Direct computation on the kinetic spectrophotometry

Hansen, Johnny; Forskningscenter Risø, Roskilde

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Direct Computation on the Kinetic Spectrophotometry

by

Johnny W. Hansen and P. Broer Pedersen

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Abstract

This report describes an analog computer designed for calculations of transient absorption from photographed recordings of the oscilloscope trace of the transmitted light intensity. The computer calculates the optical density OD, the natural logarithm of OD, and the natural logarithm of the difference between the limiting optical density OD_∞ and the actual optical density, and the reciprocal of the optical density. The calculated values are displayed on a digital voltmeter or recorded on an XY-recorder. Accuracy and linearity of the individual computing circuits are discussed and the overall performance of the system is demonstrated. In the appendices a user's manual is given.

The computer was especially developed for analysing oscilloscope photos from radiation chemical pulsed radiolysis.

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1. INTRODUCTION

In spectroscopic investigation of short living chemical species, e.g. at pulse radiolysis, a light beam is widely used as the examination tool for observing changes in absorbance due to radicals formed by stopping of a high-energy electron beam in a transparent solution. The resulting time-dependent change in the transmitted light intensity is measured by a photomultiplier, the output of which is measured on an oscilloscope, fig. 1. The oscilloscope trace is photographed by means of a Polaroid camera, and from the picture investigations of the kinetics are carried out either manually with a ruler and subsequent calculations or by enlarging the photograph for automatic reading and mathematical treatment in a computer. This examination of the experimental results is tedious and laborious and cannot be performed during the experiments. By using the small computer to be described the most significant data can be derived immediately after the exposure. The computed data are either displayed on a digital voltmeter or plotted on an XY-recorder with the abscissa as the time axis.

The analog computer unit is relatively inexpensive to produce and the computing accuracy is within a few per cent, dependent on the mode of operation, fig. 8.

2. DESIGN PHILOSOPHY

In a pulse radiolysis system the sample, a transparent chemical solution contained in a small glasscell, is irradiated by a single pulse of electrons from an accelerator. An analysing light passes through the solution into a monochromator and a photomultiplier, fig. 1. The converted light intensity signal from the photomultiplier is during - and a few microseconds after - the electron pulse observed on an oscilloscope.

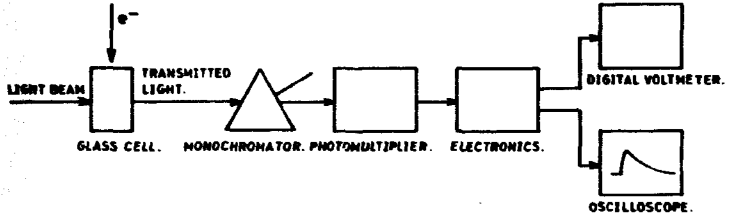


FIG.1.

In the typical pulse radiolysis set-up the analysing light level I_o is measured as a dc voltage on a digital voltmeter, while the absorption signal I is measured as an ac signal on an socilloscope at high amplification. A single oscilloscope photograph is exposed, containing all the informations about the absorption at that given wavelength, see fig. 2. With the small computer equipment calculations on the kinetics can be performed soon after the photograph has been taken, and changes in the experimental conditions may be carried out during the experiments.

The degree of complexity of mathematical treatment required for a reliable quantitative interpretation of rate curves observed in pulse radiolysis depends upon the complexity of the kinetic system under the specific conditions. It is generally desirable to select these conditions so that a given elementary reaction will nearly completely predominate. In such cases, the absolute rate constant may be determined from a simple graphical and mathematical analysis$^{1)}$. There are many variants of the simplest cases, and frequently the degree of complexity may require the use of a computer to determine rate constants adequately.

A first calculation on the transmitted light intensities I_o and I is the evaluation of the optical density D, which is the figure used for the further calculations. It is desirable to have this figure computed with an accuracy of about 2%. In the calculation of the absolute rate constant, a plot of $\ln D$ versus time will in unimolecular - or pseudo-first-order - reaction show a straight line. In the same circumstances it is of interest to evaluate the $\ln(D_\infty - D)$ plot. Here the D_∞ represents the limiting optical density attained on the time scale of the observed reaction as represented by the plateau in the absorption versus time curve, i.e. the plateau on the trace on the oscilloscope photograph. In second-order reactions the rate constant may be determined from the slope of a straight line obtained by plotting 1/D against time. In the computation of the natural logarithm and the division an accuracy of about 5% is desirable. The demands of computing accuracy may be regarded from two points of view, (i) the accuracy in reading the oscilloscope photograph, (ii) the computing accuracy for a given input signal.

As the moving board of the XY-curve tracer is manually operated and as the oscilloscope trace in fact appears with a finite thickness, the accuracy and reproducibility of the analog computer output signal to a great extent depends on how carefully the oscilloscope photograph is read. Assuming a thickness of the trace of 1 mm a reading accuracy within 0.25 mm may result in an error of about 50% for the smallest value of D and about 1% for the highest value. But as the input to the computer, i.e. the absorption signal "h", can be measured on the analog computer digital voltmeter output terminal, all the calculated values may be referred to this signal. On this background the computing accuracy is defined at the values stated above.

The computer should be capable of treating photographs of different amplification factors (scale factors) of the order of 1.0 to 5.0, i.e. varying light intensity I_o and different amplification on the oscilloscope measuring I, and provide an optical density range of o.ol to l.o. The curve tracer feeding the computer from the oscilloscope photograph should be manually operated and designed for photos with an overall size of 3 1/4 x 4 1/4 inches, and with the trace within an area of 5 x lo cm.

The specifications of calculation accuracy should hold for a room temperature of 2o°C - 5°C, + lo°C. The equipment should be easy to operate, and inexpensive in fabrication.

3. CONSTRUCTION

3.1. The Manually Operated XY-Curve Tracer

The manually operated curve tracer is a moving board with a fixed-position pointer. The board is fitted with two potentiometers as linear transducers for the X and Y coordinates. The X-axis potentiometer, lo cm long, and the Y-axis potentiometer, 5 cm long, are 1 kΩ ± 5% wire-wound sliding potentiometers with a linearity of ± o.4% and a resolution of 1.1°/oo and 2°/oo respectively of the total resistance. The potentiometers are fed from a lo V dc reference voltage generator. The output voltage from the potentiometer at the X coordinate, the time axis, is fed directly to the output terminal, the loading of which should not be less than 25 kΩ .

