Stokes parameters for electron inpact ionization/excitation coincidence experiments

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1 Introduction

The R-Martrix program [4] has been used in many different fields in atomic and molecular physics. Bartschat et al. [2] presented a program to calculate cross sections for electron impact ionization of atoms. A "fast" ionizing projectile is inelastically scattered by an atom or ion. A "slow" electron is ejected and the ion is left in an excited state. This package is an extension to the above R-Matrix program. It calculates double differential cross sections and Stokes parameters that describe the light emitted by the decaying excited residual ions. The program calculates state multipoles $\langle T(L)^{+}_{KQ}\rangle$ for the combined effect of electron impact ionization and excitation. The program uses reduced matrixelements from the R-Matrix program for impact ionization. It then calculates helping scattering amplitudes, bilinear products of these and finally the state multipoles.
From these state multipoles the double differential cross section and Stokes parameters are calculated. It is assumed that the initial angular momentum of the incident electron and of the atom is known. It is furthermore assumed that the scattered electron is not observed and the ejected electron is observed in coincidence with the light from the decaying ion.

2 Theory

The process considered is

$$
\begin{array}{lll}
\mathrm{A} + e_0^- \longrightarrow & \mathrm{I}^* & + e_1^- + e_2^- \\
& \searrow & \\
& & \mathrm{I} + \gamma
\end{array}
$$

Here A stands for the initial atoms with quantum numbers $L_0, M_0, S_0, M_{S_0}, \alpha_0, E_0$; where α represents all other quantum numbers. The incoming electron is represented by e_0^- with quantum numbers $l_0, m_0, m_{s_0}, \vec{k}_0, \epsilon_0$ and $\epsilon_0 = k_0^2$. The intermediate state of ion and ejected electron immediately after the incoming electron is scattered is described by the quantum numbers $L_1, M_1, S_1, M_{S_1}, \alpha_1, E_1$. The scattered electron, e_1^- has quantum numbers $l_1, m_1, m_{s_1}, \vec{k}_1, \epsilon_1$. The intermediate state "decays" by ejecting an electron, e_2^- with quantum numbers $l_2, m_2, m_{s_2}, \vec{k}_2, \epsilon_2$. The resulting ionic state I^* is represented by $L_f, M_f, S_f, M_{S_f}, \alpha_f, E_f$. This "final" state then decays to the ionic ground state with quantum numbers $L_g, M_g, S_g, M_{S_g}, \alpha_g, E_g$. The symbol γ represents the photon emitted during the decay.
This program calculates parameters that describe the process where the scattered electron e_1^- is not observed. Therefore the state of the excited ion I^* has to be described. This is done in terms of state multipoles $\langle T(L_f)^{+}_{KQ}\rangle$. Here $\langle T(L_f)^{+}_{00}\rangle$ is proportional to the double differential cross section. The angular distribution of light emitted by the ions I^* is determined by the relative contributions of the individual M_f levels, as expressed in the $\langle T(L_f)^{+}_{KQ}\rangle$. Finally, no spin analysis is made and therefore all spins have to be averaged over. Since there is a lot of averaging done in calculating the state multipoles, helping amplitudes f are defined as

$$\begin{aligned} f(l_1, m_1, M) &= \sum_{l_0 l_2 m_2 \lambda L_1 M_1} Y_{l_2,m_2}(\hat{k}_2) \exp\{i(\sigma_{l_2} + \sigma_{l_1} + \delta_{l_1} - \sigma_{l_0} - \delta_{l_0})\} \\ &* \quad (i)^{\lambda + l_0} (l_1 \ -m_1, \lambda \ m_1 | l_0 0)(L_0 \ M_0, L_1 \ -M_1 | \lambda \ m_1) \\ &* \quad (L_f \ M, l_2 \ m_2 | L_1 \ M_1) R^{\lambda S_a}_{L_0 l_0 S_0 L_1 L_f S_f l_1 l_2} \end{aligned} \tag{1}$$

Here λ is the multipole component of the Coulomb interaction. The $R^{\lambda S_a}_{L_0 l_0 S_0 L_1 L_f S_f l_1 l_2}$ in this formula are reduced matrix elements that contain no angular dependence anymore. They are reduced matrix elements of the T operator from [6].
The continuum wave functions are written in plane wave normalization and $Y_{l_2 m_2}(\hat{k}_2)$ is a spherical harmonic. The Coulomb phase shifts for the incoming, scattered and ejected electron are $(\sigma_{l_0}, \delta_{l_0}, \sigma_{l_1}, \delta_{l_1}, \sigma_{l_2})$.

