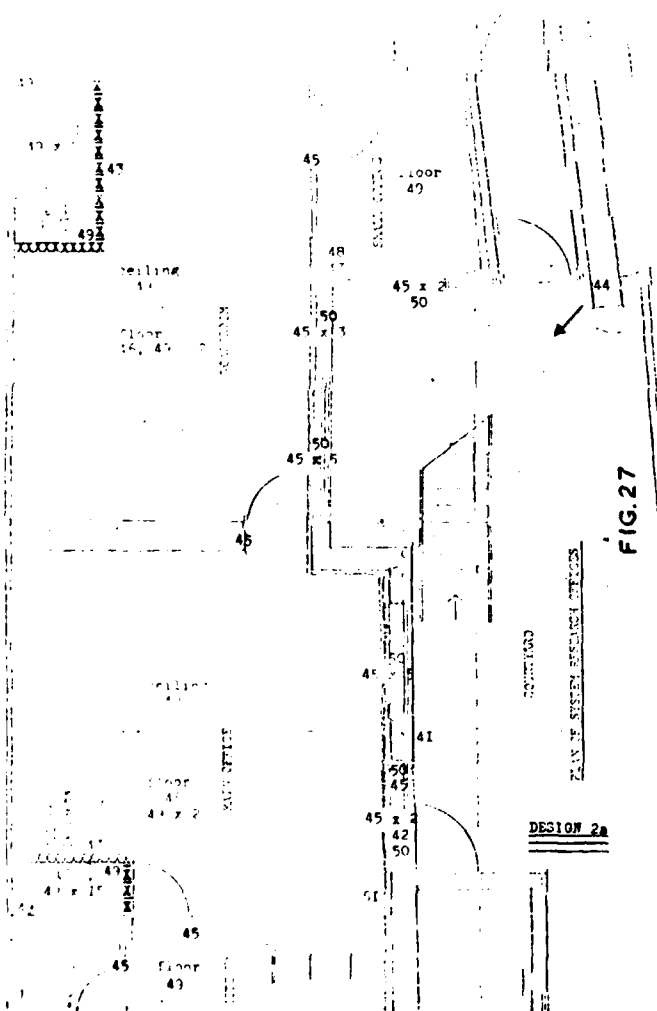
The "=" sign is replaced by ">" because the total interconnection of all the intruder detector devices considerably enhances the individual protection of any one class of property.

If any one of the above intruder detector devices should be disturbed, the front of the System Research offices would be illuminated immediately by the powerful lamp. If any two of the above intruder detector devices should be disturbed, then immediately the alarm bell would be rung and the police alerted. It is hoped that the effect of the powerful lamp and/or the alarm bell would shock most intruders into instant flight.

The whole system described above is in operation when the System Research offices are closed. However, during business hours, the only lines of defence employed are (d), (f) and the two locked latticed screens of (c) and (e). The disturbance of any two intruder detector devices contained in (d) and (f) will immediately ring the alarm bell and alert the police. The only other defence consists of the personnel of System Research Ltd., and to a lesser extent the other personnel of Woodville House. The pass key switch of item 43 allows alarm-free access to the filing cabinets (or the electronic equipment) by authorised personnel.

(6.3) Design 2a --- Parts List

Item No.	Quantity	Description	Cost
41	1	External Alarm Bell (+ light & anti-tamper switch)	£ 35.00
42	1	Door Lock (+ pass key switch)	£ 20.00
43	2	Latticed Screen (area = 7 sq. m., + pass key switch)	£ 58.00
44	1	Powerful Lamp (inset in wall with front grille & anti-tamper device)	£ 12.00
45	22	Magnetic Contacts	£ 22.00
46	2	Ultrasonic Intruder Detector (range set at 3.5 metres approx.)	£ 80.00
47	1	Power Supply	£ 35.00
48	1	Telephone Alarm-1 (Sect. 3.16) (+ independent power supply)	£ 50.00
49	32	Vibration Contact	£ 48.00
50		Window Bars/Grilles (glass area = 12 sq. m. approx)	£ 18.00
51	1	Control Unit (+ extras & logic: Voltage Check & Test Facilities 3 Entry Timers OR ("acceptable" false alarms) AND ("unacceptable" false alarms, delay between 2 inputs < 1 hour)	£ 50.00
TOTAL			£428.00



(6.4) Design 2b --- Description

The basic layout for Design 2b is shown in Fig. 28 and itemized in Sect. 6.5. The special protection for System Research Ltd. is basically the same as in Design 2a.

The offices of TUV Ltd. and XYZ Ltd. - as well as those of System Research Ltd. - are each fitted with a separate pass key switch and entry timer. Thus, the personnel of each of the above three offices can come and go quite independently, both of each other and of any other occupier.

Furthermore, a pass key switch is fitted to the front gate of Woodville House. Every occupier is issued with a suitable pass key in order to activate/deactivate those intruder alarm devices which only protect Woodville House in general, including the courtyard. The end result is that Design 2b has three independent individual alarm sub-systems as well as a general alarm sub-system.

From Sect. 6.2, the individual protection for the System Research offices can be restated in terms of Sect. 6.5 as :

- (a) items 52, 70
- (b) " 65 x 22, 66 x 2, 69 x 8
- (c) " 63, 69 x 2
- (d) " 69 x 15
- (e) " 63, 69 x 2
- (f) " 69 x 5

The general protection of Woodville House - common to all the occupiers - consists of two lines of defence :

- (g) the first line of defence physically prevents entry from the main road - items 70

(b) the second line of defense consists of intrusion into the front offices and emergency of the office.

(c) the first line of defense consists of intrusion into the front offices and emergency of the office.

(d) the second line of defense consists of intrusion into the front offices and emergency of the office.

(e) the first line of defense consists of intrusion into the front offices and emergency of the office.

(f) the second line of defense consists of intrusion into the front offices and emergency of the office.

(g) the first line of defense consists of intrusion into the front offices and emergency of the office.

(h) the second line of defense consists of intrusion into the front offices and emergency of the office.

(i) the first line of defense consists of intrusion into the front offices and emergency of the office.

(j) the second line of defense consists of intrusion into the front offices and emergency of the office.

(k) the first line of defense consists of intrusion into the front offices and emergency of the office.

(l) the second line of defense consists of intrusion into the front offices and emergency of the office.

(m) the first line of defense consists of intrusion into the front offices and emergency of the office.

(n) the second line of defense consists of intrusion into the front offices and emergency of the office.

(o) the first line of defense consists of intrusion into the front offices and emergency of the office.

(p) the second line of defense consists of intrusion into the front offices and emergency of the office.

(q) the first line of defense consists of intrusion into the front offices and emergency of the office.

(r) the second line of defense consists of intrusion into the front offices and emergency of the office.

(s) the first line of defense consists of intrusion into the front offices and emergency of the office.

(t) the second line of defense consists of intrusion into the front offices and emergency of the office.

(u) the first line of defense consists of intrusion into the front offices and emergency of the office.

(v) the second line of defense consists of intrusion into the front offices and emergency of the office.

(w) the first line of defense consists of intrusion into the front offices and emergency of the office.

(x) the second line of defense consists of intrusion into the front offices and emergency of the office.

(y) the first line of defense consists of intrusion into the front offices and emergency of the office.

(z) the second line of defense consists of intrusion into the front offices and emergency of the office.

(aa) the first line of defense consists of intrusion into the front offices and emergency of the office.

(ab) the second line of defense consists of intrusion into the front offices and emergency of the office.

(ac) the first line of defense consists of intrusion into the front offices and emergency of the office.

(ad) the second line of defense consists of intrusion into the front offices and emergency of the office.

(ae) the first line of defense consists of intrusion into the front offices and emergency of the office.

(af) the second line of defense consists of intrusion into the front offices and emergency of the office.

(ag) the first line of defense consists of intrusion into the front offices and emergency of the office.

(ah) the second line of defense consists of intrusion into the front offices and emergency of the office.

(ai) the first line of defense consists of intrusion into the front offices and emergency of the office.

(aj) the second line of defense consists of intrusion into the front offices and emergency of the office.

(ak) the first line of defense consists of intrusion into the front offices and emergency of the office.

(al) the second line of defense consists of intrusion into the front offices and emergency of the office.

(am) the first line of defense consists of intrusion into the front offices and emergency of the office.

(an) the second line of defense consists of intrusion into the front offices and emergency of the office.

(ao) the first line of defense consists of intrusion into the front offices and emergency of the office.

(ap) the second line of defense consists of intrusion into the front offices and emergency of the office.

(aq) the first line of defense consists of intrusion into the front offices and emergency of the office.

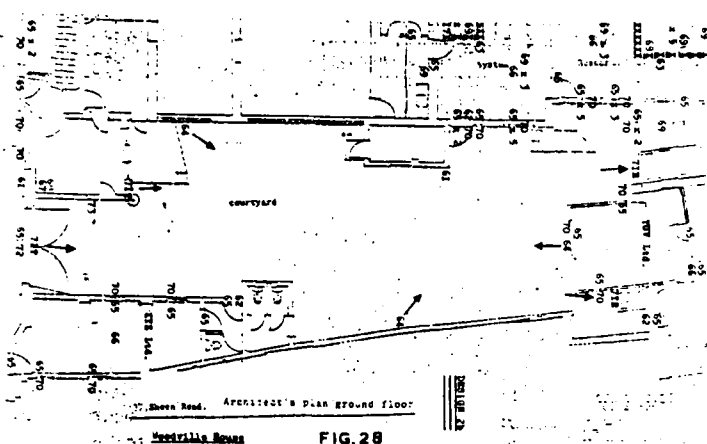


FIG. 28

(7) VARIETY OF DESIGNS

(7.1) Basic Entailment Mesh

There are basically three ingredients which together constitute the equation of this particular project :

- (i) the premises to be protected
- (ii) the intruders
- (iii) the total intruder alarm system - including the personnel.

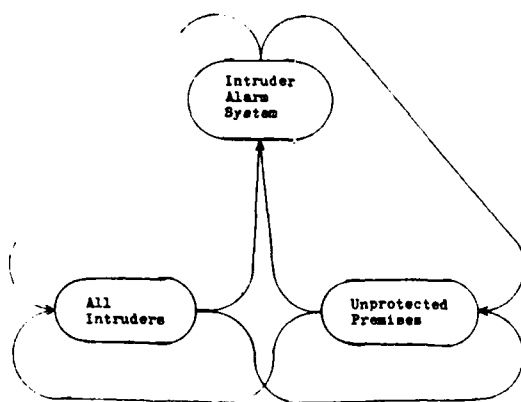
The corresponding entailment mesh is shown in Fig.29, where all possible interconnections are depicted. Immediately, it is clear that the problem can be regarded from three separate points of view which give rise to three basic designs :

- (i) Design 1 (Sect. 5) - from the point of view of the intruders
- (ii) Design 2 (Sect. 6) - from the point of view of the unprotected premises
- (iii) Design 3 - from the point of view of the alarm system.