3.2. Evaluation of the Optical Density D

In the calculation of the optical density it was a requirement that photographs with scale factors up to 5 could be prepared. This in fact might be regarded as a change in the loo% light intensity I_o and thus a change in the voltage to the Y-axis potentiometer.

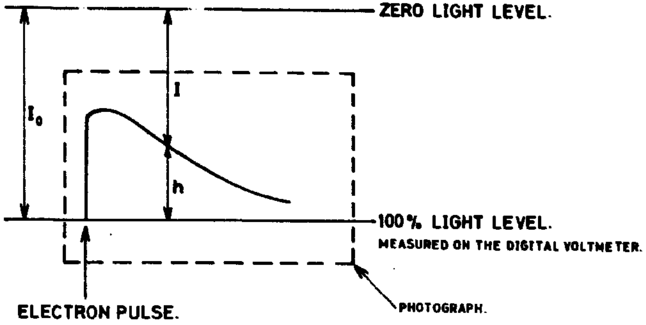


FIG.2.

$$D = -\log \frac{1}{T} \quad ; \quad T = \frac{I_o}{I} = \frac{I}{I_o - h} \quad ;$$

$$D = -\log \frac{I_o - h}{I_o} = -\log \left(1 - \frac{h}{I_o} \right) \quad ;$$

By incorporating the scale factor Q into I_o, the loo% light level, I_o may be written as: $I_o = Q + I_o'$ and $D = -\log \left(1 - \frac{h}{Q + I_o'}\right)$.

The electrical analog to the equation apart from the negative sign is shown in fig. 3:

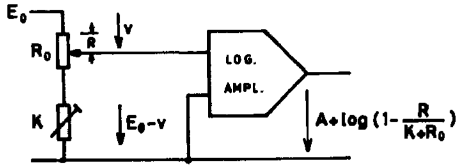


FIG. 3.

$$E_o - v = E_o \left(1 - \frac{R}{K + R_o} \right) ; \quad \log(E_o - v) = \log E_o + \log \left(1 - \frac{R}{K + R_o} \right) ;$$

$$\text{for } E_o = 1 \;=\; \log(E_o - v) = \log \left(1 - \frac{R}{K + R_o} \right) \quad ;$$

The absorption range of o.ol ≤ h ≤ o.9 gives an optical density variation of o.oo436 ≤ D ≤ 1.o. In the electrical analog the logarithmic amplifier gives an output ranging from 4.36 mV up to 1.o volt. When using Philbrick-Nexus logarithmic module 4357 a linearity of 1% of reading is guaranteed. A rated offset voltage variation with temperature of o.1 mV/°C results in an output voltage change of 2 mV in the desired temperature range, or 50% of the minimum signal to be measured. By adequate trimming of the logarithmic amplifier a somewhat better linearity can be achieved, but the offset voltage error is too big for acceptable operation. On account of this error the computation of the optical density in the lower range is performed by using the series representation of the natural logarithm function. This evaluation can easily be made accurate enough for values of the optical density overlapping the acceptable lower values of the logarithmic amplifier. The Maclaurin series representation of the base ten logarithm of the electrical analog signal is as follows:

$$\log(1-x) = 0{,}4343\ln(1-x) \simeq 0{,}4343\left(-x-\tfrac{1}{2}x^2-\tfrac{1}{3}x^3-\ldots\ldots\right) \;;$$

$$-\log\left(1-\frac{R}{K+R_o}\right) \simeq 0{,}4343\left(\frac{R}{K+R_o}\right)+0{,}2715\left(\frac{R}{K+R_o}\right)^2+0{,}1448\left(\frac{R}{K+R_o}\right)^3+\ldots \;;$$

By using a corrected constant (o.2736) for the second term and excluding the subsequent terms the series can be made to fit within 1% in the desired range. Fig. 4 shows the electrical network for the series generation of the same signal as fed to the logarithmic amplifier.

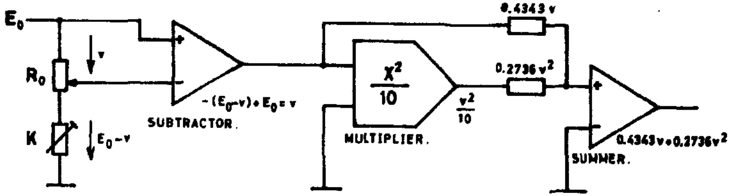


FIG.4.

A high accuracy multiplier, Analog Devices model 425K, has a rated non-linearity of o.o2% of full scale deflection, which contributes to o.13% of the accuracy of the smallest output signal. The output offset drift is 15o µV/°C which amounts to 3 mV in the temperature range of operation. This offset error is in fact too big, but by increasing the input signal v by a factor of 1o and division by 1o after multiplication and summing this influence is reduced to less than 2% of the smallest value of the optical density.

A combination of the two alternative methods of computing the optical density turns out to offer the most accurate and reliable performance. A high gain comparator driving a mercury-wetted, reed relay contact was adjusted to switch on a certain level of the input voltage v where the curves for the log. amplifier and the multiplier were considered to cross. Two comparators connected in a logic to sense both on the level of v and on the two output signals were found not to add to a more accurate operation because of a final accuracy by the manual operation of the curve tracer. The block diagram of fig. 5 shows the circuit for the evaluation of the optical density from the absorption response.

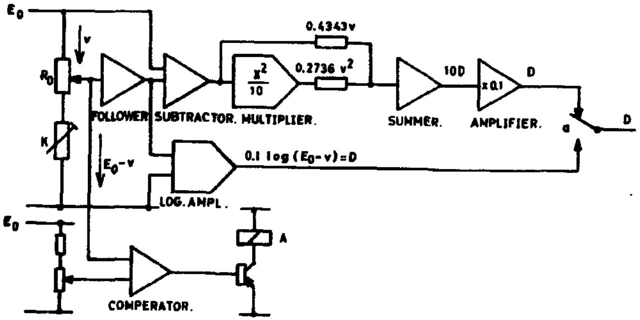


FIG.5.

The reed relay, a Clare type HGRM-17211 TOC, with mercury-wetted make before break contacts has no contact bounce, which is of great importance. A contact resistance of 2o mohms will in a load resistance of 1 kohm exhibit a voltage error of o.o2%.