From these scattering amplitudes bilinear amplitudes $\langle f_M f^*_{M'}\rangle$ are calculated according to

$$\langle f_M f^*_{M'}\rangle = \frac{32\pi}{{k_0}^2} \sum_{l_1 m_1} f(l_1 m_1, M) f^*(l_1 m_1, M') \tag{2}$$

The sum over $l_1 m_1$ represents the averaging over the direction of the scattered electron.
With the help of these averaged amplitudes state multipoles $\langle T(L_f)^{+}_{KQ}\rangle$ are

finally calculated according to [3]:

$$\langle T(L_f)^{+}_{KQ}\rangle = \sum_{MM'} (-1)^{L_f - M}(LM', L-M|KQ)\langle f_M f^{*}_{M'}\rangle \tag{3}$$

These state multipoles can, in principle, be calculated for arbitrary L_f. From [3] it can also be seen that

$$\langle T(L_f)^{+}_{00}\rangle = \frac{1}{\sqrt{2L_f+1}}\sigma \tag{4}$$

where

$$\sigma = \frac{d^2\sigma}{d\Omega_2 d\epsilon_2} \tag{5}$$

is the double differential cross section.
Because of hermicity conditions for the bilinear amplitudes and reflection invariance with respect to the $\hat{k}_0 - \hat{k}_2$ plane the following relations hold for the state multipoles. For details see [6].

$$\begin{aligned} \langle T(L_f)^{+}_{10}\rangle &= 0 \\ \langle T(L_f)^{+}_{11}\rangle &= \langle T(L_f)^{+}_{1\,-1}\rangle \\ \langle T(L_f)^{+}_{22}\rangle &= \langle T(L_f)^{+}_{2\,-2}\rangle \\ \langle T(L_f)^{+}_{21}\rangle &= \langle T(L_f)^{+}_{2\,-1}\rangle \end{aligned} \tag{6}$$

where $\langle T(L_f)^{+}_{11}\rangle$ is imaginary and all $\langle T(L_f)^{+}_{2Q}\rangle$ are real.
Following the definition of [3] for the coordinate system of the photon detector, the general expression for the intensity of the light emitted in the transition $L_f \to L_g$ is:

$$I = \sum_{KQ}\left[\frac{1}{\gamma}W(L_g, L_f)C(K)\left\{\begin{array}{ccc} 1 & 1 & K \\ L_f & L_f & L_g \end{array}\right\}\right] D^{(K)}_{0Q}(\hat{n})\langle T(L_f)^{+}_{KQ}\rangle \tag{7}$$

Here $\hat{n}$ is the direction of the photon detector with polar angles θ_D, ϕ_D and $D^{(K)}_{0Q}(\hat{n})$ is a rotation matrix which transforms the detector system into the collision system. Also, γ is the decay constant and $W(L_g, L_f)$ is the partial decay width and *C(K)* is a numerical factor with values:

$$C(0) = -\frac{2}{\sqrt{3}}, \qquad C(1) = 0, \qquad C(2) = -\sqrt{\frac{2}{3}}. \tag{8}$$

In order to completely describe the process, the polarization of the light also has to be determined. In the following Stokes parameters are defined according to [3]. Since only dipole radiation is observed, no information about multipoles of rank $K > 2$ can be obtained.
Using the symmetry properties for the state multipoles, equation (6), the Stokes parameters can be calculated as follows:

$$\begin{aligned}
I &= \frac{1}{\gamma} W(L_g, L_f)(-1)^{L_g+L_f} \Bigg[\frac{2}{3\sqrt{2L_f+1}} \langle T(L_f)^{+}_{00} \rangle \\
&- \left\{ \begin{array}{ccc} 1 & 1 & 2 \\ L_f & L_f & L_g \end{array} \right\} \Big(\bar{G}(2) \langle T(L_f)^{+}_{22} \rangle \sin^2\theta_D \cos 2\phi_D \\
&\quad -\bar{G}(2) \langle T(L_f)^{+}_{21} \rangle \sin 2\theta_D \cos\phi_D \\
&\quad +\frac{1}{\sqrt{6}} \bar{G}(2) \langle T(L_f)^{+}_{20} \rangle [3\cos^2\theta_D - 1] \Big) \Bigg] && (9) \\
\eta_3 &= \frac{1}{\gamma} W(L_g, L_f)(-1)^{L_g+L_f} \left\{ \begin{array}{ccc} 1 & 1 & 2 \\ L_f & L_f & L_g \end{array} \right\} \Big[\bar{G}(2) \langle T(L_f)^{+}_{22} \rangle \\
&\quad *(1+\cos^2\theta_D) \cos 2\phi_D + \bar{G}(2) \langle T(L_f)^{+}_{21} \rangle \sin 2\theta_D \cos\phi_D \\
&\quad +\sqrt{\frac{2}{3}} \bar{G}(2) \langle T(L_f)^{+}_{20} \rangle \sin^2\theta_D \Big] / I && (10) \\
\eta_1 &= -\frac{1}{\gamma} W(L_g, L_f)(-1)^{L_g+L_f} \left\{ \begin{array}{ccc} 1 & 1 & 2 \\ L_f & L_f & L_g \end{array} \right\} \Big[\bar{G}(2) \langle T(L_f)^{+}_{22} \rangle \\
&\quad *2\cos\theta_D \sin 2\phi_D + \bar{G}(2) \langle T(L_f)^{+}_{21} \rangle 2\sin\theta_D \sin\phi_D \Big] / I && (11) \\
\eta_2 &= -\frac{1}{\gamma} W(L_g, L_f)(-1)^{L_g+L_f} \left\{ \begin{array}{ccc} 1 & 1 & 1 \\ L_f & L_f & L_g \end{array} \right\} 2i\bar{G}(1) \langle T(L_f)^{+}_{11} \rangle \\
&\quad * \sin\theta_D \sin\phi_D / I && (12)
\end{aligned}$$

It can be seen that the Stokes parameters are normalized to the total intensity of the emitted light. In this formula the $\bar{G}(K)$ are time-averaged perturbation coefficients as described in [3]. They have to be included for non singlet–singlet transitions. The explicit form of the coefficients is for fine structure interaction:

$$\bar{G}_f(K) = \frac{1}{2S+1} \sum_J (2J+1)^2 \left\{ \begin{array}{ccc} L_f & J & S \\ J & L_f & K \end{array} \right\}^2 \qquad (13)$$

and for hyperfine structure interaction:

$$\bar{G}_h(K) = \frac{1}{2I+1} \sum_F (2F+1)^2 \left\{ \begin{array}{ccc} J & F & I \\ F & J & K \end{array} \right\}^2 \qquad (14)$$

where S is the total electronic spin of the ion, I is the nuclear spin and F denotes the total angular momentum $\vec{F} = \vec{I} + \vec{J}$.

Figure 1: flow diagram of the package

The combined effect of fine and hyperfine interaction can be calculated as follows:

$$\bar{G}_c(K) = \frac{1}{2S+1}\frac{1}{2I+1}\sum_{JF}(2J+1)^2(2F+1)^2 \left\{ \begin{array}{ccc} L_f & J & S \\ J & L_f & K \end{array} \right\}^2 \left\{ \begin{array}{ccc} J & F & I \\ F & J & K \end{array} \right\}^2 \tag{15}$$

It can be seen from these equations that $\bar{G}(0) = 1$ and therefore $\bar{G}(0)$ has been left out in the above formulae.

3 Description of the program

The flow Diagram of the program is shown in figure 1.

3.1 A brief program description

Instead of describing each subroutine separately, only a typical run is described. The package consists of two independent programs. The first is "ION_STATE", a program to calculate state multipoles from R-Matrix elements. The second is "OBSERVE_PERTUR", a program to calculate Stokes parameters from the state multipoles. Since this program does not rely on the R-Matrix elements it can be used to calculate parameters based on different theories.

3.1.1 Program ION_STATE

The input data for this program is closely related to the R-Matrix program. Energies and angular momenta have to be identical to the parameters for which the reduced matrix elements are read in. The angles of the momentum of the ejected electron for which the calculation is performed have to be submitted as the only independent parameter.
First, factorials are calculated in FACTORIAL_LOGARITHM. These are used for calculating Clebsch-Gordan coefficients in CLEBSCH_GORDAN. Next, Associated Legendre polynomials are calculated for the $Y_{l_2 m_2}$. Then the subroutine SETUP reads in the basic data from tape. It also calculates the Coulomb phaseshifts for the ejected electron.
From ITAPE1 reduced matrixelements R are read in. Each line in this file has to be of the form:
l_0, l_1, l_2, λ, L_1, Dummy, Dummy, Dummy, E2, $Re(R)$, $Im(R)$
Next, Coulomb phaseshifts $(\sigma_{l_0}, \delta_{l_0}, \sigma_{l_1}, \delta_{l_1})$ are read in from ITAPE2. They should be of the form (for each element):

