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DESIGN AND PERFORMANCE OF A TRANSPORT
SOLENOID-Si(Li) DETECTOR CONVERSION ELECTRON
SPECTROMETER FOR ON-LINE USE WITH ACCELERATORS*

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An internal conversion electron spectrometer incorporating a solenoidal magnetic field along the target-detector axis for transporting electrons from a target placed in an accelerator beam to a cooled Si(Li) detector was first demonstrated by Burginyon and Greenberg.¹ A new instrument of this general type has been constructed and successfully operated in experiments with beams from the 132 cm FFAG cyclotron of the University of Colorado. Similar spectrometers have recently been built elsewhere^{2,3} for use with heavy ion accelerators. A spectrometer which incorporates a superconducting solenoidal magnet has also been constructed for use with a target on which a thermal neutron beam is incident⁴, and others, with a 4π geometry, have been used with radioactive sources.^{5,6}

The spectrometer described in this paper has been used for the study of conversion electron spectra from isomeric transitions as well as for investigating prompt internal conversion electrons from several nuclei which were excited by reactions induced in ⁴⁹Ti, ¹⁵⁹Tb, ¹⁶⁹Tm and ¹⁸¹Ta targets by p, d, and ³He beams of various energies. During this work an energy resolution of approximately 3 keV FWHM was obtained for electron lines over a wide range of energies and the compiling of a prompt internal conversion electron spectrum with good statistics (approximately 10^5 counts above background in the strongest peaks) typically requires only one to two hours. Examples of the performance of the instrument under various experimental conditions are given in the paper of Konijn, Klank, Jett, and

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Ristinen presented at this meeting.

This article will limit itself to details of the design and performance of this spectrometer and the presentation of calculations and suggestions which may be helpful in the design of similar instruments. More technical details of the design will be published later.

The geometry of the spectrometer is as follows: the liquid nitrogen cooled Si(Li) detector with its sensitive surface perpendicular to the solenoid axis and the electron source (e.g. a radioactive source or target) are located on the axis of the solenoid which is the z-axis of the coordinate system to which the calculations which follow are referred. Both the source and the detector are assumed to be circular with radii R_s and R_{det} ; they are located at $z=0$ and $z=z_d$ respectively. For this particular instrument $z_d = 54$ cm. The internal radius of the solenoid chamber is R_{sol} (3.75 cm for the instrument described in this paper).

First, the acceptance solid angle for electrons collected on the sensitive surface of the detector by a static, homogeneous magnetic induction B will be investigated briefly. For an electron with kinetic energy E leaving the target at an angle θ between the magnetic field (=solenoid axis) and the initial velocity of the electron, the radius of curvature of the electron motion transverse to the magnetic field is

$$r(E, \theta) = \frac{(B\rho)_E}{B} \sin \theta \quad (1)$$

If, for simplicity, it is assumed that the source dimensions can be neglected ($R_s = 0$), the distances $d(z, E, \theta)$ from the axis at a point z along the axis is:

$$d(z, E, \theta) = 2r_E \sin \left(\frac{z \sin \theta}{2r \cos \theta} \right) = 2 \frac{(B\rho)_E}{B} \sin \left(\frac{zB \sin \theta}{2(B\rho)_E \cos \theta} \right). \quad (2)$$

Thus, the total solid angle $\Omega_{det}(E)$ for electrons of energy E to be collected on the sensitive surface of the detector becomes

$$\Omega_{\text{det}}(E) = \int_0^{\theta_{\text{max}}(E)} \omega_{\text{det}}(E, \theta) 2\pi \sin \theta d\theta. \quad (3)$$

$\omega_{\text{det}}(E, \theta)$ is the probability for an electron with E and θ to be incident on the sensitive surface of the detector, i.e.

$$\begin{aligned} \omega_{\text{det}}(E, \theta) &= 1 & \text{for } d(z_d, E, \theta) \leq R_{\text{det}} \\ \omega_{\text{det}}(E, \theta) &= 0 & \text{for } d(z_d, E, \theta) \geq R_{\text{det}} \end{aligned} \quad (4)$$

θ_{max} is a cut-off angle for transmission, due to high energy electrons (with $\frac{(B\rho)E}{B} > \frac{R_{\text{sol}}}{2}$) hitting the solenoid wall, i.e.