(7.2) Different Approaches

Each of the above designs (Sect. 7.1) can be approached in at least two different ways :

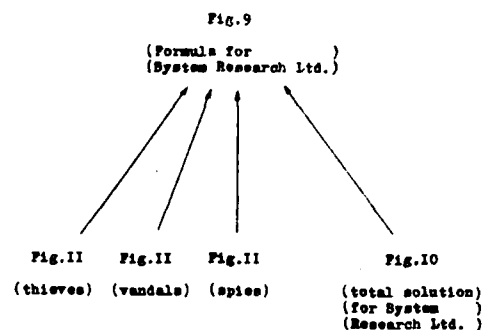
- (i) an overall approach, e.g. Design 1 (Sect. 5). This is equivalent to solving one large all-embracing formula, resulting in one total solution (Fig.31,30)
- (ii) a piecewise approach, e.g. Design 2 (Sect. 6). This is equivalent to solving a number of smaller simultaneous equations, resulting in a collection of individual solutions (Fig.32,33).



Design 1 ———
 Design 2 ———
 Design 3 ———

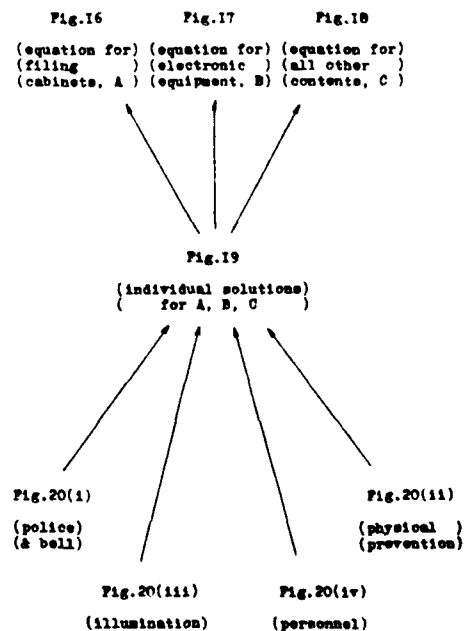
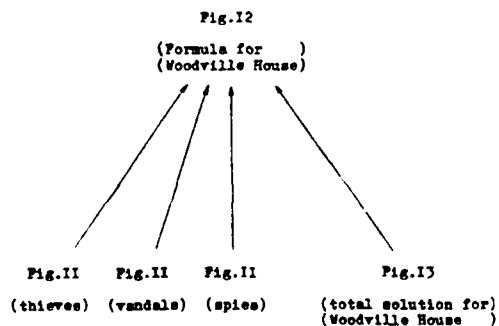
(Design 1b)

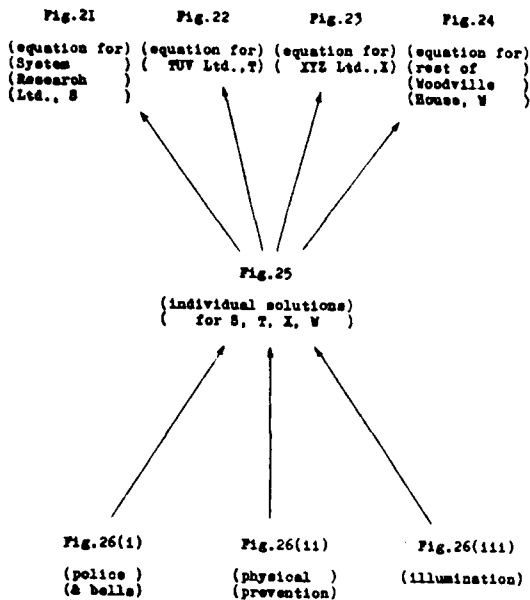
FIG. 31



(Design 2a)

FIG. 32





It should be noted that Fig.30,31,32,33 are merely block diagrams - not entailment meshes - which demonstrate the relationships between earlier diagrams (Fig.9-13) and Fig.16-26). However, it is interesting to note the basic graphical difference between Fig.30,31 and Fig.32,33 :

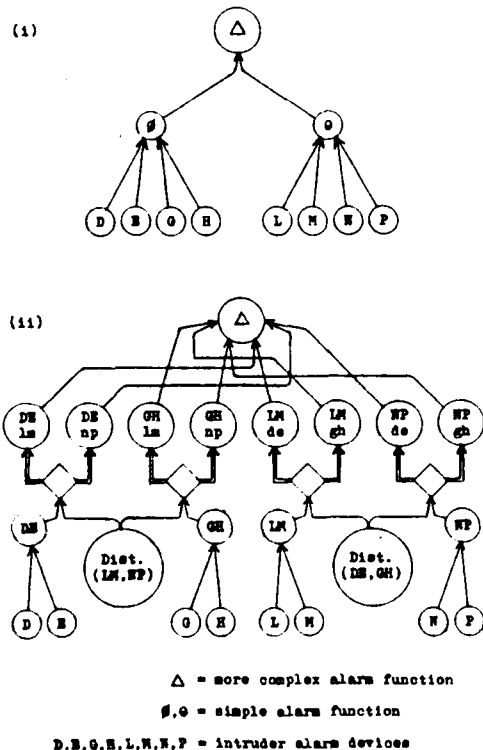
- (a) the overall approach forms an hierarchical structure in the shape of an upright pyramid with the all-embracing formula as the focal point at its apex,
- (b) the piecewise approach places the collection of individual solutions at a central focal point with branches in all directions.

This tends to suggest that the piecewise approach is the less rigid structure of the two - with greater interaction between all the parts. Finally, it can be seen that the design problem specified in Sect. 2 may be solved in not merely three, but at least six different ways.

(7.3) Variety of Intruder Alarm Devices

From Sect. 7.2 a security consultant may choose between six solutions - analogous to six forms of software. However, there exists an even greater variety of hardware - for example, the intruder detector devices listed in Sect. 3 - with which to implement the desired solution. A brief consideration of Fig. 34 soon demonstrates that as the complexity of an intruder alarm system increases, so does the number of possible ways of implementing it. Thus, for example, the simple alarm functions §,Θ can each be described in only two ways - Fig.34(i) - and

FIG. 34



the more complex alarm function Δ in only one way. However, the end result is that Δ can be implemented in four ways - Fig.34(ii). Consequently, it can be seen that, for an increasingly complex alarm system, the number of possible hardware implementations is limited only by the total number of possible useful combinations of the various intruder alarm devices.

Appendix 1 Design Brief

Design Brief

Introduction

You are to participate in a series of experiments being carried out in order to investigate individual differences in approach and methods in electronics design.

During the course of a number of design sessions you are expected to produce a working prototype unit conforming to the design specification.

During each design session you will be observed by an experimenter and at intervals there will be some discussion and analysis of the work done.

As far as possible you should carry out the design task as you would in your normal working environment. You will be provided with a log book in which you should keep a complete record of your work.

The following materials are provided.

(a) Design specification for an educational simulator to be used in an A level chemistry course.

(b) Relevant chemistry texts to provide background information.

(c) Texts on electronic theory and applications relevant to the design task (in the red folder).

(d) Operating instructions for a special purpose hybrid/analogue computer, the "Design Laboratory" which is to be used to test the prototype design.

If you feel that any of the materials or facilities provided are inadequate or unduly restrictive, please say so. You are free to enter into discussions with the experimenter at any time during the sessions.

Design Specification

Summary

You are required to produce a circuit design and working prototype for an educational simulator to be used in an "A" level chemistry course. The simulator is to be used to illustrate concepts in reaction kinetics and equilibrium. Students should be able to use the simulator to explore the behaviour of a reacting system under a wide range of reaction conditions. The device should also allow the teacher to set up specific problems to be solved by students. The user display and control interfaces should be given careful consideration and you are expected to incorporate, in the prototype, any user controls which you consider necessary.

You may assume that the unit is to be manufactured using small scale production facilities for a cost of approximately £200 per device. You should take into account, at the appropriate stages in design, constraints relating to the following factors: cost, size, and weight (the unit is to be portable), ruggedness and maintainability. Tradeoff between versatility of the simulator, its reliability and cost are open to discussion.

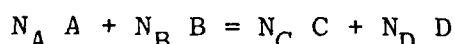
The cost is estimated in terms of modular components given in the cost table and the number of modular interconnections counted as those established by plugging up operations on the front part of the design laboratory (these are priced by the connection cost units in the cost table).

COST TABLE

<u>Modular Components</u>	<u>Cost</u> (£ units)
Integrator with Run/Reset/Hold modes of operation and buffered output	3.5
Analog multiplication module based on XR2208 operational multiplier	5
Analog division module based on XR2208 operational multiplier	5
Analog squaring module based on XR2208 operational multiplier	5
Summing/subtracting operational amplifier	1.5
Exponential function amplifier (antilog function)	5
Comparator	2
+ 15v power supply unit with + 10v reference voltage outputs	15
4 pole 3 way rotary switch	.5
Control potentiometer	.5
10v display meter	5
Run/Hold/Reset cycle control module	2
Module interconnection cost	.5

Outline of Simulator Operation

The idealised form of a chemical reaction is expressed by a so-called "Stoichiometric Equation". The underlying ideas are that chemical molecules of different kinds (symbolised as A,B...) react to produce other chemical molecules (symbolised C,D,...) and that molecules are distinct entities that combine in proportions denoted N_A , N_B or N_C , N_D ... The reactions to be simulated have a maximum of 2 reactants, A and B, and 2 products, C and D. The reaction is represented by the stoichiometric equation.



Where N_A , N_B , N_C , N_D are known as "stoichiometric coefficients" which may take values 0, 1, 2.

It is assumed that the reaction takes place inside an insulated reaction vessel and that there is no appreciable volume change.

Chemical reactions involve thermal energy changes (heat is produced by the reaction or heat is required by the reaction for it to proceed). Hence the temperature inside the reaction vessel will usually change. However, it would be possible to maintain a predetermined temperature by the action of a thermostat, which should form an optional (used or not used) part of the simulator.

In reality there are vast numbers of molecules of type A, B, C, D, and it is possible to determine their concentration or amount per unit volume which is symbolised by $[A]$, $[B]$, $[C]$, $[D]$. For the simulator the front panel meters display the concentrations of reactants and products, the temperature, and the amount of heat removed from or supplied to the system by the thermostat.

Typically, the student will be investigating the following features of the reaction :

(a) Reaction Profiles: Plotting graphs of concentration versus time for reactants and/or products. measuring reaction rate.

(b) Reaction Order, Rate Expression, Rate Constant: Determining (or verifying) reaction order by using various graphical techniques, determining the rate expression and rate constant for a reaction.

(c) Rate of Reaction and Temperature: Investigating the way in which reaction rate varies with temperature. Determining values of (yet to be specified quantities) 'activation energy' and 'frequency factor' from graphs and interpreting these quantities in terms of theoretical models for a reaction.

(d) Equilibrium Constants: Determining equilibrium constants for a reversible reaction, generally exploring the properties of the equilibrium state. Examining the relationship between equilibrium constant and temperature and the overall energy change for the reaction ("enthalpy change", in the literature).

The student is also to be encouraged to consider the overall relationships between macroscopic and microscopic properties of a reacting system and to suggest possible mechanisms and models for the simulated reactions.

The simulator is to have the following mode controls :

Reset: Initial concentrations, temperature etc may be set using the controls on the display panel.

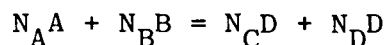
Run: The simulated reaction takes place. The time scale is arbitrary but should allow the student sufficient time to take a series of meter readings for the purpose of plotting graphs. The time scale should also be chosen so that equilibrium conditions are established reasonably rapidly.

