MASTER

JUN 30 1967

UCD-CNL 61
AEC RESEARCH AND
DEVELOPMENT REPORT

Crocker Nuclear Laboratory

University of California, Davis

NEW INTERNAL MECHANISM FOR THE
DAVIS SOLENOIDAL BETA RAY SPECTROMETER
INCLUDING POST MOMENTUM ANALYSIS BEAM FOCUSING

RECEIVED
MAY 18 1967
CALIF. PATENT GROUP

Davis, California

leg x

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

UCD-CNL 61
AEC RESEARCH &
DEVELOPMENT REPORT

CFSTI PRICES

CROCKER NUCLEAR LABORATORY
University of California, Davis

H.C. \$ 3.00; MN 65

New Internal Mechanism for the Davis Solenoidal Beta Ray Spectrometer
Including Post Momentum Analysis Beam Focussing

Willard C. Sperry

September 13, 1966

Prepared Under
Contract AT(11-1) Gen 10, P. A. #15
for the
San Francisco Operations Office
U. S. Atomic Energy Commission

Davis, California

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

I. INTRODUCTION

It was desired to design modifications for the Davis Precision Solenoidal Beta Ray Spectrometer¹ to fulfill the following requirements:

- 1) The momentum resolution is to be variable from .001% to .5% FWHM. The unmodified spectrometer has variable momentum resolution from .001% to .05%. The modifications are to permit operation in the range from .05% to .5%. The Hubert baffle arrangement² is to be retained.
- 2) A solid state electron detector is to be used in place of the present Geiger-Muller counter. This modification will result in a much smaller detector volume which will decrease the background from cosmic radiation.

II. RESOLUTION RANGE MODIFICATIONS

The modification necessary to increase the momentum resolution range consists of designing a new internal mechanism which is interchangeable with the present one. The present precise uniform magnetic field is retained without modification ($\frac{\Delta B}{B} \leq .01\%$ within a cylinder of 80 inches length and 26 inches diameter).

A. Number of Channels

Smith³ has designed a six channel longitudinal uniform field

LEGAL NOTICE

This report was prepared as an account of Government sponsored work. Neither the United States, nor the Commission, nor any person acting on behalf of the Commission: A. Makes any warranty or representation, expressed or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use privately owned rights; or B. Assumes any liabilities with respect to the use of, or for damages resulting from the use of any information, apparatus, method, or process disclosed in this report. As used in the above, "person acting on behalf of the Commission" includes any employee or contractor of the Commission, or employee of such contractor, to the extent that such employee or contractor of the Commission, or employee of such contractor prepares, disseminates, or provides access to, any information pursuant to his employment or contract with the Commission, or his employment with such contractor.

spectrometer having a point source transmission of 13.8%. Calculations were made to determine if additional channels would significantly increase the illuminosity of the modified internal mechanism. Since the dimensions of the volume of the uniform magnetic field limit the electrons' take off angle α to less than 25° and the permissible deviation from α , ϵ , is about $\pm 3\%$, only two channels would physically fit and satisfy the conditions that the trajectories of each channel must be spatially separate. The construction requirements of the internal mechanism limits the minimum values of α . See Figure 1.

The calculations showed that the two channel transmission was 3.2% and the one channel transmission 2.2%. However the illuminosities were much different. Using Beard's⁴ equation for illuminosity with an optimum source diameter ($A = .5$), the two channel modification had an illuminosity of $.0026 \text{ cm}^2$ while the one channel modification had an illuminosity of $.0031 \text{ cm}^2$. It was therefore decided to design a one channel internal mechanism.

SINGLE CHANNEL ELECTRON TRAJECTORIES

Plotted in a cylindrical coordinate system rotating with angular velocity $\omega = \frac{eB\sin\alpha}{2m}$. $r_{\max}$ and $Z_{\max}$ are the radial and longitudinal limits of the precise ($\frac{\Delta B}{B} \leq .01\%$) magnetic field. There is axial symmetry about the Z axis which is not shown for clarity.

Figure 1

B. Placement of Hubert Baffles

The positions of the Hubert baffles are calculated by solving six simultaneous equations with nine unknowns. The three additional equations are furnished specifying whichever three of the following design requirements are applicable:

- 1) Desired resolution. Baffles were calculated for resolutions of .5%, .25%, .12%, .06%, and .03%.
- 2) $r_{\max} = 12.725''$. This is determined by the maximum usable radial extent of the magnetic field.
- 3) $Z_{\max} = 79.500^\circ$. This is determined by the maximum usable longitudinal extent of the magnetic field.
- 4) The radius of baffle A is constant.
This condition simplifies the mechanical design of the internal mechanism. The momentum resolution can be changed by moving baffle A in the Z direction.
- 5) Baffles B, C, and D must lie on the same caustic curve. This condition assures that no baffle lies in the "shadow" of another.