$$\begin{aligned} \theta_{\text{max}}(E) &= \frac{\pi}{2} & \text{for } \frac{BR_{\text{sol}}}{2(B\rho)_E} > 1 \\ \theta_{\text{max}}(E) &= \sin^{-1}\left(\frac{BR_{\text{sol}}}{2(B\rho)_E}\right) & \text{for } \frac{BR_{\text{sol}}}{2(B\rho)_E} \leq 1 \end{aligned} \quad (5)$$

An electron which collides with the wall will lose energy at the collision and spiral around the magnetic field to a second collision at which it will again lose energy and so on until the entire kinetic energy is dissipated and the electron comes to rest in the wall. Therefore it has not been considered necessary to provide baffles to intercept these scattered electrons as it is not likely that they will ever reach the detector.

$\Omega_{\text{det}}(E)$ will be equal to 2π for low energy electrons (up to an energy E where $\frac{(B\rho)E}{B} = \frac{R_{\text{det}}}{2}$). Unfortunately, this energy region also contains all the electrons which are knocked out of the atomic structure of the target by collisions with accelerated beam particles (delta-rays). These electrons are so numerous that they may make prompt conversion electron spectroscopy impossible. However, since their energies are considerably lower than the energies of a great number of converted nuclear transitions, these knock-on electrons can be discriminated against by providing a baffle on the solenoid axis between the target and detector. The radius of this baffle, R_{baf} , can be estimated from knowledge of the upper energy limit for such electrons.

An upper energy limit can be obtained easily if it is assumed that the electrons will lose an amount of kinetic energy exactly equal to the binding energy in their atomic orbits as they escape the atomic potential after the collision. Estimating the kinetic energy of the electron in its bound state by means of the virial theorem and using a non-relativistic approximation yields

$$E_e = 4 \left(\frac{m_e}{m_p} E_K E_p \right)^{\frac{1}{2}} + 4 \frac{m_e}{m_p} E_p \quad (6)$$

E_e is the estimated upper energy limit for the knock-on electrons obtained from considering forward scattering of K-shell electrons (binding energy E_K) with beam particles of mass m_p and energy E_p ; m_e is the electron mass.

Unfortunately, such a baffle will not only intercept all electrons below a certain energy limit, but it will also decrease the transmission for higher energy electrons by intercepting those which have at the z-coordinate of the baffle, z_b , a distance $d(z_b, E, \theta)$ from the solenoid axis smaller than R_{baf} . Thus, for use with a baffle, the total solid angle $\Omega_{tot}(E)$ for electrons of energy E to be collected on the sensitive surface of the detector becomes (neglecting finite baffle thickness)

$$\Omega_{tot}(E) = \int_{\theta_{min}(E)}^{\theta_{max}(E)} w_{det}(E, \theta) w_{baf}(E, \theta) 2\pi \sin \theta d\theta, \quad (7)$$

where θ_{max} and $w_{det}(E, \theta)$ are given by equations (5) and (4) respectively. $w_{baf}(E, \theta)$ is the probability for an electron with E and θ to pass beyond the baffle, i.e.

$$\begin{aligned} w_{baf}(E, \theta) &= 0 \quad \text{for } d(z_b, E, \theta) \leq R_{baf} \\ w_{baf}(E, \theta) &= 1 \quad \text{for } d(z_b, E, \theta) > R_{baf} \end{aligned} \quad (8)$$

$\theta_{min}(E)$ is the smallest angle θ with which electrons of energy E can pass the baffle, i.e.

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$$\theta_{\min}(E) = \frac{\pi}{2} \quad \text{for} \quad \frac{BR_{\text{baf}}}{2(B\rho)_E} > 1$$

$$\theta_{\min}(E) = \sin^{-1}\left(\frac{BR_{\text{baf}}}{2(B\rho)_E}\right) \quad \text{for} \quad \frac{BR_{\text{baf}}}{2(B\rho)_E} \leq 1 \quad (9)$$

One very important feature is to be expected from these calculations for a spectrometer with a static magnetic field, namely that there will be fluctuations of the transmission $\Omega_{\text{tot}}(E)$ as a function of E . Such fluctuations have been observed by other groups (e.g.²) and by us when we operated the spectrometer, which usually has a time varying field, with a static field. Due to the fixed distance $d(z, e, \theta)$ from the axis for given z , E , and θ , the baffle and detector can for some energies be located with respect to each other and to the source such that the major fraction of electrons passing the baffle will not hit the sensitive surface of the detector. This will result in a minimum of $\Omega_{\text{tot}}(E)$ for this energy. It can be shown that for a fixed detector and source position this condition is a periodic function of the electron momentum.