By selecting the resistance value of the K-potentiometer to be 5 kohms a scale factor of 6 is obtained giving a maximum optical density per unit length of o.o16 D/cm on the XY-recorder. To avoid loading of the R_o and K resistors by the subtractor a follower amplifier is used. The common mode rejection ratio of this amplifier must not be less than 86 dB to make the error voltage diminishing.

3.3. Computation of the Natural Logarithm of D

In the mode of computing the natural logarithm of the optical density, lnD, an error of about 5% of the reading is tolerated. This makes it possible to use a Phillbrick/Nexus logarithmic module 4357 followed by a Phillbrick/Nexus 1oo9o1 operational amplifier, fig. 6.

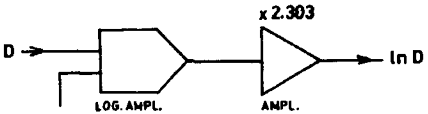


FIG.6.

Here the offset voltage drift with temperature amounts to 2.5% of the smallest measured value of lnD within the temperature range. The non-linearity is 1% of the reading.

The natural logarithm of the difference between the limiting optical density and the actual optical density, ln(D_∞ - D), is performed by connecting a

subtractor, fed from the circuit computing D and from a potentiometer giving D_∞, in front of the logarithmic amplifier, fig. 7.

The voltage of D_∞ must be continuously variable between o and 1.o volt. In this computing mode a negative signal may be fed to the logarithmic amplifier, making it reverse to a fully negative output, which may be a little confusing in operation. The accuracy of this operating mode is comparable with that of the lnD - mode.

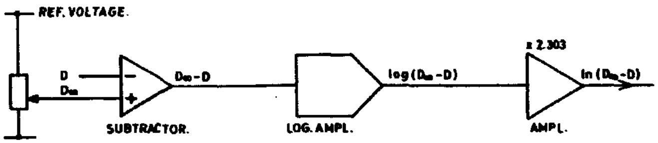


FIG.7.

3.4. Computation of the Reciprocal Value of D

The computation of one divided by the optical density, 1/D, theoretically means an output figure ranging from 1.o to infinity as the optical density from 1.o converges against zero. In the electrical analog the output voltage is limited to the dynamic range of the operational amplifiers and for the logarithmic module expecially to ± 1o volts. With a high accuracy multiplier in the division mode an accuracy as for the squaring mode cannot be expected. For small voltage values of the denominator the non-linearity is increased because of the increased loop gain. The inaccuracy for the actual smallest values of the denominator amounts to more than 2oo%. By using a logarithmic module in the antilogarithmic mode of operation the inaccuracy is decreased to an acceptable amount.

From the minimum optical density to be measured corresponding to 4.36 mV and the assignments of the logarithmic module $e_{out} = lo^{-e_{in}} \leq 1$ the output figure of 1/D has to be multiplied by a factor of lo^{-3}. The mathematical computation to be performed will then be antilog(log lo^{-3} - log o.oo436) = antilog(-3 - (-2.359)) = o.229 corresponding to an output voltage of 229 mV. The conformity to the ideal logarithmic curve of the log. module in the antilogarithmic mode is guaranteed to be 1% of the reading, and the offset voltage drift in the temperature range accounts for almost 2o% of the smallest value of 1/D. The performance specification of the low output voltages might be improved by the use of an oven for the antilog element. To increase the signal to noise ratio in the following circuits the output voltage is multiplied by a factor of lo. Fig. 8 shows the electrical analog.

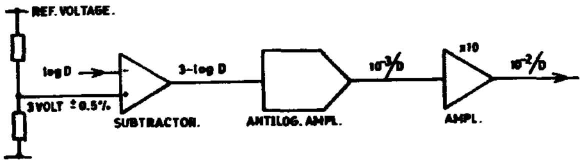


FIG.8.

4. PERFORMANCE

In the final construction of the analog computer performance tests in the temperature range 2o°C - 5°C + lo°C have shown accuracies close to the expected values apart from the dividing mode where the non-linearity at small values of D exceeds the desired limits.

The linearity of the optical density is kept within the ± 1% limit ranging from o.ol up to o.8 of h; above this value the conformity to the ideal curve is ± 1.5%. In the mode of computing the natural logarithm of the optical density, lnD, the output excursion from the ideal curve is 1% from h equal to o.o4 up to o.7; below and above these values the conformity to the ideal curve is -1.5% and +3% respectively. The dividing mode non-linearity is ± 6% from h equal to o.ol up to o.6; above this value the conformity to the ideal curve increases up to 2o% at h equal to o.9. In the performance test carried out the output signal for the three different modes is a function of the input signal I_o-I and the read error signal is demonstrated in per cent of the ideal figure, see fig. 9.

5. REFERENCE

1. M.S. Matheson, L.M. Dorfman: Pulse Radiolysis. M.I.T. Press, 1969.

Appendix 1

Operating Instructions

1. Installation

1.1. Inspection

The instrument must always be placed in a vertical position to allow proper operation of a mercury-wetted relay contact set. Further it must be noted that the cooling of the instrument should be unimpeded.

1.2. Power Requirements

The instrument may be operated from a 22o V, 5o Hz ac source. A fuse of o.25 ampere slow-blow for 22o volt operation is mounted on the rear panel.

2. Operating Control Functions

The instrument front panel is provided with terminals for the XY-curve tracer, the XY-recorder, and for the digital voltmeter, and controls and switches for the adjustment and setting of the calculation modes.

2.1. Power Switch

The power switch turns the instrument on and off, and the monitoring lamp shows when the instrument is on voltage.

2.2. POLARITY Switch

The setting of the "POLARITY" switch on "+" or "-" depends on the oscilloscope photo. If the oscilloscope base line and the beginning of the light pulse are in the lower left corner of the photo, the switch setting is "-". If the base line and the beginning of the pulse are in the upper left corner of the photo, the switch setting is "+". This results in a coordinate system with the ordinate to the left and the abscissa at the foot of the paper of the XY-recorder.

2.3. FUNCTION Switch

By means of the "FUNCTION" rotary switch the computer is switched to the required mode of operation. The read-out on the XY-recorder is only dependent on the position of this switch.

2.4. SELECTOR Switch

With the "SELECTOR" rotary switch the output terminal for the digital voltmeter is connected to the computing circuits. Besides, the digital voltmeter can be switched to two internal measuring points necessary for the operation.