Hold: At any time during the course of a reaction the reaction may be halted and meter readings compared.

Detailed Specification

Stoichiometry and Rate of Reaction

The idealised form of a reaction is given by a "stoichiometric equation". The general "stoichiometric equation" for the simulated reaction is :



Where $N_A \dots N_D$ may take values 0, 1, 2 with the restriction that the combinations of values " $N_A = 2$ and $N_B = 2$ " or " $N_C = 2$ and $N_D = 2$ " are not allowed (a simulator limitation).

The rate of reaction may be defined in such a way that it does not depend on the substance chosen to express the rate :

$$\text{Rate} = \frac{1}{N_C} \frac{d [C]}{dt} = \frac{1}{N_D} \frac{d [D]}{dt} = \frac{-1}{N_A} \frac{d [A]}{dt} = \frac{-1}{N_B} \frac{d [B]}{dt}$$

(Recall that the bracketed terms represent concentrations of reactants or products, ie. amount of substance per unit volume (the units used in the text material is mol dm^{-3})).

Plots of concentration versus time for a reaction are known as reaction profiles (Fig A1). One method of determining reaction rate at a given instant is to measure the slope of a tangent to the

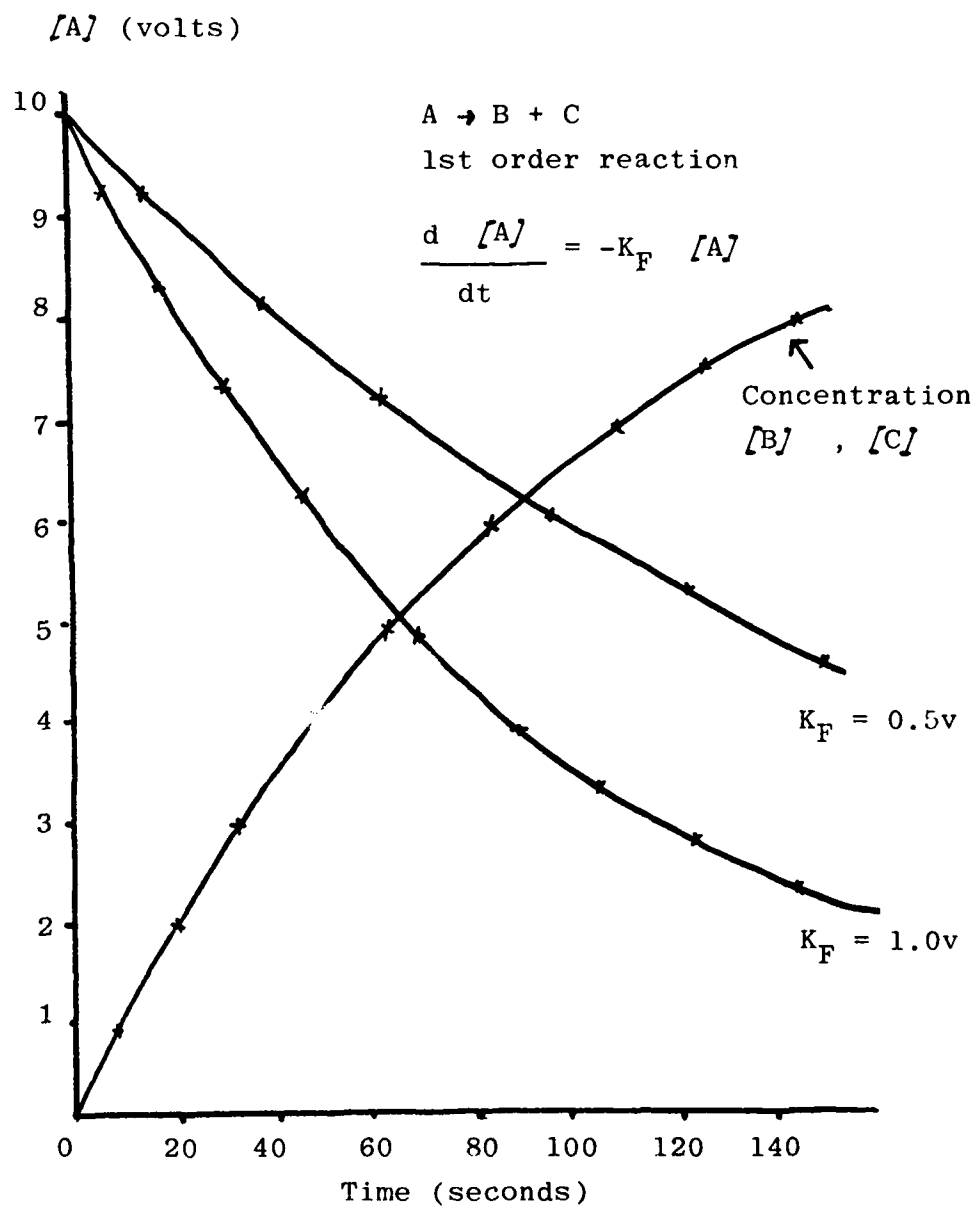


Fig A1: Graphs of simulator performance (1st order reaction) obtained during scaling tests and performance evaluation.

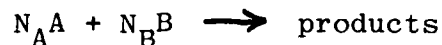
reaction profile curve.

Reactions that go in one direction

In an idealised world some reactions go in one direction only; for example, their form can be expressed by $N_A A + N_B B \rightarrow \text{products}$. Again in an idealised world the rate of a one directional reaction (conventionally, a "forward" reaction) can be expressed as a function of concentration(s) of the form :

$$\lambda_F = K_F [A]^{V_A} [B]^{V_B}$$

For a reaction with stoichiometry :



Where λ_F = forward reaction rate

$[A]$ $[B]$ = concentrations of products

K_F = forward rate constant

V_A = "order of the reaction" with respect to A

V_B = "order of the reaction" with respect to B

V_A and V_B are normally integers with values 0, 1 or 2.

The sum $V_A + V_B$ is known as the (overall) "Reaction Order".

The simulator is deliberately restricted

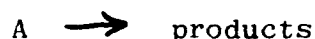
to accept only integer values of order coefficients:

For any simulated reaction $V_A = N_A$ and $V_B = N_B$, ie. the order of the reaction with respect of any reactant is equal to the stoichiometric coefficient for that reactant. This restriction means that all simulated reactions are 'elementary reactions', ie. occur in a single step. No real reactions conform to this restriction and it is a useful approximation for only a few of them used for demonstrations. However, the notion is useful

(a) Because a suitably connected array of simulations would approximate the truth, and

(b) Because the expedient of writing equations of other than integral order permits a mathematical rate prediction (which has no direct physical interpretation) that is, all the same, quite accurate. The mathematics is best learned as mathematics. Chemists have a confusing brand of double talk in which V_A , V_B , ... are "reaction orders" distinct from N_A , N_B ... "the number of molecules involved".

The rate equation for a reaction may be written in differential form (using the definition of rate given above). In many cases the differential rate equation can be solved to give an integrated rate equation which gives an expression for concentration as a function of time. For example :



$$\begin{cases} -\frac{d[A]}{dt} = K_F [A] & \text{Diff. Equation} \\ \ln [A]_0 - \ln [A] = K_F t & \text{Integrated Equation} \end{cases}$$

or

$$\begin{cases} -\frac{d[A]}{dt} = K [A]^2 & \text{Diff. Equation} \\ \frac{1}{[A]} - \frac{1}{[A]_0} = K_F t & \text{Integrated Equation} \end{cases}$$



$$\begin{cases} -\frac{d[A]}{dt} = K_F [A] [B] & \text{Diff. Equation} \\ \frac{1}{([A]_0 - [B]_0)} \left(\ln \frac{[B]_0}{[A]_0} - \ln \frac{[B]}{[A]} \right) = K_F t & \text{Int. Equation} \end{cases}$$

In many cases reaction order can be most easily verified by plotting a graph which should be linear according to the integrated rate equation (Fig A2).

Reversible Reactions

No real reaction proceeds always (under all conditions) in one direction only. Very often the approximation is too unrealistic and the simulator is to be capable of demonstrating the dynamics of reactions in which both forward and

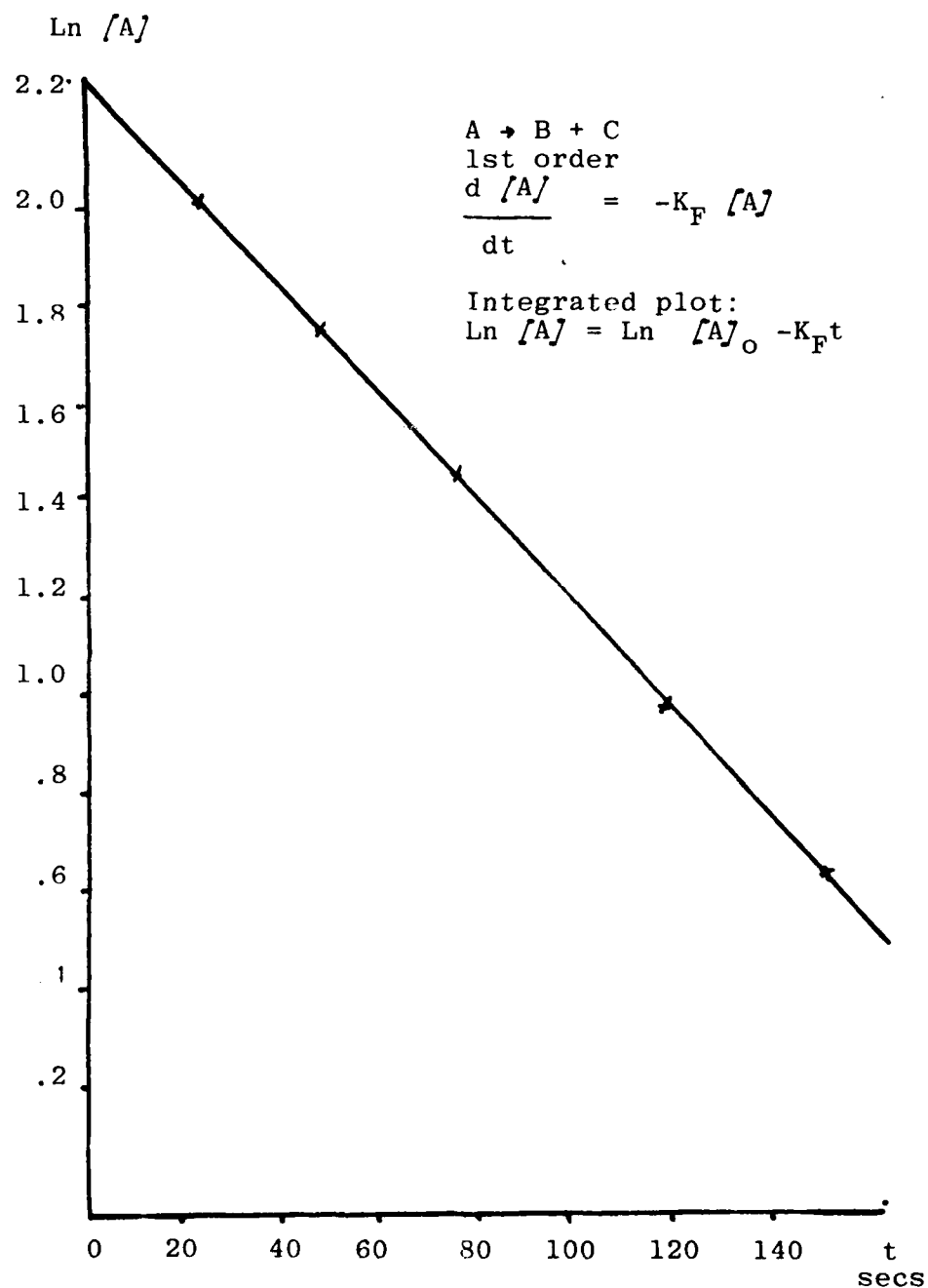
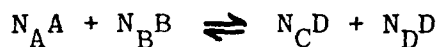