Two dummy lines and then MAXMAX_... phaseshifts.
Next, in subroutine FSCATT the helping scattering amplitudes $f(l_1, m_1, M_f)$ are calculated according to equation (1). The angular independent part of f is calculated separately and the result is stored in PART_SUM($l_1 l_2 m_1 M_f$). Then the bilinear amplitudes $\langle f_M f^*_{M'} \rangle$ are calculated according to equation (2). In subroutine STATE_MULTIPOLES $\langle T(L_f)^+_{KQ} \rangle$ are calculated from the $\langle f_M f^*_{M'} \rangle$ according to equation (3). Finally, in subroutine WRITE_AMPLITUDES the state multipoles are written to ITAPE3.

3.1.1.1 special features :

The input stream is UNIT 5, the output stream UNIT 6. The precision of all real parameters and of all complex parameters is defined by I_PREC. It is currently set to 15 digits and an exponent of maximum 300. Most array dimensions are set dynamically so that there should be no need to adjust them to different cases. The parameters are all self-descriptive.
The convergence of the results can also be checked. The input parameters starting with a *MAXMAX* are maximum angular momenta as read in from tape. In addition to that maximum angular momenta for which the calculation is performed are read in. By comparing the results for different *MAX* values convergence problems can be detected.

3.1.1.2 Description of the input data :

All input data are read from UNIT 5, the following format statements are used: FORMAT(8I5) for integer numbers (variable names beginning with I–N) and FORMAT(5F14.7) for real numbers.

short description of the input data :

1. TITLE
2. ITAPE1, ITAPE2, ITAPE3
3. NBUG1, NBUG2, NBUG3
4. L0_BIG, ML0_BIG
5. L_FINAL
6. E0, E1
7. I_THETAE_BEGIN, I_THETAE_DIFFERENCE, I_THETAE_NUMBER, I_PHIE_BEGIN, I_PHIE_DIFFERENCE, I_PHIE_NUMBER
8. MAX_L0, MAX_L1, LAMBDA_MAX, MAXMAX_L0, MAXMAX_L1, MAXMAX_LAMBDA

detailed description of the input data :

1.

TITLE The title of the run

2.

ITAPE1 Input unit for reduced matrix elements

ITAPE2 Input unit for Coulomb phase shifts

ITAPE3 Output unit for state multipoles

3.

NBUG1 Debug parameter for subroutine SETUP

- =0: No output
- >0: Print position in SETUP, print E2 as read in from ITAPE1
- >1: Print data as read in from ITAPE1
- >2: Print phase shifts as read in from ITAPE2

NBUG2 Debug parameter for subroutine FSCATT

- =0: No output
- >0: Print general position
- >1: Print position inside the second PHI, THETA loop
- >2: Print $\langle f_M f^*_{M'} \rangle$
- >3: Print IER after each call to CLEBSCH_GORDAN, IER=0 if the selection rules are violated

NBUG3 Debug parameter for subroutine WRITE_AMPLITUDES

- =0: No output
- >0: Print state multipoles

4.

L0_BIG $= L_0$, the angular momentum of the initial atoms

ML0_BIG $= M_0$, the magnetic quantum number of the initial atoms

5.

L_FINAL $= L_f$, the angular momentum of the final, excited ions

6.

E0 $= \epsilon_0$, the energy of the incident electron (in atomic units)

E1 $= \epsilon_1$, the energy of the scattered electron (in a.u.)

7.

I_THETAE_BEGIN THETAE refers to the polar angle of the ejected electron. All angles have to be integer numbers. I_THETAE_BEGIN is the first angle for which the calculation is performed.

I_THETAE_DIFFERENCE The stepsize of THETAE angles for which the calculation is performed

I_THETAE_NUMBER The total number of THETAE angles for which the calculation is performed

I_PHIE_BEGIN PHIE refers to the azimuth angle of the ejected electron. All angles have to be integer numbers. I_PHIE_BEGIN is the first angle for which the calculation is performed.

I_PHIE_DIFFERENCE The stepsize of PHIE angles for which the calculation is performed

I_PHIE_NUMBER The total number of PHIE angles for which the calculation is performed

8.