A time-varying magnetic field can be used to smear out the electron trajectories and to eliminate the fluctuations of the transmission $\Omega_{\text{tot}}(E)$. Also, from the discussions to follow, it will become evident that a homogeneous magnetic field is not desirable, but rather that at some position between the target and detector the field should have a higher value than at the target position, such that electrons of all energies with large angles θ , are prevented by a magnetic mirror effect from reaching the detector.

The spectrometer described here has provision for both a time-varying and static magnetic field as well as a possibility of changing to a certain degree the time-averaged local field strength $\overline{B}(z)$. Figure 1 shows a schematic cross-sectional drawing of the spectrometer. The solenoid was wound in 47 individual coils, each one having two layers of windings axially and six layers radially. These coils were then connected in series to form three sections of coils I, II, and III,

each section powered individually (see fig. 1). Changing the current through any one of these sections will permit a change of the magnetic field shape; in particular, it will be possible to correct, as much as might be desirable, for the decrease of the field strength at the target and detector position, by increasing the current through coil-section III, with its three sub-sections IIIa, IIIb, and IIIc which are connected in series.

During normal operation the current through coil section III is not rectified completely (about 6% ripple, 360 Hz). In addition, the currents through the individual coil-sections are adjusted such that the field at the target position is approximately 10% to 20% lower than the maximum field strength between the target and detector. The change of magnetic field during the time necessary for electrons to pass from the target to the detector is negligible and the spatial variation of the magnetic field is small over one orbit of the transverse electron motion. Thus, the action integral of the transverse motion will be a constant of the electron motion. This yields for the local, instantaneous radius at a point z

$$r_z(E, \theta) = \frac{(B_0) E}{(B(0)B(z))^{1/2}} \sin(\theta) \quad (10)$$

where $B(0)$ and $B(z)$ are the instantaneous values of the magnetic induction at the source position ($z = 0$) and at the axial coordinate z .

Conservation of energy and angular momentum result for a non-homogeneous field in an energy-independent upper angle of transmission $\theta'_{\max}$

$$\theta'_{\max} = \sin^{-1} \left(\frac{B(0)}{B_{\max}} \right)^{1/2}. \quad (11)$$

This is known as the magnetic mirror effect. $B_{\max}$ is the maximum value of the magnetic induction between the target and detector.

Accurate values for the solid angle of electrons collected on the detector face can now be obtained by calculating the instantaneous values from equations (3) and (7) and averaging over one period of the

magnetic field. To account for the inhomogeneous magnetic field, $\theta_{\max}$ must now be the smaller of the values given by equations (5) and (11) and in all equations $\frac{(B\rho)E}{B}$ must be replaced by $\frac{(B\rho)E}{(B(0)B(z))^{\frac{1}{2}}}$. There is, however, a simple approximation which introduces only a small error.

The phase φ of the transverse electron motion in a plane perpendicular to the magnetic field and situated at a distance z from the target is

$$\varphi = \varphi_0 + \frac{(B(0)B(z))^{\frac{1}{2}} z}{(B\rho)_E \cos \theta} \quad (12)$$

Thus, if z and θ are not too small, a relatively small change of the magnetic induction can result in changing φ by several multiples of 2π . Therefore, the calculation of the transmission of the solenoid can be approximated by a two-dimensional problem, namely by projecting the transverse electron orbits into the plane of the baffle or detector-face and then calculating which fraction of the orbits falls inside the dimensions of the baffle or detector. The radii of the electron orbits used for these calculations are the local values corresponding to the time-averaged field strength.

These calculations have been carried out with corrections for the finite source size R_s as well as the finite thickness of the baffle, and of the collimator with radius R_{det} usually positioned in front of the detector, d_{baf} and d_{det} respectively. In the following equations time averaged values are used for the magnetic field. Thus, $B_{\max}$ and $B_{\min}$ are the time-averaged maximum and minimum field between the target and detector; $B(0)$, $B(b)$ and $B(d)$ are the time-averaged values for the magnetic field at the target position, baffle position, or detector position.