But while the XY-recorder always shows the mode of operation to which the "FUNCTION" switch is turned, the signal displayed on the digital voltmeter is not only dependent on the position of the "SELECTOR" switch, but for some operation modes also on the position of the "FUNCTION" switch. Setting of the "SELECTOR" switch to lo·h, D, and (D_∞ -D) always gives the right figure independent of the "FUNCTION" switch. But for lo^{-2}/D, -lnD, and -ln (D_∞ -D) the "FUNCTION" switch must be switched to the same operation mode, too.

2.5. SCALE CALIBRATION

By means of the "SCALE CALIBRATION" control all computer calibration is performed for the actual oscilloscope photo.

2.6. D_∞ -Control

By means of the "D_∞"-control the limiting optical density OD_∞ is adjusted.

3. Operating Procedure

3.1. Calibration of the Analog Computer

No preparation for operation is required except for connecting the cur tracer, XY-recorder, and the digital voltmeter. It is recommended tha a 15 minute warm-up period be allowed for the equipment to reach a stabilized operating temperature.

Place the oscilloscope photo on the slide of the curve tracer with the time axis parallel to the X-axis and the beginning of the trace towards the operator. The X-axis is the lo cm long movement of the slide. With the oscilloscope base line, i.e. loo% transmission, to the right on the slide, turn the polarity switch to "-" position. With the base line to the left, turn the polarity switch to "+".

With the base line to the right on the photo, push the slide fully to the left and adjust the finger screw on the slide to bring the base line and the start of the light pulse precisely underneath the pointer. With the base line to the left, the procedure is the opposite.

Now move the slide of the curve tracer until the pointer stays at the maximum of the trace, maximum absorption h_{max}. Adjust the scale factor $h[mV]/I_o[mV]$ in accordance with the actual picture, i.e. calibrate the analog computer to the real value of h relative to I_o, the non-absorbed light intensity. The value of h in mV is measured on the oscilloscope photo. Note that the value of h displayed on the digital voltmeter is multiplied by a factor of ten. Turn "SELECTOR" to the desired function, the value of which will be displayed on the digital voltmeter. Note section 2.4.

3.2. Calibration of the XY-Recorder

3.2.1. Calibration of the X-Axis

Turn the X-axis sensitivity of the XY-recorder on o.5 volt/cm, and adjust the pen to the left on the abscissa by the offset control. The time scale on the XY-recorder is now half the time scale of the oscilloscope photo.

3.2.2. Calibration of the Y-Axis

Plotting of D:

With the "FUNCTION" switch on D, turn the XY-recorder Y-axis sensitivity

on 1 volt/cm. Place the pointer on the base line of the oscilloscope photo and adjust the pen to the beginning of the coordinate system by the offset control. Place the pointer at the maximum of the trace, h_{max}, and increase the Y-axis sensitivity until a suitable deflection is achieved. By increasing the sensitivity an offset voltage at the zero point of the XY-recorder and the analog computer is amplified, too. Therefore it is often necessary to re-adjust the XY-recorder offset and repeat the sensitivity adjustment procedure. With the Y-axis sensitivity control knob on "calibrated" it is easy to calibrate the ordinate in D/cm.

Plotting of lo^{-2}/D:

With the "FUNCTION" switch on lo^{-2}/D, turn the XY-recorder Y-axis sensitivity on 1 volt/cm. Because of a high amplification in the computer when D approaches zero, it is recommended not to adjust the Y-axis sensitivity with the pointer on the base line. Place the pointer at the maximum of the trace, h_{max}, and adjust the pen to the beginning of the coordinate system with the Y-axis offset control knob. Then place the pointer on the trace appropriately close to the base line and increase the sensitivity until a suitable deflection is achieved. With the corresponding figures on the digital voltmeter a scaling of the ordinate is rather easy.

Plotting of -lnD:

With the "FUNCTION" switch on -lnD turn the XY-recorder Y-axis sensitivity on o.5 volt/cm. This setting of the sensitivity may be convenient for any value of the scale factor. Place the pointer at the maximum of the trace, h_{max}, and adjust the pen to the beginning of the coordinate system with the Y-axis offset control knob. If a higher sensitivity is more convenient, then place the pointer on the trace appropriately close to the base line and increase the sensitivity until a suitable deflection is achieved. With

the corresponding figures on the digital voltmeter a scaling of the ordinate is rather easy.
For some settings of the scale factor and with the pointer on the base line, i.e. D = O, a negative figure may appear. This is an error due to a high amplification of a small offset voltage in the analog computer.

Plotting of -ln(D∞ -D):
Turn the "FUNCTION" switch on D and the "SELECTOR" switch on D∞ -D. Place the pointer on the trace at a position corresponding to the limiting optical density OD∞ . Adjust the D∞ -potentiometer until a zero reading on the digital voltmeter is achieved. Place the pointer at the maximum value of the trace, h_{max}, turn the Y-axis sensitivity on o.5 volt/cm and the "FUNCTION" switch on -ln(D∞ -D). Adjust the pen to the beginning of the coordinate system with the Y-axis offset control knob.

4. Specifications

4.1. Input Circuits

The X-input terminal is in reality the output from a lo-volt reference voltage generator feeding the X-axis potentiometer of the curve tracer. With the curve tracer connected, the X-axis potentiometer arm is directed to the X-output terminal.
The Y-input terminal is the computer input. The terminal is a lo volt reference voltage generator in series with a 5kΩ lo-turn potentiometer connected to ground. The Y-axis potentiometer of the curve tracer is inserted between the lo-volt generator and the 5kΩ potentiometer, and the potentiometer arm is through the "POLARITY" switch fed to a follower amplifier.

4.2. Output Circuits

With the curve tracer connected to the X-axis input terminal the X-axis recorder output terminal is the 1 kΩ X-axis potentiometer arm, and the unbalanced output voltage varies linearly between o and lo volts proportionally with the movement of the slide in the abscissa direction. With the curve tracer disconnected, the X-output terminal floats.
The Y-axis recorder output terminal is an unbalanced, low impedance output which is short-circuit protected. The voltage range of the output signal is from o to lo volts. For switch positions -lnD and lo^{-2}/D the signal may be higher than lo volts (∼14 volts), but this signal is inaccurate or mathematically undefined.
The output terminal for the digital voltmeter (DVM-output) corresponds to the Y-axis recorder output terminal except for positions lo·h and D∞ -D. Note that for positions -lnD, -ln(D∞ -D), and lo^{-2}/D of the "SELECTOR" switch the "FUNCTION" switch must be turned to the same function to get a reasonable read-out on the digital voltmeter. The voltage range is the same as for the Y-axis recorder output terminal. The DVM-output terminal is an unbalanced, low impedance output, which is short-circuit protected.