The six simultaneous equations are:

$$r = D \sin \alpha \sin \psi \quad (1)$$

$$Z = \psi D \cos \alpha \quad (2)$$

$$\tan \psi = \psi \tan^2 \alpha \quad (3)$$

$$\epsilon = \frac{2 \text{ (Resolution)}}{(.93) [3 + (\cos \alpha)^2 (\tan \psi)^2]} \quad (4)$$

$$D0 = \frac{r \text{ max.}}{[1 + \frac{\text{Resolution}}{.93}] [\sin (\alpha + \epsilon)]} \quad (5)$$

$$DP = \frac{D0[\text{Resolution}]}{.93} \quad (6); \text{ where}$$

$D = D0$ or $D0 + DP$ depending on the baffle;

$\alpha = \alpha$, $\alpha + \frac{2}{3} \epsilon$, or $\alpha - \frac{2}{3} \epsilon$ depending on the baffle; and

$$\psi = \frac{1}{2} \int_0^T \omega dt$$

The equations are given by Hubert² except for the factor of .93 in equations 4, 5 and 6. This factor is given by Beard⁴ to correct the FWHM resolution for finite optimum source size.

A FORTRAN II program was written to calculate the Hubert baffle positions. In the program r is called Y . The program is shown in Appendix 1.

The allowable tolerances for the positions of the Hubert baffles were calculated subject to the requirement that the resolution would not be changed by more than one tenth of its design value. The positions and tolerances are shown in Table 1.

C. Source

The source is a disc. Its diameter varies with momentum resolution.

TABLE 1

R
E
S
O
L

A

B

C

D

.5%	Z	75.9482 "+ 0 - .045"	73.0885 "+ 0 - .045"	Not necessary	79.5000 "+ 0 - .045"
	r	4.39067 "+ 0 - .001"	5.6545 "+ 0 - .001"	Not necessary	3.3147 "+ 0 - .001"
.25%	Z	76.1841 "+ 0 - .023"	74.0883 "+ 0 - .023"	76.3888 "+ 0 - .023"	78.6269 "+ 0 - .023"
	r	4.39067 "+ 0 - .001"	5.2655 "+ 0 - .001"	4.4025 "+ 0 - .001"	3.6100 "+ 0 - .001"
.12%	Z	76.3072 "+ 0 - .011"	74.8175 "+ 0 - .011"	76.4057 "+ 0 - .011"	77.9638 "+ 0 - .011"
	r	4.39067 "+ 0 - .0005"	4.9870 "+ 0 - .0005"	4.3963 "+ 0 - .0005"	3.8397 "+ 0 - .0005"
.06%	Z	76.3642 "+ 0 - .005"	75.2932 "+ 0 - .005"	76.4134 "+ 0 - .005"	77.5186 "+ 0 - .005"
	r	4.39067 "+ 0 - .0005"	4.8077 "+ 0 - .0005"	4.3935 "+ 0 - .0005"	3.9963 "+ 0 - .0005"
.03%	Z	76.39267 "+ 0 - .0027"	75.62666 "+ 0 - .0027"	76.41731 "+ 0 - .0027"	77.20045 "+ 0 - .0027"
	r	4.39067 "+ 0 - .0002"	4.68323 "+ 0 - .0002"	4.39209 "+ 0 - .0002"	4.10945 "+ 0 - .0002"

NOTE: The radial tolerances are for the baffle diameters and include the tolerance for concentricity about the spectrometer axis.

The source size was chosen according to Hubert's² criterion of optimization with the diameter of the disc equal to the radial width of the ring focus. The radial width was calculated at .5% momentum resolution and the formula $d \sim \text{RESOLUTION}$; where d is the source diameter, was used to determine the source diameters for the other values of the momentum resolution. The source diameters are shown in Table 2.

The source holder and positioning mechanism has been designed so that the position of the source can be varied independently in two perpendicular directions in a plane perpendicular to the axis of the magnetic field. This adjustment permits the source to be centered on the symmetry axis of the Hubert baffles. The source holder and positioning mechanism is shown in Appendix 2.

D. Transmission and Illumination

The transmission is calculated from the formula $T = \epsilon \sin \alpha$; where α is the mean take-off angle for the electron as shown in Figure 1 and ϵ is the acceptable deviation from α . The illuminosity is calculated from $L = AT$; where A is the source area. The transmissions and illuminosities are listed in Table 2.

See Table 2 page 6

TABLE 2

Resolution	Source Diameter	α Radians	ϵ Radians	T	L
.5%	.173"	.379	.058	2.16%	$3.28 \times 10^{-3} \text{ cm}^2^*$
.25%	.087"	.378	.041	1.53%	$5.86 \times 10^{-4} \text{ cm}^2$
.12%	.042"	.378	.029	1.06%	$9.43 \times 10^{-5} \text{ cm}^2$
.06%	.021"	.378	.020	0.75%	$1.67 \times 10^{-5} \text{ cm}^2$
.03%	.010"	.378	.014	0.53%	$2.68 \times 10^{-6} \text{ cm}^2$

E. Magnetic Field Control

The method of magnetic field measurement and control by nuclear magnetic resonance is retained in the modified internal mechanism. The only modification of the NMR system is to increase the resonance signal voltage for the magnetic fields used to focus low energy electrons. This is done by increasing the volume of the proton source. Previous work⁵ has shown that the magnetic field is stable to ± 1 part in 2500 at an NMR resonance frequency of 134.1 kc/sec and with a proton source of 100 cm³ of MnSO₄ solution of unknown molarity (probably saturated). This frequency corresponds to an electron kinetic energy of about 120 keV. The new volume of the MnSO₄ solution is to produce the same voltage signal at magnetic fields corresponding to electron kinetic energies of 18.5 keV. The new volume is calculated from the formula $v = C f^2 V$; where v is the resonance signal voltage, f is the resonant frequency, V is the volume of

*The previously quoted illuminosity of .0031 cm² is the result of a preliminary approximate calculation. It is included only so that it can be compared with the two channel illuminosity of .0026 cm² which is calculated to the same approximation.

the proton source sample, and C is a constant depending on the proton sample material and the geometry of the resonance sensing coils. The constant C is assumed to be the same for both internal mechanisms. The volume of MnSO_4 solution needed is found to be 487 cm^3 . The position of the solution in the internal mechanism is shown in Appendix 2.