The following results were obtained: there is an upper angle of transmission $\theta_{\max}(E)$ resulting from either collisions with the solenoid walls or the magnetic mirror effect

$$\theta_{\max}(E) = \min \begin{cases} \sin^{-1} \left[\frac{B(0)}{B_{\max}} \right]^{\frac{1}{2}} \\ \sin^{-1} \left[\frac{(B(0)B_{\min})^{\frac{1}{2}} R_{\text{sol}}}{2(B\rho)_E} \right] \end{cases} \quad (13)$$

For use of the spectrometer with a baffle there also is a minimum angle of transmission $\theta_{\min}(E)$

$$\theta_{\min}(E) = \sin^{-1} \left[\frac{(B(0)B(b))^{\frac{1}{2}} (R_{\text{baf}} - R_s)}{2(B\rho)_E} \right] \quad (14)$$

The probability $w_{\text{baf}}(E, \theta)$ that an electron with given energy E and angle θ reaches the region beyond the baffle is

$$w_{\text{baf}}(E, \theta) = 0 \quad \text{for} \quad \frac{(B\rho)_E}{(B(0)B(b))^{\frac{1}{2}}} \sin \theta \leq \frac{R_{\text{baf}} - R_s}{2}$$

$$w_{\text{baf}}(E, \theta) = 1 - \frac{1}{\pi} \cos^{-1} \left[1 - \frac{B(0)B(b)(R_{\text{baf}}^2 - \frac{1}{2}R_s^2)}{2(B\rho)_E^2 \sin^2 \theta \left[1 + \frac{(B(0)B(b))^{\frac{1}{2}} R_s}{\sqrt{2}(B\rho)_E \sin \theta} \right]} \right] \quad (15)$$

$$-\Delta_{\text{baf}}(E, \theta)$$

$$\text{for} \quad \frac{(B\rho)_E}{(B(0)B(b))^{\frac{1}{2}}} \sin \theta > \frac{R_{\text{baf}} - R_s}{2}$$

$\Delta_{\text{baf}}(E, \theta)$ is a correction for the finite baffle thickness which is given by

$$\Delta_{\text{baf}}(E, \theta) = \frac{(B(0)B(b))^{\frac{1}{2}} d_{\text{baf}}}{2\pi(B\rho)_E \cos \theta} \times \left[1 - \frac{1}{\pi} \cos^{-1} \left[1 - \frac{B(0)B(b)(R_{\text{baf}}^2 - \frac{1}{2}R_s^2)}{2(B\rho)_E^2 \sin^2 \theta \left[1 + \frac{(B(0)B(b))^{\frac{1}{2}} R_s}{\sqrt{2}(B\rho)_E \sin \theta} \right]} \right] \right]$$

$$\text{for} \quad 2\pi \frac{(B\rho)_E}{(B(0)B(b))^{\frac{1}{2}}} \cos \theta > d_{\text{baf}} \quad (16)$$

$$\Delta_{\text{baf}}(E, \theta) = 1 - \frac{1}{\pi} \cos^{-1} \left[1 - \frac{B(0)B(b)(R_{\text{baf}}^2 - \frac{1}{2}R_s^2)}{2(B\rho)_E^2 \sin^2 \theta \left[1 + \frac{(B(0)B(b))^{\frac{1}{2}} R_s}{\sqrt{2}(B\rho)_E \sin \theta} \right]} \right]$$

$$\text{for} \quad 2\pi \frac{(B\rho)_E}{(B(0)B(b))^{\frac{1}{2}}} \cos \theta \leq d_{\text{baf}}$$

The probability $w_{\text{det}}(E, \theta)$ that electrons penetrating beyond the baffle will hit the detector face is given by

$$w_{\text{det}}(E, \theta) = 1 \quad \text{for } \frac{(B\rho)_E}{(B(0)B(d))^{\frac{1}{2}}} \sin \theta < \frac{R_{\text{det}} - R_s}{2}$$

$$w_{\text{det}}(E, \theta) = \frac{1}{\pi} \cos^{-1} \left[1 - \frac{B(0)B(d)(R_{\text{det}}^2 - \frac{1}{2}R_s^2)}{2(B\rho)_E^2 \sin^2 \theta} \frac{(B(0)B(d))^{\frac{1}{2}} R_s}{\left[1 + \frac{(B(0)B(d))^{\frac{1}{2}} R_s}{\sqrt{2} (B\rho)_E \sin \theta} \right]} \right] \quad (17)$$

$$- \Delta_{\text{det}}(E, \theta),$$

$$\text{for } \frac{(B\rho)_E}{(B(0)B(d))^{\frac{1}{2}}} \sin \theta \geq \frac{R_{\text{det}} - R_s}{2}.$$