4.3. Scale Factor

A scale factor of 1.o to 6.o can be obtained, giving a density range of o.o8 to 1.ooo for full scale deflection of the curve tracer slide, i.e. a maximum density per unit length of o.o16 D/cm is obtainable.

4.4. Performance Accuracy

4.4.1. Linearity of X-axis curve tracer potentiomer: ± o.4%.
Resolution: 1.1 o/oo.

4.4.2. Linearity of Y-axis curve tracer potentiomer: ± o.4%.
Resolution: 2 o/oo.

4.4.3. Computing accuracy related to the setting of lo·h at a room temperature of 2o°C:
Computation of D: ± 1.5%.

Computation of -lnD: -1.o%, +3.o%.

Computation of -ln($D\infty$ -D): -1.o%, +3.o%.

Computation of lo^{-2}/D: ±5%.

Fig. 9 shows the percentage deviation as a function of h.

4.4.4. Temperature Variation

For operation from 15°C to 3o°C the specifications are as follows:

Computation of D: -1.6%, +3.2%.

Computation of -lnD: -1.6%, +3.2%.

Computation of -ln($D\infty$ -D): -1.5%, +3.2%.

Computation of lo^{-2}/D: -1o%, +31%.

4.4.5. Testing of Accuracy

By means of table 1 showing the accurate values it is possible to check the analog computer accuracy. Turn the "SELECTOR" switch on lo·h and adjust with the curve tracer slide and the scale factor potentiometer a listed value of lo·h. Turn the "FUNCTION" switch and the "SELECTOR" switch to the different computing functions and compare with the tabulated values. Corrections are only possible by trimming of the electronic circuits.

Appendix 2

Maintenance Instructions

All internal potentiometers are adjusted correctly and no readjustment should be necessary for a long time. The settings should not be disturbed unless there is a definite indication that the circuit is functioning incorrectly. If this happens or if a component has been replaced, the potentiometers should be set according to the following adjustment procedure. Before any corrections, allow the instrument to warm up for at least 15 minutes.

The following equipment may be required depending on the particular adjustment:

a) Digital voltmeter, $R_i \geq$ o.1 MΩ.

b) Stabilized dc voltage source giving 1 volt ± o.1%.

c) Low frequency signal generator, 2o V pp.

d) Oscilloscope, normal service instrument.

The figures in parantheses refer to the measuring points on the printed circuit boards, see fig. 11 the complete diagram and fig. 12 the power supply. Table 2 shows the connections on the printed curcuit board connectors.

1. Power Supply

Set the main power switch at ON, and allow warming-up time. Check the ± 15 V ± 1% power supply and readjust if necessary on potentiometers R2 and R3 respectively.

Check the 1o V ± o.1% reference voltage and readjust if necessary on R1.

2. Adjustment of the Optical Density Mode

2.1. The printed circuit board A, comprising amplifiers 1A and 2A, and the multiplier module 424 K, must be connected via an extension board.

2.2. Remove the strap to the positive input of amplifier 1A and short-circuit this terminal to ground potential. Adjust the offset voltage to zero (2o).

2.3. Remove the straps to the input terminals of amplifier 2A and short-circuit the negative terminal to ground potential. Adjust the offset voltage to zero (19). Replace the straps.

2.4. By means of the curve tracer Y-axis potentiometer the output (2o) of amplifier 1A is adjusted to 9.9oo volt. By means of R5 the output (19) of amplifier 2A is adjusted to o.1oo volt.

2.5. Remove the straps at the input terminals, feedback loop, and the output terminal of the multiplier module 424 K. With both inputs grounded adjust the offset potentiometer R1 until zero on the output terminal. With a 2o V peak to peak 1o Hz signal connected to the X-input, and the Y-input grounded adjust the Y feed-through potentiometer R2 for minimum output. Repeat by reversing X and Y inputs and adjust the X feed-through potentiometer R3 for minimum output. With -1o V dc on both inputs adjust the scale factor with R4 for exactly 1o V dc output. The X and Y inputs refer to the multiplier module. Replace the straps.

2.6. The printed circuit board B, comprising amplifiers 13 and 14, comparator AD 351, switch amplifier 8o5, and reed relay, must be connected via an extension board.

2.7. Remove the straps at potentiometers R6 and R7 and short-circuit the input terminals to ground potential. Adjust the offset voltage of amplifier 13 to zero. With the input of R7 floating, a voltage of 1.ooo volt is connected to the input of R6. R6 is adjusted until 434.3o mV on the output of amplifier 14. Repeat with R6 floating and adjust R7 until 273.6o mV on the output. Replace the straps.

2.8. Adjust the feedback resistor R6 of amplifier 14 to maximum value. Remove the strap to the negative input and short-circuit this terminal to ground potential. Adjust the offset to zero. Connect 1.ooo volt to the input and adjust R8 until 1oo.o mV on the output of the amplifier. Replace the strap.

2.9. By means of R9 adjust the reference voltage for comparator AD 351 to 3.oo volts.

2.1o. The printed circuit board 1, comprising amplifiers 1, 2, and 3 and the log. module 4357 must be connected via an extension board.

2.11. Remove the log. module and the straps at the negative input terminals of amplifiers 1 and 2. The amplifiers are by means of spare resistors coupled to an amplification factor of 1o, i.e. 1 kΩ at the input and 1o kΩ in the feedback loop. Short-circuit the negative inputs to ground potential and adjust the offsets to zero. Remove the spare resistors and adjust R1o to 1oo kΩ. The straps and the log. module are replaced, and with the curve tracer Y-axis potentiometer adjusted to make 1o•h equal to 9.ooo volts a voltage of 1.ooo volt should be measured on the output (16) of the logaritmic amplifier. An inaccuracy may be corrected by readjusting potentiometer R1o.

2.12. Remove the strap at the 1o kΩ resistor at the input of amplifier 3 and short-circuit this terminal to ground potential. Adjust the offset voltage to zero (29). Replace the strap.

3. Adjustment of the Natural logarithmic Mode

3.1. The printed circuit board 2, comprising the amplifiers 5, 6, 7, and 8 and the log. module 4357, must be connected via an extension board.