Fig A2: linearisation of 1st order reaction

reverse reactions occur (there are forward and reverse rates λ_F and λ_R ; there are forward and reverse rate constants K_F and K_R). For the general reaction :



Forward Rate Expression :

$$\lambda_F = K_F [A]^{N_A} [B]^{N_B}$$

λ_F = forward rate

K_F = forward rate constant

$\begin{matrix} N_A \\) \\) \\ N_B \\) \end{matrix}$ = stoichiometric coefficients

Reverse Rate Expression :

$$\lambda_R = K_R [C]^{N_C} [D]^{N_D}$$

λ_R = reverse rate

K_R = reverse rate constant

$\begin{matrix} N_C \\) \\) \\ N_D \\) \end{matrix}$ = stoichiometric coefficients

Net Rate : $\lambda_{\text{net}} = \lambda_F - \lambda_R$

$$\lambda_{\text{net}} = \frac{-1}{N_A} \frac{d[A]}{dt} = \frac{-1}{N_B} \frac{d[B]}{dt} = \frac{1}{N_C} \frac{d[C]}{dt} = \frac{1}{N_D} \frac{d[D]}{dt}$$

Equilibrium constant and ΔH (enthalpy change in the literature).

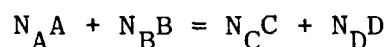
At equilibrium :-

Forward rate = reverse rate

$$K_F [A]^{N_A} [B]^{N_B} = K_R [C]^{N_C} [D]^{N_D}$$

$$\frac{K_F}{K_R} = \frac{[C]^{N_C} [D]^{N_D}}{[A]^{N_A} [B]^{N_B}}$$

This agrees with the "equilibrium law" which states that for a reaction with the stoichiometry :



$$\text{The equilibrium constant, } K_{\text{eq}} = \frac{[C]^{N_C} [D]^{N_D}}{[A]^{N_A} [B]^{N_B}}$$

Variation of Rate Constant with Temperature

The rate constant for a reaction is normally related to temperature by an expression

known as the Arrhenius Equation :

For a forward reaction

$$K_F = A_F e^{\frac{-E_F^*}{RT}}$$

Where K_F = forward rate constant

A_F = forward 'frequency factor'

E_F^* = forward 'activation energy'

R = gas constant

T = temperature ($^{\circ}\text{K}$)

The equation may also be written :

$$\ln K_F = \ln A_F - \frac{E_F^*}{RT}$$

For a reverse reaction

$$K_R = A_R e^{\frac{-E_R^*}{RT}}$$

Where K_R = reverse rate constant

A_R = reverse 'frequency factor'

E_R^* = reverse 'activation energy'

R = gas constant

T = temperature

the equation may also be written

$$\ln K_R = \ln A_R - \frac{E_R^*}{RT}$$

The parameters A and E* may be related (rather tenuously) to 'collision' models for reacting molecules in which T is the mean kinetic energy.

For a given reaction it is assumed that A_F and A_R , E_F^* and E_R^* are constant but the simulator must be capable of simulating reactions with a range of values for A and E*.

However, we do not assume that K_F and K_R necessarily change in the same way for any change of temperature as below.

Energetic Changes in a Reaction Vessel

The picture of chemical reactions painted for an A level student is certainly incomplete, but is adequate, in special cases at any rate, to bring the energetic changes that occur as a result of, or as a prerequisite for, chemical reactions which are in register with classical thermodynamics.

Roughly, the reaction vessel contains molecules of reactants and products in motion. Chemical reactions involve the making and breaking of (covalent) bonds between these atoms, of which these molecules are made up with the caveat that in order to react it is at least necessary that reactant molecules are in the same region of space. In general, bond breaking gives out thermal energy as heat, bond making absorbs thermal energy; the mean kinetic energy of the entire system of molecules is given by the (absolute) temperature. If heat is given out as an overall result of a reaction it is exothermic (ΔH is negative), if heat is absorbed the reaction is endothermic (ΔH is positive) and there is a possibility of overall balance (ΔH is zero); so the convention goes.

The total energy may be partitioned in various ways into kinetic and potential components (the potential component being associated with an organised configuration, for example, of a molecule). However, since reactions take place, the distribution is not static. Moreover, the molecules, even if not reacting, can be said to have various varieties of dynamic bond energy (the bonds have vibrational, rotational, energies and the like). In principle, however, we may plot an abstract surface of minimal potential energy for the system, and if projected onto a line this surface is called the "reaction coordinate" (it is the otherwise mysterious horizontal axis in pictures like Fig A3, representing the overall energetics of a reaction;

the plot of energy (E) vertically against this mysterious reaction coordinate).

The frequency factors A_F , A_R , of a reaction do, roughly, represent the frequency of collision between molecules; with slightly greater verisimilitude the frequency with which molecules of reactant are in a condition to react, ie. spend long enough time in close proximity to exchange energy (given the relaxation times of the rotational and vibrational kinds of energy, as well as their energy of motion), to form a complex which is transitional (an "activated complex" in the literature). Similarly, the activation energies E_F^* , E_R^* refer to the additional energy molecules of reactant must have in order to form an "activated complex" and possibly react. Recall that "collision" (ie. "being in the same neighbourhood") is a prerequisite for reaction; it does not guarantee a reaction.

Students are required to demonstrate and to model the heat (enthalpy) change for reactions at a given temperature. Thus the HEAT IN/OUT meter should indicate, in the right sense (but with arbitrary but reasonable scaling) the amount of heat removed from or supplied to the reaction vessel during thermostatically controlled (constant temperature) reactions. The temperature display indicates the absolute temperature of the reaction vessel. For reactions carried out with the "thermostat off" the temperature display should indicate, again in the right sense but with arbitrary scaling, the change of temperature inside the reaction vessel due to the enthalpy change for the reaction.

The enthalpy change for the reaction is defined as follows.

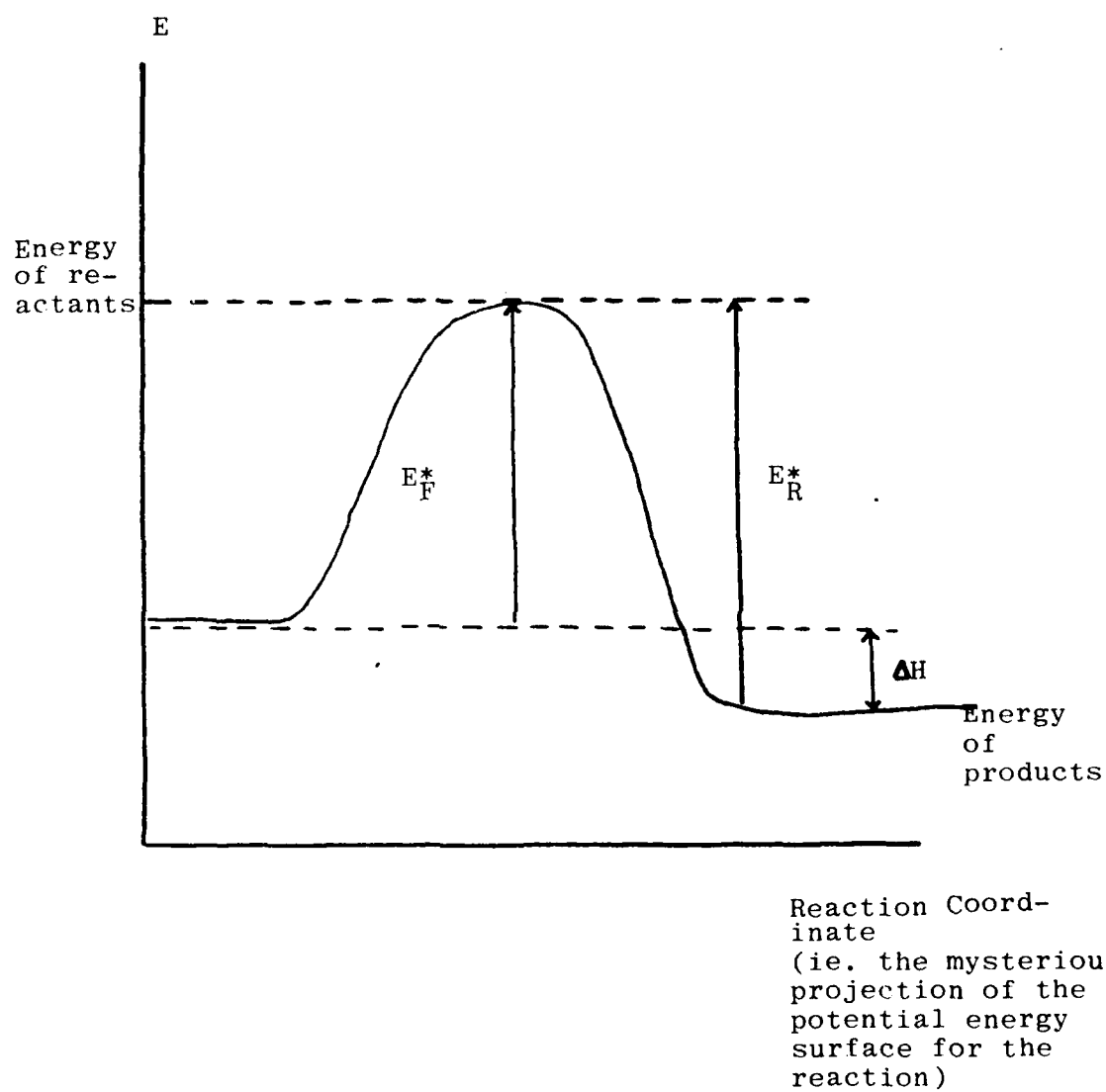


Fig A3: Typical Energy Barrier Picture

ΔH (at temp. T) = "The amount of heating or cooling done by a thermostat in order to compensate for either (a) heat absorption by an endothermic reaction (in bond formation), or (b) the heat emitted in an exothermic reaction (by bond breaking).

Where ΔH is given, graphically, as a difference in Fig A3.