MAX_L0 Maximum angular momentum of the initial electron for which the calculation is performed

MAX_L1 Maximum angular momentum of the scattered electron for which the calculation is performed

LAMBDA_MAX Maximum angular momentum of the Coulomb interaction for which the calculation is performed

MAXMAX_L0 Maximum value of l_0 for which data are read in

MAXMAX_L1 Maximum value of $= l_1$ for which data are read in

MAXMAX_LAMBDA Maximum value of λ for which data are read in

3.1.2 Program OBSERVE_PERTUR

The input data for this program are related to those for ION_STATE. As additional parameters the angular momentum of the ground state to which the excited ions decay and the angle of the photon detector have to be given. Also, NBUG5 determines the mode of the part that calculates perturbation coefficients.

At first subroutine FACTORIAL_LOGARITHM calculates the factorials needed for subroutine SYM6 which calculates 6J–symbols. Then the necessary data are read in. After that in subroutine SETUP the state multipoles are read in from ITAPE1. The format is exactly that of the output of ION_STATE. At first, 8 dummy lines are read and then $2L_f + 1$ blocks with each:

One dummy line and then θ_E, ϕ_E and the real and imaginary part of $\langle T(L_f)^{+}_{KQ}\rangle$ for $K = 0 ... 2L_f$ (outer loop) and $Q = -K ... K$ (inner loop).

The number of θ_E and ϕ_E angles have to be given as input parameters. The individual angles are read in from ITAPE1. The angles θ_E and ϕ_E in file ITAPE1 have to be the same but not in the same order for each $K,\ Q$.
Next, the perturbation coefficients are calculated in subroutine PERTUR. This subroutine is adapted from [1]. Details can be found there. After that the Stokes parameters are calculated in subroutine STOKES_PARAMETERS according to equations (9)-(12). In the explicit calculation the common factor $\frac{1}{\gamma}W(L_g, L_f)(-1)^{L_f+L_g}$ has been left out. Finally the Stokes parameters are written to ITAPE2 in subroutine WRITE_PARAMETERS.

3.1.2.1 special features of the program :

The input and output streams as well as the convention for the numbers are the same as above.

3.1.2.2 Description of the input data :

All input data are read from UNIT 5, the following format statements are used: FORMAT(8I5) for integer numbers (variable names beginning with I–N) and FORMAT(5F14.7) for real numbers.

short description of the input data :

1. TITLE
2. ITAPE1, ITAPE2
3. NBUG1, NBUG2, NBUG3,NBUG4,NBUG5
4. L_FINAL, L_GROUND
5. E0, E1, E2
6. I_THETAE_NUMBER, I_PHIE_NUMBER
7. I_THETAD_BEGIN, I_THETAD_DIFFERENCE, I_THETAD_NUMBER, I_PHID_BEGIN, I_PHID_DIFFERENCE, I_PHID_NUMBER
8. (depends on the value of NBUG5)

detailed description of the input data :

1.

TITLE The title of the run

2.

ITAPE1 Input unit for state multipoles

ITAPE2 Output unit for Stokes parameters

3.

NBUG1 Debug parameter for subroutine SETUP and main program

- =0: No output
- >0: Print data read in from UNIT 5
- >1: Print data as read in from ITAPE1

NBUG2 Debug parameter for subroutine STOKES_PARAMETER

- =0: No output
- >0: Print general position

NBUG3 Debug parameter for subroutine WRITE_PARAMETERS

- =0: No output
- >0: Print Stokes parameters

NBUG4 Debug parameter for subroutine PERTUR

- =0: No output
- =1: Output of PERTUR is printed

NBUG5 Determines what action the subroutine PERTUR performs. GPT-BAR(K) are the perturbation coefficients.

- =0: All GPTBAR are set to 1.0
- =1: GPTBAR are calculated for fine structure interaction
- =2: GPTBAR are calculated for hyperfine structure interaction
- =1: GPTBAR are calculated for the combined effect of fine structure and hyperfine structure interaction

4.

L_FINAL $= L_f$, the angular momentum of the final, excited ions

L_GROUND $= L_g$, the angular momentum of the ground state to which the excited ions decay.

5.

E0 $= \epsilon_0$, the energy of the incident electron (in a.u.)

E1 $= \epsilon_1$, the energy of the scattered electron (in a.u.)

E1 $= \epsilon_2$, the energy of the ejected electron (in a.u.)

6.

I_THETAE_NUMBER THETAE refers to the polar angle of the ejected electron. All angles have to be integer numbers. I_THETAE_NUMBER is the number of angle for which the calculation is performed.