3.2. Offset adjustment and adjustment of amplifiers 5 and 6 and log. module is performed as described in section 2.11.

3.3. Remove the strap to the positive input of amplifier 7 and short-circuit this terminal to ground potential. Adjust the offset voltage to zero (12). Connect 1.ooo volt to the input and adjust R12 until 2.3o3 volts on the output of the amplifier. Replace the strap.

3.4. Remove the straps to the input terminals of amplifier 8 and short-circuit the negative input to ground potential. Adjust the offset voltage to zero (8). Short-circuit the positive and negative inputs and connect a reference voltage of 1.ooo volt. Adjust R11 until zero (8) on the output terminal. Replace the straps.

4. Adjustment of the Division Mode

4.1. The printed circuit board 3, comprising amplifiers 9, lo, 11, and 12 and log. module 4357, must be connected via an extension board.

4.2. Adjustment of amplifier 9 is performed as described in section 3.4. Adjust by means of R13 the 3 volt ± o.5% reference voltage. The straps at the input terminals must be mounted during the adjustment of the reference voltage.

4.3. Adjustment of amplifiers lo and 11 and log. module is performed as described in section 2.11. An inaccuracy at the highest output voltage may be corrected by adjusting the loo kΩ potentiometer R15.

4.4. Remove the strap to the positive input of amplifier 12 and short-circuit this terminal to ground potential. Adjust the offset voltage to zero (12). Connect a 1.ooo volt reference voltage to the positive input terminal and adjust R16 until lo volts on the output of the amplifier. Replace the strap.

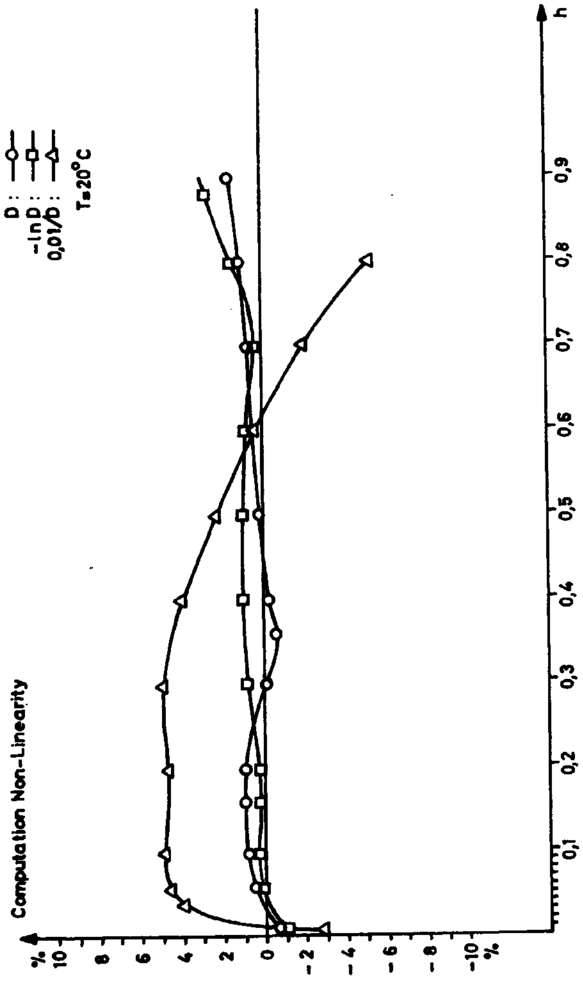


FIG.9

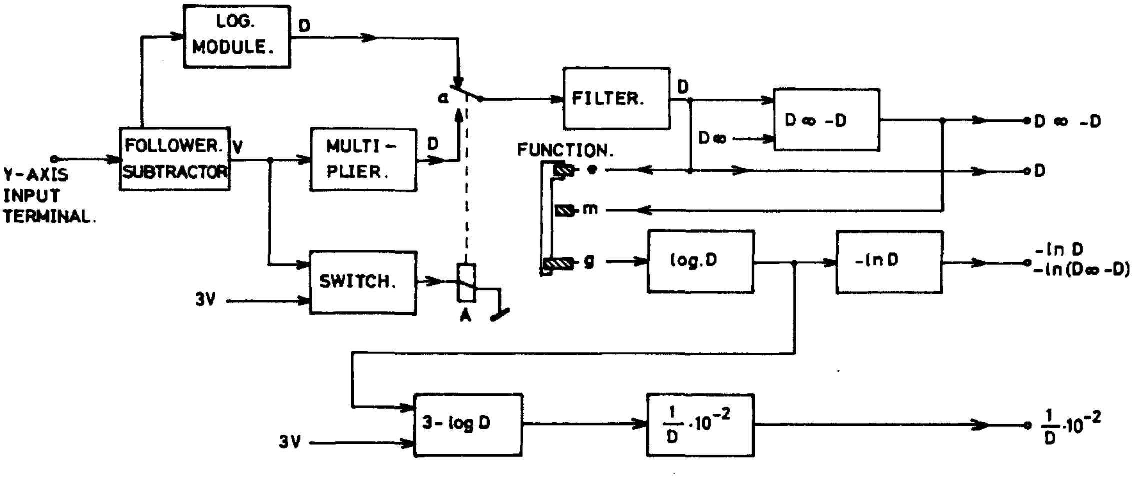

LOG. MODULE.
D
FOLLOWER. SUBTRACTOR
V
Y-AXIS INPUT TERMINAL.
MULTI-PLIER.
D
SWITCH.
3V
A
a
FILTER.
D
D∞ -D
D∞
FUNCTION.
e
m
g
log.D
-ln D
D ∞ -D
D
-ln D
-ln (D∞ -D)
3- log D
3V
$\frac{1}{D}\cdot10^{-2}$
$\frac{1}{D}\cdot10^{-2}$

FIG.10.