Some Classical Thermodynamic Considerations

The free energy change of a reaction, ΔG , is obtained (if there are means for determining the entropy change of a reaction, as a well specified change in organisation of the overall

system) from the temperature, T, and the enthalpy change ΔH . Thus

$$\text{Change in Free Energy } \Delta G = \Delta H - T \Delta S$$

where ΔH = Enthalpy change as before

ΔS = Change in enthalpy of entire system

T = Absolute temperature, as before

Usefully, the relationship between the Equilibrium Constant K_{eq} and the absolute temperature is given in terms of ΔG . Thus

$$\Delta G = -RT \log K_{eq}$$

Since the simulator is restricted to elementary reactions the relationship between K_{eq} and temp may be derived as follows :-

$$K_{eq} = \frac{K_F}{K_R} = \frac{A_F e^{\frac{-E_F^*}{RT}}}{A_R e^{\frac{-E_R^*}{RT}}} \quad \begin{array}{l} \text{(Arrhenius} \\ \text{functions for} \\ \text{forward and} \\ \text{reverse rate} \\ \text{constant)} \end{array}$$

therefore :

$$\ln K_{eq} = \ln \frac{A_F}{A_R} - \frac{(E_F^* - E_R^*)}{RT}$$

But $E_F^* - E_R^* = \Delta H$ (Fig- A3), the enthalpy change for the reaction.

Therefore :

$$\ln K_{eq} = \ln \frac{A_F}{A_R} - \frac{\Delta H}{RT}$$

and students are required to investigate the variation of K_{eq} with T , and the variation of rate constant with T as defined by the Arrhenius function (Figs A4 and A5).

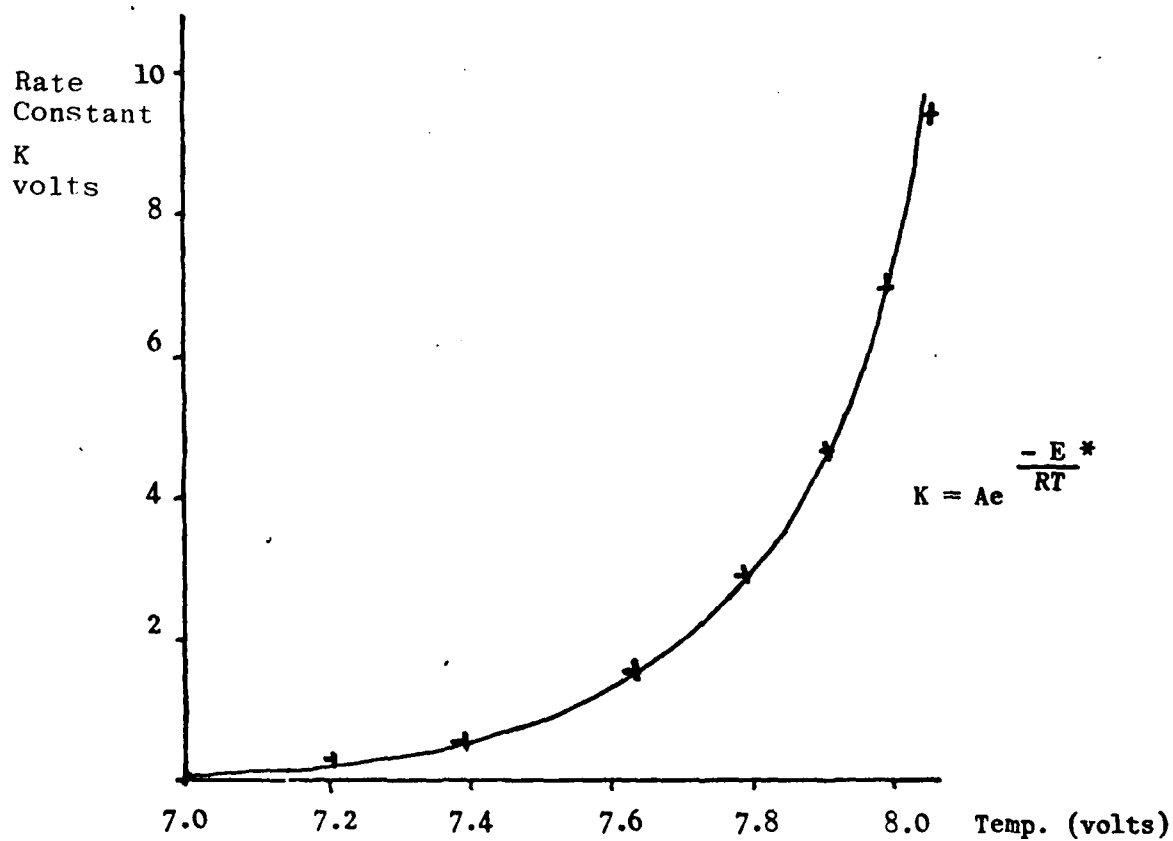


Fig A4: Variation of rate constant with temperature (any reasonable scaling)

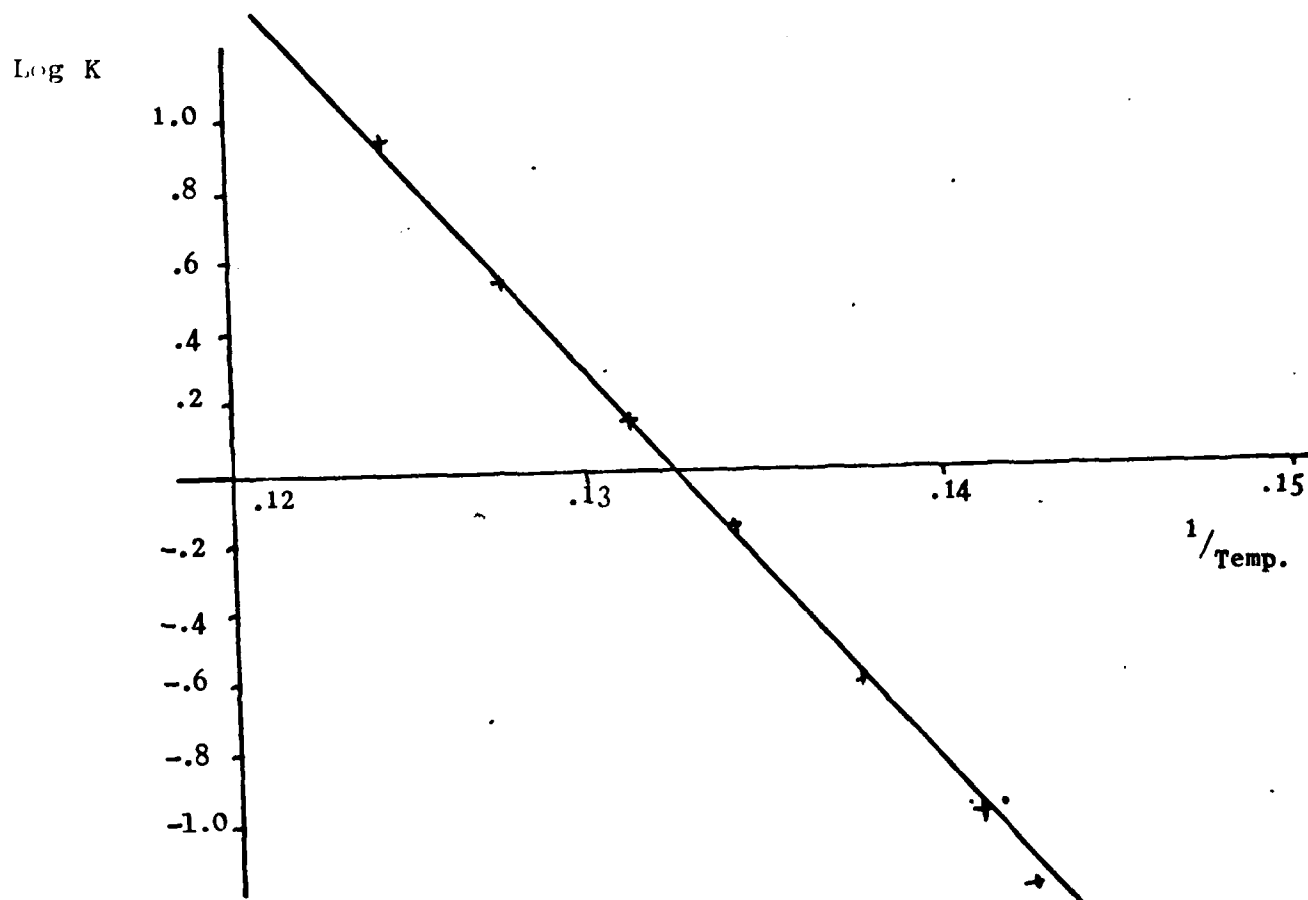


Fig A5: Arrhenius Function linearisation
(log rate constant vs. temperature
inverse)

Interconnection of Simulations to Simulate Complex Reactions

At a later stage in the project we plan to extend the simulation of reactions to include 'complex' reactions, ie. reactions occurring as a combination of elementary reactions in parallel and/or series. This is to be achieved by the interconnection of a number of the type of simulator described in this specification. When simulations are interconnected the resulting system should exhibit more complex rate equations typical of many non-elementary chemical reactions.

The simulator design should, therefore, incorporate a means of connecting with other simulators in a series/parallel arrangement. It is intended that the simulated complex reaction should take place in a reaction vessel with a single thermostatic temperature control, ie. only one thermostat and display will be required. Impedance and voltage level standards are open to discussion.

Programming

The production model of the simulator should be capable of being programmed with values of stoichiometric coefficients. Arrhenius parameters etc using a plug in card or similar device. This is intended to allow the teacher to set up specific problems on the simulator. The physical

means for programming the simulator need not be incorporated in the prototype but the designer should take the programmability requirement into account where appropriate in the circuit design.

Simulator Controls and Displays

You are provided with a panel containing most of the essential displays and controls :

Concentration Meters: Display values of concentration for reactants A, B and products C, D.

Stoichiometric Coefficients: LEDs indicating pre-set values of stoichiometric coefficients

N_A, N_B, N_C, N_D .

Temperature: Indicates temperature of reaction vessel ($^{\circ}\text{K}$). The range of temperatures displayed by the meter is to be specified as part of the design. If the thermostat switch is in the 'ON' position, the temperature is to remain reasonably constant. If the thermostat is switched off the temperature should change in the appropriate direction as the reaction proceeds. The temperature may be an arbitrary function of extent of reaction provided the temperature increases if the reaction is exothermic and decreases if the reaction is endothermic.

Heat IN/OUT: When the reaction temperature is thermostatically controlled heat will be removed from the reaction vessel or supplied depending on whether the reaction is exothermic or endothermic. Again, the amount of heat may be an arbitrary function of extent of reaction.

Set Initial Concentrations: Controls which allow initial values of reactant and/or product concentrations to be established when the simulator is in the reset mode.

Add Reactant A, Remove Product C: These push buttons simulate the effect of adding more reactant A or removing some of product C while the reaction is taking place. This facility is useful for demonstrating the tendency of a reaction at equilibrium to return to equilibrium (with the same value of K_{eq}) if the equilibrium is disturbed.

Reset, Run, Hold: Controls on the lower panel of the analogue computer unit. These switches control the mode of operation of the integrated circuits.

Stoichiometric coefficients: Four rotary switches on the lower panel labelled N_A , N_B , N_C , N_D .

Additional Controls/Displays

In addition to the displays and controls provided, the prototype simulator should incorporate

the following controls :

(a) Arrhenius Function Parameters:
Potentiometers to establish values of A and E^* for forward and reverse reactions.

(b) Switches which allow the rate constants to be set manually (using potentiometers) or computed using the Arrhenius equation.

(c) Monitoring sockets: Forward and reverse rate constants, ΔH .

Any additional controls or monitoring sockets considered useful, either to the potential user or to facilitate simulator testing, should be included in the prototype.