F. Mechanical Design

The modified internal mechanism is mechanically similar to the present one. The principal mechanical changes are in the source holder and positioning mechanism, and a mechanism to permit the momentum resolution of the spectrometer to be changed without letting it down to air. The parts are shown in Appendix 2.

The mechanical design was done by Mr. R. W. Rothrock and Mr. C. D. Goodart.

III. ELECTRON DETECTOR MODIFICATIONS AND POST MOMENTUM ANALYSIS BEAM FOCUSING

Figure 1 shows how the electron trajectories diverge after they pass through the ring focus. The electron detector is placed with its window in a position along the axis where the first electron trajectory touches the Z axis. This position allows the minimum diameter possible for the detector. The position and diameter of the detector windows are shown in Table 3.

<u>Resolutions</u>	<u>Z</u>	<u>Diameter</u>
.5%	85.55"	2.78"
.25%	86.25"	2.04"
.12%	86.75"	1.46"
.06%	87.05"	1.08"
.03%	87.30"	0.72"

A silicon surface barrier solid state detector with 5/8 inch diameter has been used with the unmodified internal mechanism at 0.05% momentum resolution. The measured background is about 4 counts/minute. The Geiger-Muller detector has a measured background of about 20 counts/minute. Table 3 shows that the minimum beam bundle diameter is too large to be contained by a 5/8 inch diameter detector. A method, described below, was found to decrease the minimum beam bundle diameter to the necessary 5/8 inch diameter by bending the trajectories of the electrons after they had passed through the Hubert baffles.

A. The Various Methods Considered to Bend the Electron Trajectories

Figure 2 shows the trajectories of the electrons and the position of the last Hubert baffle for a momentum resolution of 0.5%.

See page 9 for Figure 2

Radial Extent of Electron Beam (r) vs. Distance From Source (Z). 2 MeV
Electrons, .5% Momentum Resolution.

FIGURE 2

It also shows that the mechanism necessary to focus the electron trajectories to a bundle 5/8 inch diameter must be located in a cylindrical volume about 6 inches diameter and about 6 inches long.

The requirements for the focussing mechanism are:

- 1) The device to focus the electron bundle must not alter the electron trajectories on the source side of the Hubert baffles.
- 2) The device must fit into a cylindrical volume about 6 inches long and 6 inches in diameter

A non-relativistic calculation was made to determine the potential difference required to focus the electron bundle using an electrostatic lens. It was found that over one million volts was necessary and the electrostatic technique was abandoned.

Dolmatova and Kelman⁶ have developed a magnetic focussing method to reduce the bundle diameter by placing a toroidally wound current carrying coil in the electron bundle. This method has the advantages of a well contained bending magnetic field and also the field is approximately perpendicular to the electron's trajectories. It has the disadvantage that the coils are in the electron bundle and thus cause a loss of effective illuminosity. The approximately 10% decrease in illuminosity that would be result from a toroidal coil in the modified internal mechanism was excessive; and the toroidal coil method was not used.

It was decided to use magnetic focussing by current carrying coils placed coaxial with the Z axis of the spectrometer and having radii just larger than the electron trajectories. The coil positions and current senses were adjusted until the requirements were satisfied. All coils carry the same current.

B. Coil Placement and Current Requirements

Both the positions of the coils and the currents were determined by trial and error. The electron trajectories were calculated by solving the general equation⁷ for a relativistic electron in a magnetic field:

$$\frac{d^2r}{dZ^2} = \frac{-(1 + \frac{dr^2}{dZ})e^2A^2}{p^2 - e^2A^2} \left[\frac{\partial A}{\partial r} - \frac{dr}{dZ} \frac{\partial A}{\partial Z} \right] ;$$

where r and Z are defined in Figure 1, p is the electron's momentum, e is the electron's charge, and A is the magnetic potential at point (r, Z) .

This equation was reduced to two first order equations and programmed in FORTRAN. The Range-Kutta method was used for the simultaneous solution of the equations. The starting conditions $(0,0)$ and $\frac{dr}{dZ}|_{r=Z=0}$ are known and used to start the Range-Kutta iteration. The magnetic potential is that of the uniform field and the coils. The magnetic of the coils is calculated from standard formulae.⁸ The program is written so that the position, diameter, and current of each coil can be varied. The program is shown in Appendix 3.

After a few attempts at coil placements it was suspected that the electrons whose trajectories defined the bundle limits at the source

no longer did so after focussing. The trajectories of eleven values of α and electron momentum, all comparable with actual conditions, were calculated. The relative values of alpha and electron momentum calculated are shown in Figure 3.