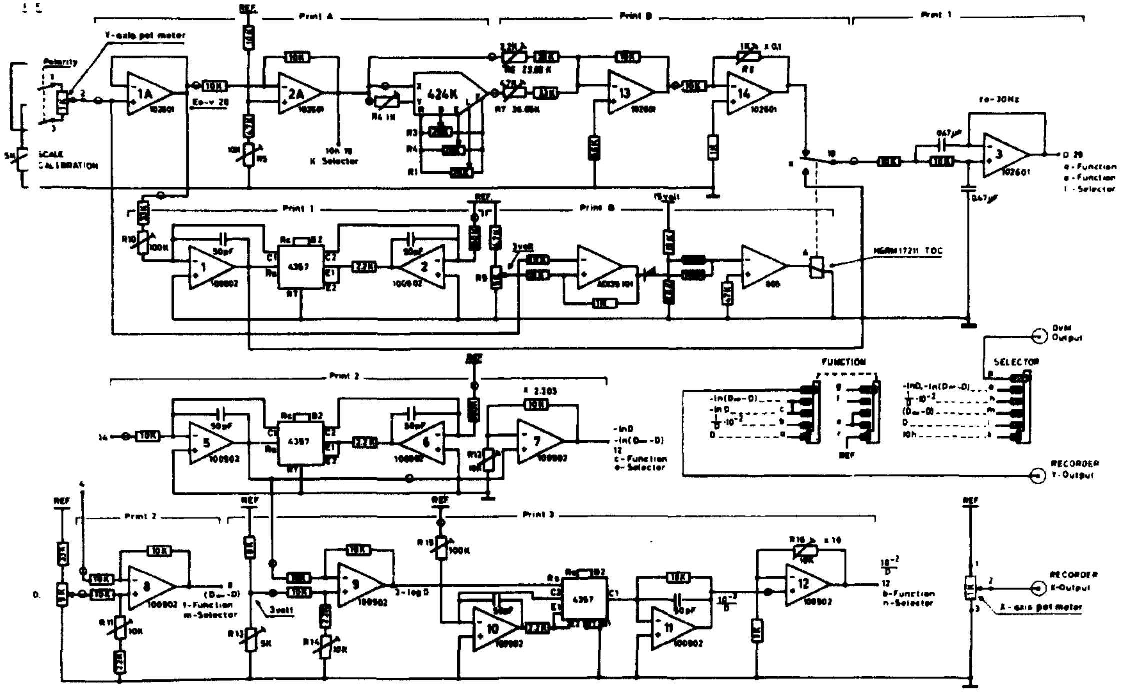
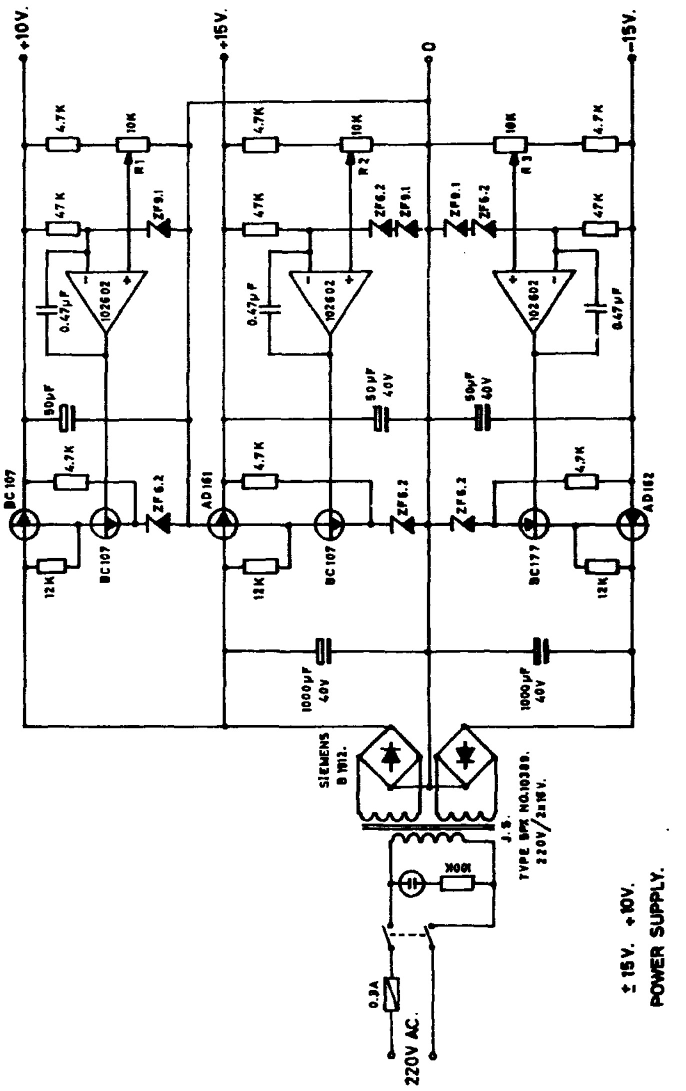

Print A
Print B
Print 1
Print 2
Print 3
Y-axis pot meter
Polarity
SCALE CALIBRATION
REF
1A
2A
424K
13
14
fo=30Hz
3
D 29
e-Function
a-Function
l-Selector
HGRM 17211 TOC
3volt
15volt
1
2
4357
DVM Output
FUNCTION
SELECTOR
-ln(D∞-D)
-ln D
$\frac{1}{D}\cdot10^{-2}$
D
-lnD, -ln(D∞-D)
(D∞-D)
RECORDER Y-Output
5
6
7
-lnD
-ln(D∞-D)
c-Function
e-Selector
8
(D∞-D)
f-Function
m-Selector
9
3-log D
3volt
10
11
12
$\frac{10^{-2}}{D}$
b-Function
n-Selector
RECORDER X-Output
X-axis pot meter

FIG.11



± 15V. +10V.
POWER SUPPLY.

FIG.12.

-1-

A.E.H. PROGRAM NO. 1   PROBLEM NO. 1   4/3.1976
JOHNNY HANSEN. ACC.

