Transformation of photo-electrons and Auger electrons into conduction electrons.

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"Our task is not to penetrate into the essence of things, the meaning of which we don't know anyway, but rather to develop concepts, which allow us to talk in a productive way about phenomena in nature. "

Niels Bohr

The purpose of this work is not to study the transformation of δ-electrons into conduction electrons, but to develop practically useful model for application in modelling of gaseous detectors.

- Fast (at computer calculations),
- Reliable (scientifically justified, understandable, predictable behavior, verified with experiments),
- Universal (applicable for wide range of substances).

Modelling of ionization effect in gaseous detectors:

1. Energy transfers from incident particle,
    - In a simpler model the detector response can be computed as proportional to the sum of energy transfers from given particle or as proportional to the amount of ionization which is computed according to w and F for given media.
2. Absorption of "virtual" photons,
3. Emittance of a primary δ-electron (photo-electron) with correct energy,
4. Atomic relaxation cascades,
5. Emittance of secondary δ-electrons and fluorescent photons,

6. Transport and absorption of δ-electrons.
   - In a simpler model they may be absorbed in the point of origin or somewhere according to "practical range" formulas.
7. Transport and absorption of photons (for absorption go to item 2).
8. Production of "conduction electrons",
   - In a simpler model the number of conduction electrons can be computed as proportional (with possible low-energy corrections) to the energy of δ-electron according to w and F for given media..
9. Drift of conduction electrons (and ions) to chamber electrodes with signal induction, multiplication of conduction electrons in too strong electric field etc...

HEED deals with items from 1 to 8.

- PAI cross section: energy transfers from incident particle to media without distinction between shells.

  PAIR cross section (PAI plus Relaxation): shells are separated and relaxation cascades become possible.

- Making absorption in point of origin is not precise enough since practical ranges are similar to space resolution of modern gaseous detectors. The direct use of practical range formula leads to uncertainties and singularities.
  The full generic simulation of δ-electrons is not feasible.
  Needed intermediate approach:

  "not to penetrate into the essence of things",
  but to model the detectors in a productive way.

This report deals with transfer from item 6 to item 8.

- Passing initial δ-electron by many straight steps.
- Leaving none, one or many conduction electrons at each step.
- Rotating trajectory at the end of each step.

Approximation: δ-electron can leave only conduction electrons, but cannot kick out another δ-electron.

But: integration of an ordinary continuous energy-loss formula together with taking into account elastic scattering gives the practical range compatible with practical range formulas.

The problem: to deposit conduction electrons along the δ-electron trajectory in a way consistent with reality.

Use of w and F. Problem to simulate straggling according to F and possibly a space straggling of conduction electrons along trajectory of δ-electron.

The problem of rounding is solved by passing the rest to the next step.

The most "elegant" way is introduction of a straggling of energy necessary for each next conduction electron. This allows to introduce some space straggling and in addition to model straggling corresponding to desirable F automatically.

Algorithm

1. Choose a small enough straight step Δx.

2. Compute by a phenomenological formula the energy loss ΔE of the δ-electron at this step.

3. If this is the first δ-electron step, choose the energy E_c necessary for the next conduction electron by random sampling from a some (empirical) distribution. Otherwise take E_c as prescribed by item [5].

4. Let an auxiliary variable ΔE_r be initially equal to ΔE.

5. If $E_c \leq \Delta E_r$, a new conduction electron is deposited at a point spaced from the previous one at $E_c/(\Delta E/\Delta x)$, E_c is subtracted from ΔE_r.

   The process (generation of E_c and then according to the item 5) is repeated until the next E_c is more than ΔE_r. The difference $E_c - \Delta E_r$ becomes the first E_c for the next step.

6. Subtract ΔE from energy of δ-electron.

7. If the energy of δ-electron is NOT exhausted, rotate the trajectory of δ-electron according to elastic scattering and go to item 1.

8. If the energy of δ-electron is exhausted, the last difference remains unused, but the δ-electron itself becomes the last conduction electron.

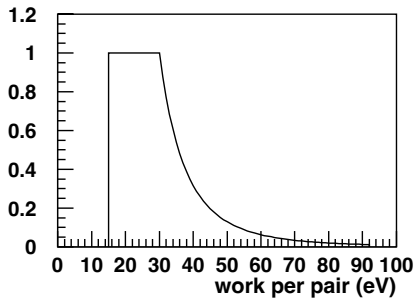

Figure 1: Distribution of energy for pair-production E_p.

This distribution gives the average w and the dispersion corresponding to $F = 0.174...$

It is convenient to generate a random number E_{cs} with some "standard" value w_s (in HEED $w_s = 30.0$ eV and $F_s = 0.174$) and to pass to the actual supplied by the user values of w and F by formulas: $E_c = kE_{cs} + a$, $k = w/w_s \cdot \sqrt{F/F_s}$, $a = w(1 - \sqrt{F/F_s})$.

According to some sources W has behavior:

$$W(E_e) = \frac{W_a}{1 - V/E_e} \ , \tag{1}$$

It is is approximately reproduced by this algorithm with the following energy dependence for differential w:

$$w(E_e) = \frac{w_a}{1 - (V/E_e)^2} \ . \tag{2}$$

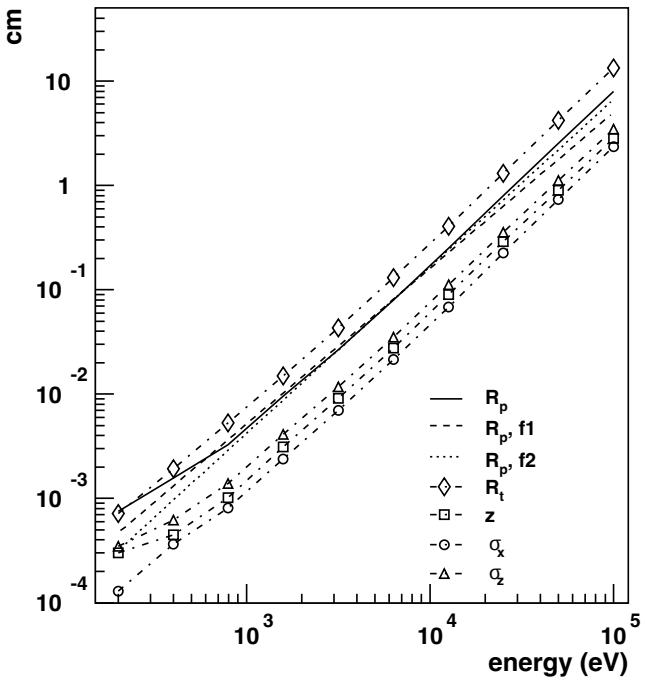

Figure 2: The practical range R_p of the electrons in argon calculated by HEED (solid line) and two empirical formulas (dashed and dotted lines). Also shown are the total length of way of electrons R_t by HEED (rhombuses), the mean z-position $\overline{z}$ (if z is the initial direction of movement) of the "centers of gravity" of the ionization clouds (boxes) and its fluctuations (RMS) along the z-axis σ_z (triangles) and x-axis σ_x (circles).

Other methods (covering all items from 1 to 8 or part of them):
Bichsel and Saxon 1975, Bichsel 1988, 1985, 1990, 2006,
Akimov 1993, Brigida et al. 2004,
Collaboration PENELOPE 1992–2003.
and programs
GEANT3, GEANT4, GHEISHA, FLUKA, MARS, UNIMOD, ETRAN, SANDYL,
ITS, EGS4, PENELOPE, TATITA, MCNP, HETC, CALOR.