See page 13 for Figure 3

Relative Momentum and Take-off Angle of the Eleven Electrons Tested to Determine the Limits of the Electron Bundle. See Hubert² for a description of the graph.

FIGURE 3

It was found that the electrons with the initial parameters TOP, BOTTOM, AND #6 defined the bundle limits. These three were then used in the calculations.

The calculations showed that 24 coils each carrying 1000 amps and placed as shown in Appendix 2 would focus a 2 MeV electron bundle to 0.471 inch diameter at $\frac{1}{2}\%$ momentum resolution. The calculations were made for a point source and the diameter of the source was added to the point source focus diameter. The .471 inch diameter was determined in this way i.e., 0.299 inch diameter for the point source bundle plus 0.172 inch diameter for the finite source. The trajectories are shown in Figure 4. The positions of the TOP and BOTTOM trajectories at the Z coordinate of the three upper Hubert baffles compared to the positions of these trajectories without focussing are shown in Table 4. The coils were helically wound to minimize the magnetic dipoles caused by transferring the current from turn to turn. A calculation of the magnetic field at the last Hubert baffle due to these magnetic dipoles was made for the focussing conditions for 2 MeV electrons and $\frac{1}{2}\%$ momentum resolution. The field was 0.4 gauss which is acceptable.

Table 4

<u>Baffle</u>	<u>B</u>	<u>C</u>	<u>D</u>
TOP	.0004" low	.0007" high	.0052" high
BOTTOM	.0027" low	.0022" high	.0002" high

FIGURE 4

Radial Extent of Electron Beam (r) vs. Distance From Source (Z) with Focussing Coils 2 MeV Electrons, .5% Momentum Resolution.

The allowable tolerances of the positions and diameters of the coils were determined by changing these parameters in the calculations and finding the change in the trajectories. It was found that increasing the diameter of all the coils by .040" lowered the TOP trajectory by .0003" and did not affect the BOTTOM trajectory. Also moving the right fourteen coils to the left by .020" lowered the trajectories by .002". All of these trajectory movements are within the tolerances for the positions of the Hubert baffles and thus tolerances of $\pm .040''$ on the diameter of the coils and $\pm .020''$ on the Z coordinate of the coils were specified.

C. Power Connections and Power Supplies

The focussing coils are rectangular copper tubing $1/8'' \times 3/16''$ with 0.035" wall. This is a standard size. The cross section of the copper is .0179 in² which gives an electrical resistance of .0220 Ω per 40 ft at 20° C and .0237 Ω per 40 ft at 40° C. Approximately 40 ft of the tubing is required to make the coils. The current required for focussing is proportional to the electron's momentum. Table 5 gives the current-energy values for 1/2% momentum resolution.

Table 5

<u>Electron Energy</u>	<u>Focussing Current</u>
.25 MeV	229 amps
.50 MeV	354 amps
.75 MeV	469 amps
1.00 MeV	584 amps
1.25 MeV	687 amps
1.5 MeV	792 amps
2.0 MeV	1000 amps
2.5 MeV	1210 amps
3.0 MeV	1420 amps

Coaxial conductors are used to bring the current to the coils. These conductors consist of $\frac{1}{4}$ inch EXTRA HEAVY copper pipe inside $\frac{3}{4}$ inch diameter copper tubing with .065 inch wall thickness (No. 16 Stubs Gauge). The electrical resistance of the coaxial conductors is 0.00303Ω per 40 ft at 40° C. The coaxial conductors are shown in Appendix 2. The total electrical resistance of the coils and coaxial conductors is nominally 0.03Ω at 40° C.

The power supply requirements are calculated for focussing 3 MeV electrons with the coil assembly at a temperature less than 40° C. Using nominal values; $V = iR = (1500 \text{ amps}) (.03\Omega) = 45 \text{ volts}$. Thus the power supply must supply from 0 to 45 volts and 0 to 1500 amps with a maximum load requirement of 45 volts at 1500 amps. Trajectory calculations have shown that a 1% decrease in coil current produces a 6% increase in the focus diameter ($\sim .030$ inch). From this it appears that 2% voltage regulation and 2% maximum ripple is satisfactory for the power supplies. The power supply requirements are:

- 0 - 45 volts
- 0 - 1500 volts
- 2% voltage regulation
- 2% maximum ripple

The coils will dissipate 55.2 Kilowatts when focussing 3 MeV electrons at .5% momentum resolution. Water will be used to cool the coils and coaxial conductors. It is assumed that deionized water at 20° C will enter the coils and a 20° C temperature rise is allowed. Design tables⁹ were used to calculate the flow rate and pressure drop in each coil if the coils were each water connected in parallel, and in the arrangement where two coils are water connected in series and the twelve groups of two

coils water connected in parallel. Table 6 presents this information.

Table 6

Water Cooling Parameters for 3 MeV Electrons at $\frac{1}{2}\%$ Momentum Resolution

	Each Coil in Parallel	Two Coils in Series and the Twelve Groups in Parallel
Q	.44 gallons/min.	.88 gallons/min.
ΔP	14.5 psi	116 psi

Appendix 2 shows each coil water connected in parallel, but the two coils in series arrangement is to be used. This will simplify the fabrication of the coils.

