Charge Exchange in Low Energy hadron models

1. Background

2. Elastic scattering models: generic and n-p

3. Charge exchange models in inelastic classes

4. Discussion



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"Low Energy" and "High Energy" model categories

- Derived from GHEISHA as interfaced to Geant 3.
 - Low energy: Wellisch & Chuma (the lion's share), Jones (cross sections, elastic scattering, fission, n-capture)
 - High energy: H.Fesefeldt
- Nominally based on a code translation/conversion of Gheisha routines, resulting in models able to reproduce Geant 3 results.
- In Geant 3 and in G4 High Energy models, elastic and inelastic interactions share a common substructure and are not functionally separated.
- In G4 Low Energy, the intention was to have separate elastic and inelastic processes, models, and cross sections.
- The LE and HE models are still used in some physics lists and many applications.

Low energy models – coherent scattering

- In Low Energy Models, elastic scattering (for all projectiles and targets) was encapsulated in a single class, G4LElastic.
- Within the inelastic code conversion, charge-exchange and strangeness-exchange code fragments (found in Gheisha cascade routines) were encapsulated in a utility class G4LightMedia, with methods G4XxxxxExchange for all Gheisha hadrons.
 - Where relevant, occurrence of charge exchange is sampled.
 - If CX occurs, a secondary (new identity of primary particle) is returned, otherwise a NULL is returned.
- In G4LElastic, following Gheisha, for n or p targets (atno2 < 1.5) the Exchange method is invoked for the incident hadron. Note: atno2 is the mass number!
 - If a secondary is returned, it replaces the primary and the primary is killed.
 - Elastic scattering of [new] primary follows, as in G3 COSCAT.

Scattering off Hydrogen: G4LEpp and G4LEnp

- Early in G4 production, the need arose for a better treatment of elastic scattering off hydrogen (a user requirement).
- Gheisha diffraction models are inadequate for low-energy nucleonnucleon scattering and so new specific classes G4LEpp and G4LEnp were developed (Greeniaus and Jones).
- They have their own data sets derived from SAID database (R. Arndt PSA of 1998) for energies 10 Mev – 1.2 GeV.
 - Two data sets for p-p, with and without Coulomb effect.
- They Sample the CM scattering angle from tabulated CDF's
 - Generates final-state momenta for scattered and recoil particle. For n-p scattering, charge exchange is *implicit in the data*.
 - Later, a block of code was added to G4LEnp to simulate "charge exchange" by swapping n & p identities. This is incorrect. All results shown here are with this erroneous code removed.
- These classes are not in any physics list, although they are in use by end users.

G4LEnp: 1.2 GeV









G4LEnp: 630 and 37.5 MeV





G4LEnp and experimental data





Figure 7.10: Examples of the differential cross-section in neutron-proton elastic scattering. The data are taken from Scanlon *et al.* $[S_3]$, Stahl *et al.* $[S_{15}]$, Kazarinov *et al.* $[K_1]$. Thomas *et al.* $[T_3]$, and Kazarinov *et al.* $[K_2]$.

Interim conclusions

- The specific model classes for np and pp scattering appear to be correct within their context.
 - Differential cross sections are consistent with measurements from 37.5 MeV – 630 MeV (see Lock & Measday 1970).
 - Kinematics look o.k. except for discretization of lab angle near 90°.

Problems observed:

- G4LEnp cannot be used for hydrogen in a mixture
 - Forum item 05 Mar 2007
 - Models can only be assigned to "material" not target nuclei.
 - Needs better integration with generic scattering model(s).
- Limited energy range: max 1.2 GeV
 - SAID data coverage and PSA would allow extension to ~5 GeV although there are gaps in the measured data.
 - Someone "fixed" G4LEnp by changing the energy range to 0 – 1.2 TeV !

n-p scattering with G4LElastic

G4LElastic is based on COSCAT, used in Gheisha for coherent elastic scattering off all nuclei except hydrogen, where it is done as part of TWOB (two-body reactions) which includes an approximate treatment of elastic and quasi-elastic scattering (probably faster than COSCAT). Lab and recoil angles G4LElastic n-p 1.2 GeV

Lab angle

150

200

100

Recoil lab angle



Observations

- Problems observed in G4LElastic
 - Governing cross-sections are in question since charge exchange is "rolled in" to the Gheisha inelastic cross sections.
 - There is no real treatment of charge exchange other than swapping particle identities.
 - In Gheisha COSCAT there is no recoil. Eventually a recoil secondary was added to G4LElastic. A logic error was introduced:
 - If no CX occurs (G4XxxxxExchange returns NULL), a recoil secondary is generated.
 - If CX occurs, no recoil secondary is generated!
- Has been replaced with improved version G4HadronElastic in a number of the physics lists. Charge exchange via G4LightMedia has been expunged from this version.
- G4LElastic will persist in applications and should be made as faithful as possible to original Gheisha physics. Isolation from inelastic models needs to be reviewed.