TABLE OF THE FUNCTIONS

N	Y	10-Y	U	-LOG U	-LN U	3+LOG U	0.01/U	A=1.0-U	-LOG A	-LN A
0.01	0.10	9.90	0.00436	2.36003	5.43418	0.63997	2.29105	0.99564	0.00190	0.00437
0.02	0.20	9.80	0.00877	2.05681	4.73597	0.94319	1.13974	0.99123	0.00383	0.00881
0.04	0.40	9.60	0.01773	1.75132	4.03257	1.24868	0.56406	0.98227	0.00777	0.01789
0.06	0.60	9.40	0.02687	1.57070	3.61666	1.42930	0.37213	0.97313	0.01183	0.02724
0.08	0.80	9.20	0.03621	1.44115	3.31836	1.55885	0.27615	0.96379	0.01602	0.03688
0.10	1.00	9.00	0.04576	1.33954	3.08440	1.66046	0.21854	0.95424	0.02034	0.04684
0.12	1.20	8.80	0.05552	1.25557	2.89106	1.74443	0.18012	0.94448	0.02481	0.05712
0.14	1.40	8.60	0.06550	1.18375	2.72568	1.81625	0.15267	0.93450	0.02942	0.06775
0.16	1.60	8.40	0.07572	1.12079	2.58070	1.87921	0.13206	0.92428	0.03420	0.07874
0.18	1.80	8.20	0.08619	1.06456	2.45125	1.93544	0.11603	0.91381	0.03914	0.09013
0.20	2.00	8.00	0.09691	1.01363	2.33397	1.98637	0.10319	0.90309	0.04427	0.10193
0.22	2.20	7.80	0.10791	0.96695	2.22650	2.03305	0.09267	0.89209	0.04959	0.11418
0.24	2.40	7.60	0.11919	0.92377	2.12707	2.07623	0.08390	0.88081	0.05512	0.12691
0.26	2.60	7.40	0.13077	0.88350	2.03433	2.11650	0.07647	0.86923	0.06086	0.14015
0.28	2.80	7.20	0.14267	0.84567	1.94724	2.15433	0.07009	0.85733	0.06685	0.15393
0.30	3.00	7.00	0.15490	0.80994	1.86496	2.19006	0.06456	0.84510	0.07309	0.16830
0.32	3.20	6.80	0.16749	0.77601	1.78683	2.22399	0.05970	0.83251	0.07961	0.18331
0.34	3.40	6.60	0.18046	0.74363	1.71227	2.25637	0.05542	0.81954	0.08643	0.19901
0.36	3.60	6.40	0.19382	0.71260	1.64083	2.28740	0.05159	0.80618	0.09357	0.21545
0.38	3.80	6.20	0.20761	0.68276	1.57210	2.31724	0.04817	0.79239	0.10106	0.23270
0.40	4.00	6.00	0.22185	0.65394	1.50576	2.34606	0.04508	0.77815	0.10894	0.25083
0.42	4.20	5.80	0.23657	0.62604	1.44150	2.37396	0.04227	0.76343	0.11723	0.26994
0.44	4.40	5.60	0.25181	0.59892	1.37907	2.40108	0.03971	0.74819	0.12599	0.29010
0.46	4.60	5.40	0.26761	0.57250	1.31824	2.42750	0.03737	0.73239	0.13526	0.31144
0.48	4.80	5.20	0.28400	0.54669	1.25879	2.45331	0.03521	0.71600	0.14508	0.33407
0.50	5.00	5.00	0.30103	0.52139	1.20055	2.47861	0.03322	0.69897	0.15554	0.35815
0.52	5.20	4.80	0.31876	0.49654	1.14332	2.50346	0.03137	0.68124	0.16670	0.38384
0.54	5.40	4.60	0.33724	0.47206	1.08695	2.52794	0.02965	0.66276	0.17865	0.41135
0.56	5.60	4.40	0.35655	0.44788	1.03129	2.55212	0.02805	0.64345	0.19148	0.44091
0.58	5.80	4.20	0.37675	0.42395	0.97617	2.57605	0.02654	0.62325	0.20534	0.47281
0.60	6.00	4.00	0.39794	0.40018	0.92145	2.59982	0.02513	0.60206	0.22036	0.50740
0.62	6.20	3.80	0.42022	0.37653	0.86699	2.62347	0.02380	0.57978	0.23673	0.54510
0.64	6.40	3.60	0.44370	0.35291	0.81261	2.64709	0.02254	0.55630	0.25469	0.58644
0.66	6.60	3.40	0.46852	0.32927	0.75817	2.67073	0.02134	0.53148	0.27451	0.63209
0.68	6.80	3.20	0.49485	0.30553	0.70350	2.69447	0.02021	0.50515	0.29658	0.68290
0.70	7.00	3.00	0.52288	0.28160	0.64841	2.71840	0.01912	0.47712	0.32137	0.73998
0.72	7.20	2.80	0.55284	0.25740	0.59268	2.74260	0.01809	0.44716	0.34954	0.80484
0.74	7.40	2.60	0.58503	0.23282	0.53610	2.76718	0.01709	0.41497	0.38198	0.87954
0.76	7.60	2.40	0.61979	0.20776	0.47838	2.79224	0.01613	0.38021	0.41998	0.96703
0.78	7.80	2.20	0.65758	0.18205	0.41919	2.81795	0.01521	0.34242	0.46544	1.07171
0.80	8.00	2.00	0.69897	0.15554	0.35815	2.84446	0.01431	0.30103	0.52139	1.20055
0.82	8.20	1.80	0.74473	0.12800	0.29474	2.87200	0.01343	0.25527	0.59300	1.36542
0.84	8.40	1.60	0.79588	0.09915	0.22831	2.90085	0.01256	0.20412	0.69011	1.58905
0.86	8.60	1.40	0.85387	0.06861	0.15797	2.93139	0.01171	0.14613	0.83527	1.92327
0.88	8.80	1.20	0.92082	0.03583	0.08249	2.96417	0.01086	0.07918	1.10138	2.53602
0.90	9.00	1.00	1.00000	-0.00000	-0.00000	3.00000	0.01000	-0.00000	************	************

Table 1.

Print 1.

lo volt	pin	1.
h	"	2.
+15 volt	"	6.
-15 volt	"	8.
E_o-v	"	lo.
0-ground	"	14.
log(E_o-v)	"	16.
0-ground	"	24.
Filter output D	"	29.

Print 2.

+15 volt	pin	1.
-15 volt	"	2.
D	"	4.
pot.meter D_∞	"	6.
D_∞-D (f)	"	8.
lo volt	"	lo.
lnD, ln(D_∞-D)	"	12.
ε	"	14.
0-ground	"	16.
logD	"	26.

Print 3.

-15 volt	pin	2.
+15 volt	"	3.
logD	"	6.
lo^{-2}/D	"	12.
0-ground	"	14.
lo volt	"	16.
3-logD	"	24.
lo^{-3}/D	"	26.

Print A.

E_o-v	pin	8.
v^2	"	12.
-15 volt	"	13.
0-ground	"	16.
+15 volt	"	17.
v	"	19.
lo volt	"	26.

Print B.

v	pin	6.
v^2	"	8.
-15 volt	"	13.
0-ground	"	14.
0-ground	"	15.
0-ground	"	16.
+15 volt	"	17.
E_o-v	"	2o.
lo volt	"	22.
log(E_o-v)	"	23.
0-ground	"	24.
D	"	26.

Table 2.