D. Electron Detector

Silicon surface barrier detectors are readily available* with window diameters of 0.444 inch, 0.546 inch, 0.625 inch, and 0.770 inch. All the electrons transmitted through the Hubert baffle at .5% momentum resolution will pass through a detector window having .546 inch diameter placed 85.2 inches from the source. The same diameter detector placed 85.6 inches from the source will receive all the electrons transmitted at .25% momentum resolution. The position of the detector for the other values of momentum resolution has not been determined.

Figure 5 shows the detector electronics which gave 4 counts/minute background. The single channel analyzer is set in the NORMAL mode and the LOWER LEVEL used to discriminate against low level noise. The signal to the scaler is the logic pulse from the SLOW COINCIDENCE circuit and therefore is constant amplitude independent of electron energy.

* Oak Ridge Technical Enterprises, Oak Ridge, Tennessee

FIGURE 5

E. Mechanical Design

The mechanical design of the focussing coils and detector is not completed. The blue prints and design sketches are shown in Appendix 2.

Mr. Charles Goodart has done the mechanical design.

BIBLIOGRAPHY

1. J. A. Jungerman, M. E. Gardner, C. G. Patten, N. F. Peek,
Nuclear Instr. and Methods, 15, 1 (1962)
2. P. Hubert, Annale de Physik, 8, 662 (1953)
3. S. M. Smith, Thesis, University of California, Davis, 1953
4. D. B. Beard, Rev. of Sci. Instr., 28, 19 (1957)
5. J. A. Jungerman, Unpublished (NMR Data Book, 21 Jan 1958)
6. K. A. Dolmatova, V. M. Kelman, Nuclear Instr. and Methods, 5,
(1959)
7. W. K. H. Panofsky, Melba Phillips, Classical Electricity and
Magnetism, Addison-Wesley Publishing Co. Inc., 1955
8. W. R. Smythe, Static and Dynamic Electricity, McGraw-Hill Book
Co. Inc., 1950
9. W. M. Brobeck, D. T. Scalise, UCRL-3687, Physics and Mathematics,
University of California, September 1957.

APPENDIX 1

```

C   INTERIOR MECHANISM FOR BETA RAY SPECTROMETER.  RESOLUTIONS= .5,
C   .25, .12, .06, AND .03 PERCENT.  YMAX = 12.725 INCHES
C   ZMAX = 79.5 INCHES AT .5 PERCENT RESOLUTION
C   SENSE SWITCH 1 ON TO PRINT MAINLINE ANGLES AND PARAMETERS
C   SENSE SWITCH 2 ON TO PRINT ALONE CONVERGING
C   SENSE SWITCH 3 ON TO PRINT TWO ALFAA
C   SENSE SWITCH 4 ON TO PRINT A1 CONVERGING
      ZF(PSYT,D,ALF) = PSYT * D * COSF(ALF)
      YF(XD,XALF,XPSYT) = XD * SINF(XALF) * SINF(XPSYT)
  9   FORMAT (F14.7)
999  FGMAT(F14.7,2X,F14.7)
      RESOL = .005
      RMAX = 12.725
      READ 9, PREC
      DGTRD = 3.14159265359 / 180.0
      ALFA = 21.0 * DGTRD
  1   PSY = 149.0 * DGTRD
      PSYY = ANGLE(ALFA,PSY,PREC)
      EPSI = EPSI(ALFA,PSYY,.005)
      ALFAC = ALFA - (.6666667 * EPSI)
      PSYD = ANGLE(ALFAC,PSY,PREC)
      ALONE = TRYAL(EPSI,PSYD)
      IF (SENSE SWITCH 2) 3100,3200
3100 TYPE 999, ALONE
3200 BB = ABSF(ALONE - ALFA)
      IF (BB - (PREC * DGTRD)) 100,100,200
200  ALFA = ALONE
      GO TO 1
100  ALFAA = ALFAD + (.6666667 * EPSI)
      PSYA = ANGLE(ALFAA,PSY,PREC)
      ALFAB = ALFAD + (1.3333333 * EPSI)
      PSYB = ANGLE(ALFAB,PSY,PREC)
      DB = RMAX / ((1. + (RESOL / .93)) * SINF(ALFAA + EPSI))
      DP = (DB * RESOL) / .93
      IF (SENSE SWITCH 1) 8,7
  8   TYPE 999, ALFAA,PSYA
      TYPE 999, ALFAB,PSYB
      TYPE 999, ALFAD,PSYD
      TYPE 9, EPSI
      TYPE 9, BB
      TYPE 9, DP

```

ML

```

7  DCPDP = CC + CP
   YA = YF(DC,ALFAA,PSYA)
   YB = YF(DCPDP,ALFAB,PSYB)
   YC = 0.0
   YD = YF(DCPDP,ALFAD,PSYD)
   ZA = ZF(PSYA,DC,ALFAA)
   ZB = ZF(PSYB,DCPDP,ALFAB)
   ZC = 0.0
   ZD = ZF(PSYD,DCPDP,ALFAD)
   CALL GUTPUT(1,ALFAA,EPST,DOPDP,ZA,ZB,ZC,ZD,YA,YB,YC,YD)
   CALL TWC(DC,DP,YA,PREC)
   STOP
   END