Observations...

- Problems observed with G4LightMedia
 - Error in coding for PionPlusExchange, KaonZeroExchange, and NeutronExchange: instead of a "<" there is a ">", resulting in way too many charge exchanges, increasing to 100% with increasing energy! (This was verified by meticulous comparisons with Gheisha and with the High Energy models).
 - Side effect: combined with error in G4LElastic, this will result in far fewer recoils in hydrogen.
 - G4LightMedia represents code fragments pulled out of context. In Gheisha they are deeply imbedded in the cascade routines for each hadron. G4LightMedia is currently used only by G4LElastic... the Low Energy G4LExxInelastic models make no reference to it.

Observations on inelastic models

- Handling of charge exchange is part of a multi-stage process.
 - In the simplest instance, a charge exchange occurs in the initial interaction of the projectile with a nucleon and is followed by elastic (two-body) scattering, but other outcomes are possible.

Charge exchange is sampled for appropriate projectiles (p, n, π , etc.) and targets (free p or n, or p or n sampled from nucleus).

CX probability is tabulated by lab momentum. These data are inherited verbatim from the original Gheisha Fortran arrays in the cascade routines CASxx.

Note: these probabilities are subject to pre- and postconditions for CX to occur.



HE and LE models compared

- HE models min. energy is 20-45 GeV (20 GeV stated in user's guide).
 Physics Reference manual refers to medium energy scattering down to 1 GeV. The current low energy limit may be set artificially high.
- HE models perform an initial interaction in which CX may occur, under certain conditions of available energy and incident lab energy. A fraction of the CX events may "survive" the subsequent processing which bottoms out in elastic scattering.
- HE models conform more closely to the original Gheisha cascade routines and are hence instructive. LE models contain more abstractions, encapsulation, and deeply nested logic.
- In some (not all) of the Gheisha CASxx routines is a comment that charge exchange is "included in the inelastic cross section". In others "part of the elastic cross section" is converted to a CX process.
- Gheisha and HE models include charge/strangeness exchange sampling for virtually all hadrons.
- In the LE models this sampling seems to be *completely absent* except for: AntiKaonZero, KaonMinus, PionMinus, PionPlus.

HE and LE models compared for π^- p

- Low energy limit of HE models was reduced to allow CX reactions.
- $\pi^- p \rightarrow \pi^0 n$ 200 MeV π^- on hydrogen, 100000 events
 - G4HEPionMinusInelastic: 7954 π^{0} n observed in final state.
 - G4LEPionMinusInelastic: 3684 π^+ n, 293 π^0 p, but no π^0 n.

LE model predicts ~100% charge exchange for 34–171 MeV pions and ~0 charge exchange events at other energies.

HE model shows very few CX, drops out below 171 MeV and glitches at ~1.8 GeV and above.



Measurements compared with LE & HE models



Notes:

- The G4 results are from a unit-test & should be confirmed by simulation.
- For direct comparison the G4 plot needs to be scaled by total x-section.

Measurements compared with corrected HE model



- The G4 results are from a unit-test & should be confirmed by simulation.
- For direct comparison the G4 plot needs to be scaled by total x-section.

Discussion

- Things to do next
 - Fix the obvious errors.
 - Trace the CX problem in G4LEPionMinusInelastic.
 - Test the other 3 inelastic classes which have CX.
 - Restore missing CX to the other classes where relevant, to be consistent with Gheisha cascade routines.
 - Review role of CX in G4LElastic.
- Points for discussion
 - General strategy for the Gheisha-based models.
 - Cross sections and independence of process classes.
 - Possibility to extend energy range and species range of specific models (G4LExy) of Hadron-Nucleon elastic and CX scattering, via further mining of SAID.



New models (for reference)

Coherent_elastic model category:

- G4HadronElastic: 0 100 TeV
 - Used in FTFC, FTFP_EMV, QGSP and QGSP_BERT.
 - Invokes (through generic pointer) GetExchange() methods of CHIPS.
- G4ChargeExchange[Process]
 - Not currently in physics lists ?
 - Invokes (through generic pointer) GetExchange() methods of CHIPS.
 - G4ChargeExchange: no reaction if target A < 3.