The correction $\Delta_{\text{det}}(E, \theta)$ for finite collimator thickness is

$$\Delta_{\text{det}}(E, \theta) = \frac{(B(0)B(d))^{\frac{1}{2}} d_{\text{det}}}{2\pi (B\rho)_E \cos \theta}$$

$$\times \frac{1}{\pi} \cos^{-1} \left[1 - \frac{B(0)B(d)(R_{\text{det}}^2 - \frac{1}{2}R_s^2)}{2(B\rho)_E^2 \sin^2 \theta} \frac{(B(0)B(d))^{\frac{1}{2}} R_s}{\left[1 + \frac{(B(0)B(d))^{\frac{1}{2}} R_s}{\sqrt{2} (B\rho)_E \sin \theta} \right]} \right]$$

$$\text{for } 2\pi \frac{(B\rho)_E}{(B(0)B(d))^{\frac{1}{2}}} \cos \theta > d_{\text{det}} \quad ; \quad (18)$$

$$\Delta_{\text{det}}(E, \theta) = \frac{1}{\pi} \cos^{-1} \left[1 - \frac{B(0)B(d)(R_{\text{det}}^2 - \frac{1}{2}R_s^2)}{2(B\rho)_E^2 \sin^2 \theta} \frac{(B(0)B(d))^{\frac{1}{2}} R_s}{\left[1 + \frac{(B(0)B(d))^{\frac{1}{2}} R_s}{\sqrt{2} (B\rho)_E \sin \theta} \right]} \right]$$

$$\text{for } 2\pi \frac{(B\rho)_E}{(B(0)B(d))^{\frac{1}{2}}} \cos \theta \leq d_{\text{det}}.$$

The solid angle of electrons collected on the detector face is:
for us without baffle

$$\Omega_{\text{det}}(E) = \int_0^{\theta_{\text{max}}(E)} w_{\text{det}}(E, \theta) 2\pi \sin \theta d\theta \quad (19)$$

for use with baffle

$$\Omega_{\text{tot}}(E) = \int_{\theta_{\text{min}}(E)}^{\theta_{\text{max}}(E)} \omega_{\text{det}}(E, \theta) \omega_{\text{baf}}(E, \theta) 2\pi \sin \theta d\theta \quad (20)$$

Values for the transmission have been calculated and measured for detectors of 9 mm and 19.2 mm diameter and for various magnetic field shapes. Calculated values for both detectors and measured values for detectors of 9 mm diameter are plotted in fig. 3 for the magnetic field of fig. 2. Measured values for 19.2 mm detectors will differ by a larger fraction from the calculated values than is the case for 9 mm detectors. This is because most of the increase in transmission achieved with the larger detectors is due to electrons with big angles θ which are less likely to be detected in the absorption peak because of back scattering which will be described in the following paragraphs.

The disagreement between the measured and calculated values is due to the variations of the detector response at different angles of incidence. The measured values for the transmission were obtained by taking the electron spectra of various sources with a Si(Li) detector at a known geometry outside the solenoid. Then the same detector was used inside the transport solenoid spectrometer for obtaining spectra from the same sources. The ratio of electrons detected in the full-energy peak determined the ratio of the two solid angles. It should be noted that this is not the efficiency which must include the detector response and has to be measured with calibrated sources.

For the calibration measurements without solenoid, the electrons were incident upon the detector at angles near the normal direction ($\theta=0$). Thus, about 85% of the incident electrons are expected to be detected in the full energy peak.^{7,8} When used with the solenoid, however, most of the electrons will be incident upon the detector face at larger angles θ , especially if a baffle is used which intercepts the electrons with small angles θ . Therefore, the fraction of electrons detected in the absorption peak may be expected to be as

much as 20% to 40% smaller as compared to normal incidence. These considerations of detector response also show that it is desirable to provide for an inhomogeneous magnetic field that will result in a magnetic mirror which prevents electrons at large angles θ from reaching the detector. The gain in transmission that might be obtained from the transmission of electrons with large angles θ will be offset by the large number of electrons being detected in the low energy tail and by the loss of resolution due to the straggling which results from the effectively thicker detector window seen by these electrons.