Performance Requirements

It is difficult to quantify the requirements for simulator accuracy needed to produce an effective tutorial device. Accordingly, the following performance guidelines are provided :

(a) Given input parameters set to produce an nth order reaction a graph of concentration of a reactant or produce versus time should give the appropriate reaction profile. The order of the reaction as determined by the use of either the

integrated rate equation or the initial rates method should be unmistakably nth order.

(b) For any given setting of input parameters the value(s) obtained for the rate constant (from graphs) should be predictable and repeatable.

(c) The rate constant should approximately double for every 10° Kelvin rise in temperature and plots of $\text{Log. (rate constant) vs (Temp)}^{-1}$ should be linear.

(d) If the Activation Energy parameter, for either forward (E_F^*) or reverse reactions (E_R^*), is increased then the rate constant (K_F or K_R) should decrease.

(e) If the frequency factor A_F (for the forward reaction); A_R (for the reverse action); is increased then K_F or K_R should increase.

(f) If $E_F^* < E_R^*$ then the enthalpy change for the reaction ($\Delta H = E_F^* - E_R^*$) is negative and the reaction is exothermic.

If $E_F^* > E_R^*$ then the enthalpy change is positive and the reaction is endothermic.

(g) Observed values of the equilibrium constant for a reaction should agree with expected values (according to the "equilibrium law") to within typical margins of experimental error (10%).

(h) The equilibrium constant for a reaction should increase with temperature rise if the reaction is endothermic and decrease with temperature rise if the reaction is exothermic. Graphs of $\text{Log (equilibrium constant) vs. (Temp)}^{-1}$ should be linear.

Appendix 2

MANUAL FOR PROGRAMMING DESIGN TASK

Manual for Programming Design Task

This manual describes the BASIC variables reserved for actuating displays and reading controls on the reaction kinetics console; BASIC statements and functions and a number of useful routines (which act as special functions), for example, integration and means for obtaining real time values so that the display can change with time in a suitable manner for depicting the progress of a chemical reaction.

Further information, either about the programming language, or about physical chemistry is available on request, though the manual is sufficiently informative for you to satisfy the program design specification.

(a) Reserved Variables

<u>Programming Task Variables</u>		<u>Variable</u>	<u>Range</u>
<u>Concentrations.</u> Reactant	A	M1	0-255
	B	M2	0-255
	C	M3	0-255
	D	M4	0-255
Initial Concentration	A	N1	0-255
	B	N2	0-255
	C	N3	0-255
	D	N4	0-255
Time (Simulation Time)		J ϕ	0-255
<u>Stoichiometric Coefficients</u>			

Reactant	A	L1	0, 1 or 2	(all x 50)
	B	L2	0, 1 or 2	(all x 50)
	C	L3	0, 1 or 2	(all x 50)
	D	L4	0, 1 or 2	(all x 50)

Temperatures

Initial temperature	T0	0-255
Reaction vessel temperature	T1	0-255
Thermostat on/off	T2	0 or 1 (both x 50)

Arrhenius Function Parameters

P _F	P1	0-255
P _R	P2	0-255
Q _F	Q1	0-255
Q _R	Q2	0-255

Rate Constants

K (forward)	K1	0-255
K (reverse)	K2	0-255

K manual or compute (forward)	L1	0 or 1 (both x 50)
K manual or compute (reverse)	L2	0 or 1 (both x 50)

Heat (Enthalpy Change)

ΔH	H1
H	H2

Additional reactant variables

Add	Reactant	A	L5	+1 — +100
Subtract	Reactant	C	L6	-1 — -100
Mode Control number input			J1	1, 2, 3, 4 (all x 50)
(Reset, run, hold, repeat)				

1 2 3 4

(b) The following extracts from the CED BASIC manual summarise the BASIC statements and functions.

Section 3

ELEMENTS OF THE LANGUAGE

3.1 INTRODUCTION

A BASIC program consists of one or more BASIC lines. A BASIC line consists of a line number followed by a BASIC statement, and terminated by a non-printing carriage return character. A line number consists of from one to four decimal digits in the range of 1 to 9999, and is used to establish the order of the lines in a program. BASIC statements are executed in the ascending order of their line numbers beginning with the lowest numbered executable statement and proceeding through successively higher numbered executable statements except where specifically directed otherwise by control statements such as GOTO, IF, or GOSUB. When writing a BASIC program, it is advisable to number BASIC lines by fives or tens to allow for the possible later insertion of new lines.

A BASIC statement is made up of a sequence of keywords, operands, and operators.

A keyword is a sequence of letters having special significance to the system. In the statement definitions in Section 4, they are shown in capital letters. Examples of keywords are PRINT, INPUT, and LET.

An operand is a variable, a constant, or a function reference. During execution of a BASIC program an operand has a value which is a positive or negative real number whose magnitude is either zero or in the approximate range 2.71×10^{-20} to 9.23×10^{18} . This provides more than six decimal digits of accuracy.

Space characters may be freely used anywhere in a BASIC line to improve the appearance and readability of the BASIC program.

3.2 CONSTANTS

A constant is an item whose value is always defined during execution of a program. Constants may be expressed as integers, decimal numbers, or in exponential format, i.e., a decimal number times some power of ten. A constant consists of a sequence of digits possibly containing a decimal point (.), and possibly followed by a decimal exponent consisting of the letter E, an optional sign, and one or two digits, in that order. The following are examples of constants:

7	Integer
325	Integer
2.6	Decimal number
3.14	Decimal number
.000314E+4	Decimal number in exponential format
314E-02	Decimal number in exponential format

3.3 VARIABLES

A variable is an item, represented by a symbol, that may be assigned a value. A simple variable is either a letter or a letter followed by a digit. A subscripted variable is a letter followed by one or more expressions enclosed in parentheses; if multiple expressions are used, they are separated by commas. For example:

A	Simple variable
B2	Simple variable
X(3)	Subscripted variable
E(A*3)	Subscripted variable
J(Y2,I+5)	Subscripted variable

3.4 FUNCTION REFERENCE

A function reference consists of a three letter function name followed by a parenthesized list of arguments. If there is more than one argument they are separated by commas. The number of arguments supplied in a function reference must agree with the number of arguments supplied in the function definition. Reference to a function produces a value which in general is dependent on (i.e., a function of) the current values of the arguments. The system supports both user-defined and system-defined functions as described in section 6.

3.5 OPERATORS

An operator is a symbol used in forming an expression. There are two types of operators as listed below:

ARITHMETIC OPERATORS

Symbol	Example	Meaning
+	A+B	Addition
-	A-B	Subtraction
*	A*B	Multiplication
/	A/B	Division
↑	A↑B	Exponentiation

RELATIONAL OPERATORS

Symbol	Example	Meaning
<	A<B	A less than B
>	A>B	A greater than B
<=	A<=B	A less than or equal to B
>=	A>=B	A greater than or equal to B
=	A=B	A equal to B
<>	A<>B	Z not equal to B

Operators are said to operate on operands; more precisely, they operate on the current values of the operands.

3.6 EXPRESSIONS

An expression is a sequence of operands and operators, possibly grouped by parentheses. An operand standing by itself is an expression, and if E and F are expressions and @ is any operator, then E @ F, (E), +E, and -E are also expressions.

3.7 EXPRESSION EVALUATION

Within an unparenthesized expression the order of evaluation is:

- Exponentiation
- Multiplication and division
- Addition and subtraction
- Relationals

Within a sequence of consecutive operators of the same type, evaluation is from left to right.

Parentheses may be used to override this basic rule for order of evaluation. Parenthesized portions of expressions are evaluated first. Nested parenthesized groups are evaluated beginning with the inner-most grouping, working outward.

All expression evaluation is done in standard floating-point form as defined above. When a pair of operands is operated on by a relational operator, the result is either one or zero depending on whether the relation is true or false, respectively.

The following table shows examples of expressions and the values that would result from their evaluation. It is assumed that the operands X, Y, and Z have the value 4, 3.14, and -2.7, respectively.

<u>Expression</u>	<u>Value</u>
X	4
Z+7	4.3
-2	-2
SGN(Z)	-1
INT(Y+ABS(Z+1))	4
X↑2*Z+Y	-40.06
X↑2*(Z+Y)	7.04
X<Y<Z	0

Note that relational operators are not restricted to use in IF statements. For example, the statement

LET X = 5*(Y>0) + 4*(Y<=0)

may be used to substitute for a sequence of several statements.

Section 4

BASIC STATEMENTS

4.1 INTRODUCTION

This section defines the general form and operation of the BASIC statements. Section 4.2 defines those statements included in both the BASIC-1 and BASIC-2 Systems, whereas section 4.3 defines the statements that are only applicable to BASIC-2 Systems.

In the following presentation of the general form of each BASIC statement, the following conventions apply:

1. Elements in capital letters, such as FOR, THEN, and GOSUB, are required and must appear exactly as shown. (Exception: see LET description.)
2. Elements in lower-case are supplied by the user.

GOTO line number

3. Square brackets surrounding an element of the language indicate that the element is optional and may be included or omitted at the user's option.

INPUT variable [,variable]

4. A right square bracket followed by an ellipsis (...), indicates that the enclosed element may be omitted or repeated an arbitrary number of times.

DATA constant [, constant] ...

4.2 BASIC-1 STATEMENTS

The BASIC-1 language consists of 18 statements. There are two classes of statements: Executable and non-executable.

Non-executable statements are used to specify data items and functions to be used in a program, or to include comments concerning the purpose or operation of a program. The non-executable statements include:

DATA - used to introduce a constant, or a series of constants, into a program.

DIM - used to reserve storage space for arrays.

DEF - used to specify user-defined functions.

REM - used to include program descriptive remarks.

Executable statements control the input and output of data, the evaluation of mathematical formulas, and the control of the program flow. Executable statements include

READ - used to select constants from DATA statements and assign their values to the variables supplied in READ statements.

INPUT - used to accept data from the input device.

PRINT - used to output formatted data to the output device.

RESTORE - used to permit DATA statement constants to be re-used.

LET - used to assign a value to a variable.

GOTO - used to branch to a specified statement.

GOSUB - used to call a subroutine.

RETURN - used to return from a subroutine.

FOR - NEXT - used in combination to define a program loop.

IF - THEN (or IF - GOTO) - used for conditional branching.

ON - used to conditionally select the next statement for execution based on the evaluation of an expression.

STOP - used to return the system to the command mode.

END - used to signify the end of program execution.

4.2.1 READ Statement (Executable)

The READ statement is used in conjunction with DATA statements to permit the assignment of constants to variables as a program is executed. The general form of the READ statement is:

READ variable [,variable]...

For each variable in the list the next constant is obtained from the consolidated DATA statement list; it is converted to internal floating-point form, and the resulting value is assigned to the variable.

4.2.2 DATA Statement (Non-Executable)

The DATA statement is used to introduce a constant, or a series of constants, into a program. The general form of the DATA statement is:

DATA signed constant [,signed constant]...