```

ANGLE

```

FUNCTION ANGLE(A,P,PREC)
  DGTRC = 3.14159265359 / 180.0
  N = 0
  TANA = SIN(A) / COS(A)
72  ANGLE = (ATANF(-P * TANA * TANA)) + 3.14159265359
  DIFF = ABSF(ANGLE - P)
  IF (DIFF - (PREC * DGTRD)) 70,70,71
71  P = ANGLE
  N = N + 1
  IF (N - 20) 72,70,70
70  RETURN

```

END

```

FUNCTION EPS(AL,PS,RESOL)
  TANPS = SIN(PS) / COS(PS)
  G = 3. + (COSF(AL) ** 2) * (TANPS * TANPS)
  EPS = SQRTE((2. * RESOL) / (.93 * G))
  RETURN

```

EPS

END

```

FUNCTION TRYAL(E,PY)
  RIGID = 79.5 / 12.725
  TOP = COSF(.6666667 * E) - (RIGID * SIN(E) / PY)
  BOT = (RIGID * COS(E) / PY) - SIN(.6666667 * E)
  TRYAL = ATANF(TOP / BOT)
  RETURN

```

TRYAL

END

```

SUBROUTINE GUTPUT(1,AL,E,DOPDP,ZA,ZB,ZC,ZD,YA,YB,YC,YD)

```

```

9  FORMAT (F14.7)

```

```

990 FORMAT (22HK.5 PERCENT RESOLUTION)

```

OUTPUT

```
991 FORMAT (23HK,25 PERCENT RESOLUTION)
992 FORMAT (23HK,12 PERCENT RESOLUTION)
993 FORMAT (23HK,06 PERCENT RESOLUTION)
994 FORMAT (23HK,03 PERCENT RESOLUTION)
995 FORMAT (4X2HZA15X,2HZB13X,2HZC13X,2HZD/)
996 FORMAT (4X2HYA15X,2HYB13X,2HYC13X,2HYD/)
997 FORMAT ((26HK ALPHA EPSILON)
998 FORMAT(F14.7,2X,F14.7,2X,F14.7,2X,F14.7)
999 FORMAT(F14.7,2X,F14.7)
```

```
1000 FORMAT (21HK DQPCP /)
```

```
GO TO (10,20,30,40,50),I
```

```
10 PRINT 990
```

```
GO TO 11
```

```
20 PRINT 994
```

```
GO TO 11
```

```
30 PRINT 993
```

```
GO TO 11
```

```
40 PRINT 992
```

```
GO TO 11
```

```
50 PRINT 991
```

```
GO TO 11
```

```
11 PRINT 997
```

```
PRINT 999,AL,E
```

```
PRINT 1000
```

```
PRINT 9, DQPCP
```

```
PRINT 995
```

```
PRINT 998, ZA,ZB,ZC,ZD
```

```
PRINT 996
```

```
PRINT 998, YA,YB,YC,YD
```

```
RETURN
```

```
END
```

```
SUBROUTINE TWO(DC,DP,YA,PREC)
```

```
YF(YD,YALF,YPSYT) = YD * SINF(YALF) * SINF(YPSYT)
```

```
ZF(ZPSYT,ZD,ZALF) = ZPSYT * ZD * COSF(ZALF)
```

```
9 FORMAT (F14.7)
```

```
DQPCP = DC + CP
```

```
DGTRC = 3.14159265359 / 180.0
```

```
RESCL = .C003
```

```
J = 1
```

```
99 R = RESCL / .93
```

```
DC = DQPCP / (1. + R)
```

TWO

```

CP = DC * R
A = 21.0 * DGTRC
P = 149.0 * DGTRD
CALL TWGAL(YA,DC,A,P,ALFAA,PSYA,PREC)
IF (SENSE SWITCH 3 ) 101,202
101 TYPE 9, ALFAA
202 EPSI = EPSI(ALFAA,PSYA,RESCL)
ALFAB = ALFAA + (.6666667 * EPSI)
XXXXX = 149.0
PSYB = ANGLE(ALFAB,XXXXX,PREC)
ALFAD = ALFAA - (.6666667 * EPSI)
PSYD = ANGLE(ALFAD,XXXXX,PREC)
YA = YF(DC,ALFAA,PSYA)
YB = YF(DCPDP,ALFAB,PSYB)
YC = YF(DCPDP,ALFAA,PSYA)
YD = YF(DCPDP,ALFAD,PSYD)
ZA = ZF(PSYA,DC,ALFAA)
ZB = ZF(PSYB,DCPDP,ALFAB)
ZC = ZF(PSYA,DCPDP,ALFAA)
ZD = ZF(PSYD,DCPDP,ALFAD)
GO TO (11,22,33,44), J
11 CALL OUTPUT (2,ALFAA,EPSI,DCPDP,ZA,ZB,ZC,ZD,YA,YB,YC,YD)
J = 2
RESCL = .0006
GO TO 99
22 CALL OUTPUT (3,ALFAA,EPSI,DCPDP,ZA,ZB,ZC,ZD,YA,YB,YC,YD)
J = 3
RESCL = .0012
GO TO 99
33 CALL OUTPUT (4,ALFAA,EPSI,DCPDP,ZA,ZB,ZC,ZD,YA,YB,YC,YD)
J = 4
RESCL = .0025
GO TO 99
44 CALL OUTPUT (5,ALFAA,EPSI,DCPDP,ZA,ZB,ZC,ZD,YA,YB,YC,YD)
RETURN
END
SUBROUTINE TWGAL(Y,D,A,P,ALFAA,PSYA,PREC)
9  FORMAT (F14.7)
NUMBER = 1
DGTRC = 3.14159265359 / 180.0
Z = Y/D