The electron transport solenoid- Si(Li) detector spectrometer described in this paper has provision for a Si(Li) or Ge(Li) photon spectrometer which can be positioned approximately 1.5 cm from the target on that side opposite to the electron detector. This arrangement permits γ -e or X-e coincidence measurements. Whereas the transmission of the spectrometer is sufficient for taking conversion electron spectra, it may be desirable to increase the transmission for some coincidence measurements. This increase could be achieved by replacing the baffle with an electrostatic barrier between the target and detector. Preliminary measurements with such a potential barrier have been promising. An additional benefit of replacing the baffle by a potential barrier is that this will permit the observation of lower energy electrons in on-line work.

If it is assumed that the field of this barrier is such that the orbits of those electrons which penetrate the barrier are not significantly disturbed, the transmission with such an electrostatic filter, $\Omega_{fil}(E)$ becomes

$$\begin{aligned} \Omega_{fil}(E) &= 0 && \text{for } E \leq eV \\ \Omega_{fil}(E) &= \int_0^{\theta'_{\max}(E)} \omega_{det}(E, \theta) 2\pi \sin \theta d\theta && \text{for } E > eV \end{aligned} \quad (21)$$

where V is the potential of the barrier and $w_{\text{det}}(E, \theta)$ is given by equation (17). $\theta'_{\text{max}}(E)$ is the upper angle for transmission, given by

$$\theta'_{\text{max}}(E) = \sin^{-1} \left[\left(1 - \frac{eV}{E} \right) \frac{B(0)}{B(f)} \right]^{\frac{1}{2}}, \quad (22)$$

where $B(f)$ is the magnetic induction at the position of the electrostatic filter. It should be noted that the electrostatic barrier prevents electrons of all energies with large θ from reaching the detector. Therefore, the earlier arguments against a homogeneous magnetic field do not apply in this case. Values for $\Omega_{\text{fil}}(E)$ have been calculated for a homogeneous magnetic field and for the field of fig. 2, as well as for 9 mm and 19.2 mm diameter detectors. The results are shown in fig. 4.

In view of the present interest in directional correlation measurements involving internal conversion electrons, one last feature of the transport solenoid-Si(Li) spectrometer will be described briefly. If the instrument is used with a static magnetic field, the position of an electron in a given plane perpendicular to the solenoid axis is a function of the electron's initial direction and its energy only. Thus, the use of one or, for increased accuracy, more baffles with suitable apertures will permit the passage of electrons in a small angular range only. Changing the magnetic field strength or the axial baffle position will result in the passage of different angles. The data obtained by this method will be in a somewhat unfamiliar form since the angles passed for given aperture position and field strength will be a function of the electron energy. This can, however, be easily accounted for by a suitable analyzing procedure.

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Figure Captions

Figure 1 Schematic cross section of the transport solenoid-Si(Li) spectrometer in the plane containing the solenoid axis and the beam from the accelerator.

a, b, c: sub-sections of coil-section III

d: coil-section II

e: coil-section I

Figure 2 Time averaged magnetic induction $B(z)$ used for most of the experimental work with the following current distribution.

$$I_I = I_{II} = 555A, I_{III} = 570A.$$

Figure 3 Calculated and measured spectrometer transmission curves. Differences between calculated and measured values are discussed in the text.

a. Measured $\Omega_{tot}(E)$ for

$$R_{det} = 0.45 \text{ cm}; d_{det} = 0.1 \text{ cm}; R_{baf} = 0.63 \text{ cm};$$

$$d_{baf} = 0.15 \text{ cm}; R_s = 0.1 \text{ cm. The magnetic field is that plotted in fig. 2.}$$

b. Calculated $\Omega_{tot}(E)$ for same conditions as curve a.

c. Measured $\Omega_{det}(E)$, no baffle, otherwise same conditions as curves a and b.

d. Calculated $\Omega_{det}(E)$, same conditions as curve c.

e. Calculated $\Omega_{tot}(E)$ for

$$R_{det} = 0.96 \text{ cm}; d_{det} = 0.1 \text{ cm}; R_{baf} = 0.63 \text{ cm}; d_{baf} = 0.15 \text{ cm}; R_s = 0.1 \text{ cm. The field is that shown in fig. 2.}$$

f. Calculated $\Omega_{det}(E)$, no baffle, otherwise same conditions as curve e.

Figure 4 Calculated values for the transmission $\Omega_{fil}(E)$ expected with an electrostatic potential barrier of 60 kV.

a: for the magnetic field shown in fig. 2

b: for a homogeneous magnetic field ($B(z) = 5500$ gauss)