DATA statements establish a sequence of values to be accessed by the READ statements in the program. There may be any number of DATA statements in a program, each containing any number of constants (within the constraints imposed by the length of a BASIC line). When the last constant in a DATA statement has been accessed by a READ

statement, the next constant accessed by the same or a different READ statement will be the first constant in the next DATA statement.

```

10 DATA 1, -2, 1.25
20 READ A, B, C, D, E
30 DATA 50
40 READ F, G
50 READ H
60 DATA 20.0E3, 0.155E-10, 252
70 END

```

In the preceding example, the READ statement at line 20 will assign the values 1, -2, 1.25, 50, and 20,000 to the variables A, B, C, D, and E. The READ statement at line 40 will assign the values 0.155 E-10 and 252 to the variables F and G. The READ statement at line 50 attempts to access a value after the last constant in the last DATA statement has been used. The BASIC System will then return an error message, terminate program execution, and return to the command mode.

4.2.3 RESTORE Statement (Executable)

The RESTORE statement permits the re-use of DATA statement constants. The general form of the RESTORE statement is:

RESTORE

Execution of this statement causes the series of constants defined by the DATA statements of the program to be re-used. That is, the first value obtained by the logically next READ statement will be derived from the first constant in the physically first DATA statement in the program.

Example:

```

10 DATA 0,1
20 READ A,B
30 PRINT A,B
40 RESTORE
50 READ E,F
60 END

```

The variables E and F will be assigned the values 0 and 1, respectively.

4.2.4 INPUT Statement (Executable)

The INPUT statement is used to enter data from the input device while a program is running. The general form of the INPUT statement is:

INPUT variable [,variable]...

When an INPUT statement is executed, the system prints a prompt character '?' at the user's terminal to indicate that it is ready to accept a line of data. The user then may type in one or more constants formatted exactly the same as specified for the DATA statement (but without the keyword DATA), followed by a carriage-return character. The system then converts the constants into internal floating-point form and assigns the resulting values in order to the variables listed in the INPUT statement.

If the user supplies fewer constants than there are variables, the system prints another prompt character and waits for another line of data. If the user supplies more constants than there are variables in the INPUT statement, the extra constants are ignored.

Example:

```
INPUT X1, X2, L(1), L(2), L(3)
```

4.2.5 PRINT Statement (Executable)

The PRINT statement is used to output formatted data on the output device. The general form of the PRINT statement is:

```
PRINT [print element]...
```

If there is no list following the keyword PRINT, a line is skipped on the user's terminal. If there is a list, the items in it are formatted as described below and printed on one or more lines on the user's terminal.

4.2.6 LET Statement (Executable)

The LET statement is used to assign a value to a variable. The general form of the LET statement is:

```
LET variable = [variable=]...expression
```

The expression on the right is evaluated and the resulting value becomes the current value for each of the variables appearing to the left of an equals sign.

Examples:

```
10 LET X=4+Z1
20 LET A(1)=A(2)=0
30 LET W=X=Y+Z
40 LET W=X+Y=Z
```

Note that in line 30 the second equals sign acts as a replacement (assignment) operator, whereas in line 40 the second equals sign acts as a relational operator.

Expressions appearing as subscripts are evaluated before any value replacements are done. For example, if the current value of J is 4, the assignment statement

```
LET X(J-1)=J=3
```

will replace the value of X(3), not X(2).

For the operator's convenience, the word "LET" may be omitted when typing in a LET statement. This is handled internally as follows: Since each statement normally begins with a keyword of two or more consecutive alphabetic characters, and since in a LET statement the variable which follows the word "LET" must be of the form

```
A=
or A(1,2)=
or A$=
or A$(1,2)=
```

none of which begin with two alphabetic characters, the statement processing logic assumes that any statement which begins with an alphabetic character followed by a non-alphabetic character is a LET statement with the word "LET" omitted. When this situation is encountered, the internal processor inserts the four characters

```
LET
```

into the line where the first alphabetic character was encountered. Thus a subsequent listing of such a line will appear with the word "LET" inserted.

Example:

```
*100 A=1.2
*200 END
*LIST
100 LET A=1.2
200 END
*
```

4.2.7 GOTO Statement (Executable)

The GOTO statement is used to unconditionally alter the sequence of statement execution. The general form of the GOTO statement is:

```
GOTO line number
```

When control reaches a GOTO statement during the execution of the user's program, control is unconditionally transferred to the statement having that line number.

Example:

```
10  INPUT X
20  PRINT EXP (X)
30  GOTO 10
40  END
```

Execution of this program converts the user's terminal into a device which automatically types out the value of e^x each time a value (X) is typed in.

4.2.8 GOSUB and RETURN Statements (Executable)

The GOSUB and RETURN statements give the BASIC language a subroutine capability. The general form of the GOSUB and RETURN statements is:

GOSUB line number

RETURN

Execution of a GOSUB statement transfers control to the specified line number. Execution of a RETURN statement sends control to the first executable statement following the most recently executed GOSUB statement for which a RETURN has not yet been executed.

Example:

```
10  LET X=5
20  GOSUB 60
30  LET X=7
40  GOSUB 60
50  STOP
60  LET A(I) =X
70  LET I=I+1
80  RETURN
```

Subroutines may also be nested; i.e., subroutines may contain calls to other subroutines. Such nesting can be carried to any level. The following example illustrates subroutine nesting with a shared RETURN statement.

```
20  GOSUB 30
25  STOP
30  LET X=5
31  LET Y=7
32  GOSUB 40
33  LET X=X 2
34  LET Y=Y 2
35  GOSUB 40
36  LET X=X*5
37  LET Y=Y*9
40  PRINT X,Y
45  RETURN
```

4.2.9 FOR and NEXT Statements (Executable)

The FOR and NEXT statements are used to specify the beginning and ending points of program loops. The general form of the FOR and NEXT statements is:

FOR simple variable=expression TO expression [STEP expression]

NEXT simple variable

The FOR statement in conjunction with the NEXT statement provides the user with a convenient mechanism for defining program loops in which a simple variable varies linearly as the loop proceeds. The association between FOR and NEXT statements is established by the identifier of the simple variable. FOR and NEXT statements must be paired within a program, and the set of statements through which control passes between them is called the range of the FOR statement. Referring to the first, second, and third expressions in the FOR statement as X, Y, and Z, respectively, X is the first initial value of the simple variable for the first execution of the range. Z specifies the value to be added to the current value of the simple variable each time control reaches the associated NEXT statement. If Z is missing from the FOR statement a value of +1 is used. If Z is specified, it must be preceded by the keyword STEP. Then if the quantity $(Y-X)/Z$ is not less than zero, control is passed to the first executable statement following the FOR statement; otherwise, control passes to the first executable statement following the NEXT statement. The values used are the ones obtained when the FOR statement is first encountered. The range of the FOR statement is always executed at least once even if the quantity $(Y-X)/Z$ is less than zero to start with.

The following is an example of nested FOR statements:

```
10  DIM      A(20,20), B(20,10), C(10,20)
20  FOR I =   1 to 20
30  FOR J =   1 to 20
40  LET      A(I,J)=0
50  FOR K =   1 to 10
60  LET      A(I,J)=A(I,J)+B(I,K)*C(K,J)
70  NEXT K
80  NEXT J
90  NEXT I
100 END
```

4.2.10 IF Statement (Executable)

The IF statement is used to provide a conditional program branch. The general form of the IF statement is:

IF expression THEN line number
 or
IF expression GOTO line number

When an IF statement is executed, the expression is evaluated and interpreted as a logical value. If the value is false, control is transferred to the next executable statement. If the value is true, control is transferred to the statement having the specified line number. A value of zero is false; any non-zero value is true.

The expression usually takes the form $E@F$, where @ is one of the relational operators, and E and F are expressions.

```

10  INPUT X
15  IF X<=0 THEN 30
20  PRINT LOG (X)
25  GOTO 10
30  PRINT "POSITIVE VALUES REQUIRED"
35  GOTO 10
40  END

```

4.2.11 ON Statement (Executable)

The ON statement is used as a conditional GOTO statement to alter the sequence of statement execution. The general form of the ON statement is:

ON expression GOTO line number [,line number]...

When an ON statement is executed, the expression is evaluated and the result is truncated to an integer. The integer is then used as an index to select one of the line numbers in the list. Control is transferred to the statement having the selected line number. If the integer is less than one or greater than the number of line numbers specified, control passes to the statement after the ON statement.

The ON statement gives the user a multi-directional switch capability.

```

2   INPUT X
4   ON SGN (X)+2 GOTO 6, 10, 14
6   PRINT "IMAGINARY"
8   GOTO 2
10  PRINT "UNDEFINED"
12  GOTO 2
14  PRINT LOG (X)
16  GOTO 2

```

4.2.12 STOP Statement (Executable)

The STOP statement is used to terminate program execution. The general form of the STOP statement is:

STOP

Upon encountering a STOP statement during the execution of a program, execution ceases and the system reverts to the command mode of operation. (See section 2).

STOP statements can be used anywhere in a program to designate the logical rather than the physical end of a program. STOP is useful in debugging programs, and in suspending program execution at critical points where a user may wish to display intermediate results, and then alter program execution depending on the displayed results.

4.2.13 DIM Statement (Non-Executable)

The DIM statement is used to reserve storage space for data arrays. The general form of the DIM statement is:

```
DIM letter(constant[,constant]...),letter(constant ,constant ...)...
```

The DIM statement defines the name and dimensionality of arrays. Each "letter" appearing in a DIM statement becomes the name of an array, so that a maximum of 26 arrays may be declared in a program. The dimensionality of an array is determined by the number of constants in parentheses following the name. Each constant must be a positive integer, and the value of the constant defines the largest value that a subscript expression in that position may have. The minimum value that any subscript expression may have is zero. Every reference to an element of the array must contain exactly as many subscript expressions as there are constants in the declaration of the array. For example, the statement

```
DIM P(5), Q(8,6,4), R(2,2,2,2,3)
```

defines three arrays, containing 6, 315, and 324 elements, respectively. Q is a 9x7x5 array, and references elsewhere in the program to elements of Q must carry a parenthesized list of three subscript expressions. The reference Q(0,0,0) refers to the first element of Q. P is a one-dimensional array (vector).

It is permissible for an array name to be the same as the name of a simple variable.

DIM statements may appear anywhere in the program, and they are not required to precede references to the arrays they define.

4.2.14 DEF Statement (Non-Executable)

The DEF statement enables the introduction of a user defined function. The general form of the DEF statement is:

```
DEF FN letter(simple variable[,simple]variable...)=expression
```

The DEF statement gives the user a convenient means of avoiding rewriting expressions which occur frequently in his program and differ only in their operands. The "FN letter" combination becomes the name of an explicitly defined function which may then be used whenever a function reference is permitted. Such a reference causes the evaluation of the names shown in the definition. The 'letter' in the function name may be any of the 26 alphabetic characters, thus giving the user a potential repertoire of 26 explicitly defined functions.

The DEF statement which defines a function name need not precede the reference.

It is permissible (although not necessarily desirable) for the argument names in the definition to be the same as names used elsewhere in the program.

Example:

Using the recursive definition

$$X_m + 1 = \frac{1}{2}(X_m + Y/X_m)$$

make three iterations starting with $X_1 = 1$.

```
10 DEF FNQ(C)=(C+Y/C)/2
20 LET Y=4
30 LET X=FNQ(FNQ(FNQ(1)))
```

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The general form and the effect of executing each of the twelve matrix statements is defined below. The reader is presumed to have a knowledge of matrices and matrix operations.