I_PHIE_NUMBER PHIE refers to the azimut angle of the ejected electron. I_PHIE_NUMBER is the number of angle for which the calculation is performed.

7.

I_THETAD_BEGIN THETAD refers to the polar angle of the photon detector. I_THETAD_BEGIN is the first angle for which the calculation is performed.

I_THETAD_DIFFERENCE The stepsize of THETAD angles for which the calculation is performed

I_THETAD_NUMBER The total number of THETAD angles for which the calculation is performed

I_PHID_BEGIN PHID refers to the azimuth angle of the ejected electron. I_PHID_BEGIN is the first angle for which the calculation is performed.

I_PHID_DIFFERENCE The stepsize of PHID angles for which the calculation is performed

I_PHID_NUMBER The total number of PHID angles for which the calculation is performed

8. etc.

NBUG5=0: empty

NBUG5=1: 8. XL, XS, final angular momentum (L_f) and spin (S_f)

NBUG5=2: 8. XJ, total electronic angular momentum

9. NISO, number of isotopes

10 ... 10+NISO XI,XMIX nuclear spin and relative contribution for each isotope

NBUG5=3: 8. XL, XS, XJ

9. NISO

10 ... 10+NISO XI,XMIX

NBUG5=4: 8. GPTBAR(1), GPTBAR(2)

4 Testrun

The program has been tested for Helium. The incident electron energy was chosen as E0 = 9.4083a.u., the energy of the scattered electron as E1 = 6.9089007a.u., and the energy of the ejected electron as E2 = 0.1102536a.u.. The transition considered is $(1s^2) \rightarrow (2p)$.

4.1 Testrun output

```
-------------------------------------------------------------------------

 ELECTRON IMPACT IONIZATION OF HE(1S2)  ... ION_STATE ... JAN 1995

-------------------------------------------------------------------------

                     *************************
                     *                       *
                     *   I O N   S T A T E   *
                     *                       *
                     *************************


TAPE UNITS : 10 11 12
DEBUG PARAMETERS :  1  0  0
L0_BIG =  0  ML0_BIG =  0
L_FINAL =  1
E0(AU)=     9.4083000     E1(AU) =     6.9089007
I_THETAE_BEGIN =  0  I_THETAE_DIFFERENCE = 20  I_THETAE_NUMBER =  3
 I_PHIE_BEGIN =  0  I_PHIE_DIFFERENCE =180  I_PHIE_NUMBER =  2
MAX_L0 = 10  MAX_L1 = 10  LAMBDA_MAX =  4  MAXMAX_L0 = 90
MAXMAX_L1 = 90  MAXMAX_LAMBDA =  4

DEBUG READ REDUCED MATRIXELEMENTS
DEBUG CALCULATE THE COULOMB PHASE SHIFTS, E2=     0.1102536AU
DEBUG READ PHASESHIFTS


***** DATA WRITTEN TO UNIT 12 *****




***  END OF ION_STATE  ***



ELECTRON IMPACT IONIZATION OF HE  ... OBSERVE ... JAN 1995
INPUT UNIT= 10  OUTPUT UNIT= 11
DEBUG PARAMETER=    1    0    0    1    1
L_FINAL=  1  L_GROUND=  0
ENERGY (AU):
```

```
INITIAL ELECTRON= 0.9408300E+01
SCATTERED ELECTRON= 0.6908901E+01
EJECTED ELECTRON= 0.1102536E+00

NUMBER OF ANGLES FOR THE EJECTED ELECTRON:
NUMBER OF THETA-ANGLES=   3
NUMBER OF PHI-ANGLES=   2

ANGLES OF THE PHOTON DETECTOR:
I_THETAD_BEGIN= 90 I_THETAD_DIFFERENCE=  0 I_THETAD_NUMBER=  1
I_PHID_BEGIN=  0 I_PHID_DIFFERENCE= 90 I_PHID_NUMBER=  2

*****  OUTPUT FROM PROGRAM PACKAGE     P E R T U R     *****



PERTURBATION COEFFICIENTS FOR FINE STRUCTURE INTERACTION

L =  1.0   S =  0.5


**********    PERTURBATION  COEFFICIENTS   **********

PERTUR_COEFF(1) = 0.77778     PERTUR_COEFF(2) = 0.33333


*********  END OF OUTPUT FROM     P E R T U R     *********



    **** END OF OBERSERVE ****
```

5 Acknowledgements

References

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