```

Two A

```

3  S = SIN(P)
   C = COS(P)
   T = S / C
   SC = 1. / C
   TA = SIN(A) / COS(A)
   Q = 2 / S
   SA = 1. / COS(A)
   SAS = SA * SA
   TT = TA * TA
   QR = 1. / SQRT(1. - (Q * Q))
   SCS = SC * SC
   ASQ = 1.5707963050 + Q*(-.2145988016 + Q*(.0889789874 + Q*(
1-1.0501743046 + Q*(.0308918810 + Q*(-.0170881256 + Q*(.0066700901 -
2Q * .0012624911))))))
   UP = A - (3.14159265359 / 2. - ((SQRT(1. - Q)) * ASQ))
   PU = ((P * SCS) - 1) / (P * P)
   AP = TT + (T / P)
   DEN = (2. * TA*SAS * QP * Q / T) - PU
   DA = ((UP * PU) - (AP * QP * Q / T)) / DEN
   DP = ((UP * 2. * TA * SAS) - AP) / (-DEN)
   A1 = A + DA
   IF (SENSE SWITCH 4) 111,222
111 TYPE 9, A1
222 P1 = P + DP
   IF (ABS(A - A1) - (PREC * DGTRC)) 1,1,2
2   IF (NUMBER - 25) 4,1,1
4   A = A1
   P = P1
   NUMBER = NUMBER + 1
   GO TO 3
1   ALFAA = A1
   PSYA = P1
   RETURN
   END

```


APPENDIX 2

CNL mechanical drawings, Beta Ray Spectrometer MK II #126 to #161 and 142 b,d,e and Sketch "Detector Holder"; available from Crocker Nuclear Laboratory, University of California, Davis, California 95616.

APPENDIX 3

11 SEPT. 1963

CORRECTIONS FOR 7040

```

ENTER SOURCE PROGRAM, PUSH START
08300 C GOOD MORNING SIR OR MADAM AS THE CASE MAY BE, HERE ARE THE ELECTRONS
08300 C MAINLINE PROGRAM
08300 C FOCUSING ELECTRONS IN BETA RAY SPECTROMETER WITH AIR CORE
08300 C CIRCULAR LOOPS
08300 C JUNGEMAN, PILLSBURY, SPERRY 2 OCT 1962
08300 C ZA(1)=DISTANCE OF THE ITH COIL FROM THE SOURCE
08300 C A(1)=RADIUS OF THE ITH COIL
08300 C AMP(1)=CURRENT IN THE ITH COIL
08300 C D=CHARACTERISTIC PARAMETER OF SPECTROMETER IN INCHES.
08300 C P=MOMENTUM OF ELECTRON(ETA) IE. UNITLESS
08300 C Q=CHARGE OF ELECTRON (SQRT OF JOULE METERS)
08300 C USES CYLINDRICAL COORDINATES WITH THE ORIGIN AT THE SOURCE
08300 C USES RATIONALIZED M.K.S. UNITS
08300 C DIMENSION AMP(14),A(14),ZA(14),C(14),EL1(14),EL2(14)
08300 C DIMENSION AK(4),BK(4),AE(4),BE(4)
08300 DO 7 I = 1,4
08312 7 READ 346, AK(1),BK(1),AE(1),BE(1)
08504 346 FORMAT (F13.11,F13.11,F13.11,F13.11)
08542 C INPUT FORMATS
08542 780 FORMAT (I2)
08564 781 FORMAT(F14.7)
08586 782 FORMAT(F14.7,2X,F14.7)
08624 783 FORMAT(F14.7,2X,F14.7,2X,F14.7) ←
08678 123 READ 780, N, ENDR IFLENDER.LT.0) STOP.
08702 DO 124 I = 1,N
08714 124 READ 783, AMP(I),ZA(I),A(I)
08870 READ 783, X,Y1,Y2
08918 READ 782, P,D
08954 P = P * 9.108 * 2.99793 * 1.E-23
09026 D = D * .02540005
09074 C CALCULATES CONSTANTS AND TERMS DUE TO SPECTROMETER FIELD
09074 C USES RATIONALIZED M.K.S. UNITS
09074 Q = SQRTF(10.544 / (2.997929 * 137.04)) * 1.E-18
09158 CON = P / (D * Q)
09218 READ 781, W
09242 C OUTPUT FORMATS
09242 C RUNGA-KUTTA SOLUTION OF TWO SIMULTANEOUS FIRST ORDER DIFFERENTIAL
09242 C EQUATIONS
09242 Q1 = 0.
09278 Q2 = 0.
09314 400 L = 0
09350 C COMPUTES K(I)**2=C(I), K(I)=CS(I), PAR(I)=1-(K(I)**I/I), CSP(I)=
09350 C SQRT(1-K(I)**2), EM(I)=1-CSP(I)/1+CSP(I)
09350 999 DO 1 I = 1,N
09362 1 C(I)=(4.*A(I)*Y2)/((ABSF(A(I)+Y2)**2)+(ABSF(ZA(I)-X)**2))
09698 C CALCULATES COMPLETE ELLIPTIC INTEGRALS OF FIRST KIND (EL1) AND SEC
09698 C KIND(EL2)
09698 DO 66 I = 1,N
09710 AMY = ABSF(A(I) - Y2)
09794 APY = ABSF(A(I) + Y2)
09878 ZMX = ABSF(ZA(I) - X)
09962 ETA = ((AMY ** 2) + (ZMX **2)) / ((APY ** 2) + (ZMX **2))
10154 FI = -LOGF(ETA)