4.3.1.1 Matrix Replacement

General Form:

`MAT matrix=matrix`

Effect:

Each element of the first matrix is assigned the current value of the corresponding element of the second matrix. The two matrices must have the same dimensions.

4.3.1.2 Matrix Addition

General Form:

`MAT matrix=matrix+matrix`

Effect:

Each element of the first matrix is assigned a value which is the sum of the corresponding elements of the other two matrices. All three matrices must have the same dimensions.

4.3.1.3 Matrix Subtraction

General Form:

`MAT matrix=matrix-matrix`

Effect:

Each element of the first matrix is assigned a value which is the difference between the corresponding elements of the second and third matrices. All three matrices must have the same dimensions.

The preceding three kinds of matrix statements (replacement, addition, and subtraction), may be used with matrices of any dimension as long as they match.

4.3.1.4 Matrix Multiplication

General Form:

`MAT matrix=matrix*matrix`

Effect:

The elements of the first matrix are assigned values such that it is the product of the other two matrices according to the usual rule for matrix multiplication. The standard restrictions concerning the dimensions of the three matrices apply. That is if x, y, and z represent integer constants, then the following relationship must exist between the dimensions of three matrices A, B, and C:

`DIM A(x,z),B(x,y),C(y,z)`
`MAT A=B*C`

The matrix on the left side of the equal sign must not be the same matrix as either of the matrices on the right.

4.3.1.5 Scalar Multiplication

General Form:

`MAT matrix=(expression)*matrix`

Effect:

Each element of the first matrix is assigned a value which is the product of the value of the expression and the corresponding element of the second matrix. The two matrices must have the same dimensions.

4.3.1.6 Matrix Transposition

General Form:

`MAT matrix=TRN(matrix)`

Effect:

The first matrix is made the transpose of the second matrix. The two matrices must be square and have the same dimensions; they may be the same matrix.

4.3.1.7 Matrix Inversion

General Form:

MAT matrix=INV(matrix)

Effect:

The elements of the first matrix are assigned values such that it is the inverse (in the usual mathematical sense) of the second matrix. The two matrices must be square and have the same dimensions.

NOTE

The algorithm used by the INV function will output the "SM" error message if the matrix to be inverted is singular (determinant=zero) or nearly singular (any main diagonal element=zero). To invert a nearly singular matrix, the user may either perform elementary row operations on the matrix to make a main diagonal element non-zero, or use the Inversion library routine described in section C.2 which accepts nearly singular matrices.

4.3.1.8 Zero Matrix

General Form:

MAT matrix=ZER

Effect:

The value of each element of the matrix is set to zero.

4.3.1.9 Identity Matrix

General Form:

MAT matrix=IDN

Effect:

The value of every element of the matrix is set to zero except for the elements on the principle diagonal which are set to one. The matrix must be square.

4.3.1.10 Constant Matrix

General Form:

MAT matrix=CON

Effect:

The value of each element of the matrix is set to one.

4.3.1.11 Print Matrix

General Form:

`MAT PRINT matrix[separator]matrix ...separator`

Effect:

The value of every element of each of the elements in the list is printed in the format described under the PRINT statement. Each separator is either a comma or a semicolon, and it governs the spacing on the print line between each matrix element in the same way as for ordinary printing. The matrix elements are ordered row-wise, and each row is started in a new line.

4.3.1.12 Read Matrix

General Form:

`MAT READ matrix[,matrix]...`

Effect:

Every element of each matrix in the list is assigned a value taken from a constant in the consolidated DATA statement list. The matrix elements are ordered row-wise.

4.3.3 CALL Statement (Executable)

In BASIC-2 and BASIC-3 programs, the CALL statement communicates with a Machine Language Subroutine previously linked and loaded as a part of the BASIC Processor.

The general form of the statement is:

`CALL (n[,argument]...)`

The integer value of the variable or constant shown as n corresponds to one of 20 possible subroutine names, from ML1 thru ML20.

Each argument can be either a constant or the name of a non-subscripted variable. The name of an array or of a function is not acceptable.

This CALL statement transfers control to ML6, and passes it 2 names and 2 constants:

`CALL (6, X2, A$, 255, "MESSAGE")`

Section 5

BASIC COMMANDS

5.1 INTRODUCTION

The BASIC System accepts six commands for controlling a user's operating environment. Each command consists of a unique keyword of from three to five letters. Commands are not preceded by a line number, and are always executed immediately upon entry. Square brackets surrounding an element of the line indicate that parameter is optional and may be included or omitted as required. The six commands are:

LIST - List all or part of a user's program
PUNCH - Output all or part of a user's program to paper tape
CLEAR - Initialize a user's word area
RUN - Begin execution of a user's program
TAPE - Accept program input from paper tape
TYPE - Accept program input from the keyboard

5.2 LIST COMMAND

The LIST command is used to print all or part of a user's BASIC program as it currently stands in a user's work area. The general form of the LIST command is:

LIST [line number[,line number]]

If there are no line number parameters following the keyword, the entire program is printed. If only a single line number is given, that line is printed. If the command contains two line number parameters, that portion of the program whose line numbers lie between the values is printed.

If the line to be listed is non-existent, the next higher numbered line will be printed. If there is no higher numbered line, no listing will occur.

Although the user may have originally entered his program statements in any order, they are maintained in the work area in order of ascending line number, and this is the order in which they are listed.

5.3 PUNCH COMMAND

The PUNCH command is used to output all or part of a user's BASIC program as it currently stands in the user's work area to paper tape or disc file. The general form of the PUNCH command is:

PUNCH [line number[,line number]]

If there are no line number parameters following the keyword, the entire program is punched. If only a single line number is given, that line is punched. If the command contains two line number parameters, that portion of the program bounded by the specified line numbers is punched.

Although the user may have originally entered his program statements in any order, they are maintained in the work area in order of ascending line number, and this is the order in which they are punched.

The format of the program on paper tape is such that it can be read back into the user's work area at a later time for execution or further modification.

5.4 CLEAR COMMAND

The CLEAR command is used to initialize a user's work area. The general form of the CLEAR command is:

CLEAR

When a CLEAR command is entered a user's work area is cleared of all program text, and his relation with the BASIC System is re-initialized. After execution of a CLEAR command the only meaningful action on the part of the user is a series of program editing directives to construct a new program in his work area.

5.5 RUN COMMAND

The RUN command is used to begin execution of a user's BASIC program. The general form of the RUN command is:

RUN

Upon receiving a RUN command the BASIC System leaves the command mode of operation and enters the execution mode. The user's program as it currently stands in the work area is executed statement by statement, beginning with the first (lowest numbered) executable statement, and continuing until a STOP or END statement is encountered, or until an abnormal condition occurs. At this point a message identifying the cause and location of the termination is printed, the System re-enters the command mode of operation and prints the asterisk prompt character.

5.6 TAPE COMMAND

The TAPE command is used to inform the BASIC System that a BASIC program is to be input from disc or paper tape. The general form of the TAPE command is:

TAPE

Section 6

BASIC FUNCTIONS

6.1 FUNCTIONS

The BASIC System includes 13 pre-defined functions to perform mathematical operations. A function reference consists of a three letter function name followed by a parenthesized list of arguments. If there is more than one argument, they are separated by commas. The number of arguments supplied in a function reference must agree with the number of arguments specified in the function definition. Reference to a function produces a value which in general is dependent on (i.e., a function of) the current values of the arguments.

COMMON FUNCTIONS:

EXP	(X)	E raised to the X power
LOG	(X)	Natural logarithm of X
ABS	(X)	Absolute value of X
INT	(X)	The largest integer not greater than X
MOD	(X,Y)	X modulo Y
SGN	(X)	A value indicating the sign of X
SQR	(X)	Square root of X
RND	(X)	A random number between 0 and 1

The arguments X and Y to the functions may be a constant, a variable, an expression, or another function.

The value of the argument to the RND function governs the generation of random numbers in the following way: if the value is zero then the random number is generated from the previously generated random number (or from a fixed value if this is the first request for a random number within the current execution); if the value is non-zero then it takes the place of the previously generated number (or the fixed value) in the algorithm that produces the new random number. In this way, the user has the option of always generating the same sequence of random numbers (for check-out purposes, perhaps) or of generating a different sequence for each execution of his program.

The SGN function returns the value -1, 0, or +1, depending on whether the value of the argument is negative, zero, or positive.

In addition to the 13 pre-defined functions listed above, the CAI BASIC System supports user-defined functions, where the function reference is of the form:

FNa	(X)	User-defined function; a is any letter; and the function must be defined in a DEF statement.
-----	-----	--

(c) Special routines for operation A/D or D/A converters.

The general format for any output given to any D/A conversion is as follows where X, Y, will be explained.

(1) "Call(6, X, Y)" Assigns to a meter Y = 1 to 6 the value of the variable X

For example, "Call(6, M1, 1)" (X = M1, Y = 1)
Assigns the value of variable M1 to meter 1.

(2) For input, the statements assign the value on a given potentiometer or switch to a given variable. Again, the forms used are transparent.

"Call(7, X, Y)" Assigns the value of potentiometer or switch Y, to a variable X.

For example, "Call(7, D1, 1)" gives variable D1, the (initial concentration) the value on potentiometer, 1.

(3) "Call(5, J)" Outputs the value of RTC to the regulation time variable, J (the time intervals lie between 0 and 255 but can be divided to alter the preset simulation interval)

For example,
"Call(5, J)" assigns the variable J (previously set to 0, say) the current RTC value (0 to 255)

(4) "Call(5, 0)" Initialises RTC (for example, in reset)

(d) This routine is one quite convenient method of computing any integral between limits of some function FNF (Z) of a variable Z; for example, of $Z = J$. It works by successive summation of areas beneath the curve of the function using approximation rules (Simpsons, Midpoint, and Tripezoidal) and iterating, as required, to reduce the size of the rectangular segments beneath the curve, until there are negligible differences between the different area approximations that are used.

It is necessary to specify, Z, to Define the function of Z, and to define the limits Z1, Z2, between which the value of the integral (called Z0) is to be found. The output assigns a value to Z0.

It is assumed below that instructions are written with the usual 5 line gaps, starting at line XY05. As written, the routine is part of a program. If used as a subroutine, it is entered by GOSUB XY05 and XY86 is Return.

```

XY05 Let DEF FNF (Z) = Whatever Expression (say  $e^{\frac{-RZ}{T}}$ )
XY10 Let Z0 = 0
XY15 Let Z1 = Lower limit
XY20 Let Z2 = Upper limit
XY25 Let Z3 = Z2 - Z1
XY30 Let Z4 = (FNF(Z1) + FNF(Z2)) * Z3
XY35 Let Z5 = 0
XY40 Let Z4 = (Z4 + Z5)/2
XY45 Let Z5 = 0
XY50 For Z = Z1 + Z3/2 to Z2 Step Z3
XY55 Let Z5 = Z5 + FNF(Z)
XY60 Next Z
XY65 Let Z5 = Z5 * Z3
XY70 Let Z6 = (Z4 + 2 * Z5)/3
XY75 Let Z0 = Z6 (Current value of the integral of FNF(Z))
XY80 Let Z3 = Z3/2
XY85 If ABS (Z4 - Z5)/ABS(Z6) > 1E-4 Then XY40 (Test to end
iteration loop);

```