```

```

2 10202 E=1.38629436+ETA*(AK(1)+ETA*(AK(2)+ETA*(AK(3)+AK(4)*ETA)))
10334 EL1(1)=E+ (.5+ETA*(BK(1)+ETA*(BK(2)+ETA*(BK(3)+BK(4)*ETA)))*FL
10514 GG = 1.+ETA*(AE(1)+ETA*(AE(2)+ETA*(AE(3)+AE(4)*ETA)))
10646 66 EL2(1)= GG+ (ETA*(BE(1)+ETA*(BE(2)+ETA*(BE(3)+BE(4)*ETA)))*FL
10850 C COMPUTES THE TWO FINITE SERIES IN TRAJECTORY EQUATION
10850 SER1 = 0
10886 SER2 = 0
10922 DO 2 I = 1,N
③ 10934 S1=AMP(1)*SQRTF(A(1))*(((1.-(C(1)/2.))*EL1(1))-EL2(1))/SQRTF(C(1))
11258 SER1 = SER1 + S1
③ 11306 S2 = AMP(1) / SQRTF(A(1))
11402 SS2 = (((1. - (C(1) / 2.)) * EL2(1)) / (1. - C(1))) - EL1(1)
③ 11642 ST2 = (2. * A(1)) / SQRTF(C(1))
③ 11774 SU2 = SQRTF(C(1)) * (A(1) + Y2)
③ 11906 2 SER2 = SER2+S2*SS2*(ST2-SU2+(Y1*SQRTF(C(1))*(ZA(1)-X)))
12194 C CALCULATES CONSTANTS AND TERMS DUE TO SPECTROMETER FIELD
12194 C USES RATIONALIZED M.K.S. UNITS
12194 CONR = CON * Y2
12242 C CALCULATES FIRST DERIVATIVES
12242 C EQUATIONS OF FIRST DERIVATIVES
12242 AB = 4.E-7 * SER1
12290 XY = 1.E-7 * SER2
③ 12338 ABC = CONR+(AB/SQRTF(ABSF(Y2)))
③ 12410 XYZ = CON-(XY/(ABSF(Y2)*SQRTF(ABSF(Y2))))
12518 CTT = -(Q*Q*ABC*1.E30*(1.+(Y1*Y1))*XYZ)
12674 CT1 = CTT / ((P * 1.E30 * P) - (Q * Q*ABC*1.E30*ABC))
12842 L = L + 1
12890 GO TO (111,222,333,444) , L
12974 111 CAY1 = W * CT1
13022 CAY2 = W * Y1
13070 Y1 = Y1 + (.5 * (CAY1 - (2. * Q1)))
13166 Y2 = Y2 + (.5 * (CAY2 - (2. * Q2)))
13262 Q1 = Q1 + (1.5 * (CAY1 - (2. * Q1))) - (.5 * CAY1)
13406 Q2 = Q2 + (1.5 * (CAY2 - (2. * Q2))) - (.5 * CAY2)
13550 GO TO 999
13558 222 CAY1 = W * CT1
13606 CAY2 = W * Y1
③ 13654 B = 1. - SQRTF(.5)
13714 Y1 = Y1 + (B * (CAY1 - Q1))
13786 Y2 = Y2 + (B * (CAY2 - Q2))
13858 Q1 = Q1 + ((3. * B) * (CAY1 - Q1)) - (B * CAY1)
14026 Q2 = Q2 + ((3. * B) * (CAY2 - Q2)) - (B * CAY2)
14194 GO TO 999
14202 333 CAY1 = W * CT1
14250 CAY2 = W * Y1
③ 14298 G = 1. + SQRTF(.5)
14346 Y1 = Y1 + (G * (CAY1 - Q1))
14418 Y2 = Y2 + (G * (CAY2 - Q2))
14490 Q1 = Q1 + (3. * G * (CAY1 - Q1)) - (G * CAY1)
14658 Q2 = Q2 + (3. * G * (CAY2 - Q2)) - (G * CAY2)
14826 GO TO 999
14834 444 CAY1 = W * CT1
14882 CAY2 = W * Y1
14930 Y1 = Y1 + ((CAY1 - 2. * Q1) / 6.)
15026 Y2 = Y2 + ((CAY2 - 2. * Q2) / 6.)
15122 Q1 = Q1 + ((CAY1 - (2. * Q1)) / 2.) - (.5 * CAY1)
15266 Q2 = Q2 + ((CAY2 - (2. * Q2)) / 2.) - (.5 * CAY2)
15410 X = X + W
15458 PRINT 783, X, Y1, Y2
15506 IF (Y2 - 0.) 500,500,400
15574 500 GO TO 123
15582 END

```