# Study for Stopping Power of Proton in Different materials – A Geant4 Simulation

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***Abstract-*** The stopping power in heavy charged particles is an important parameter in determining the energy loss. In this paper we calculated the stopping power of proton in materials like Brass, Al, Cu, Pb, Water, Plexiglas, Galactic within an energy range 0.1 to $10^5$ MeV. This is done through a Monte-Carlo method using an object oriented tool-kit i.e. GEANT4 which is developed for the virtual study of high energy particle physics. The results of the stopping power of proton and its applications are all discussed in detail.
***Keywords*- Geant4, Software toolkit, Stopping power, Proton**

## I.INTRODUCTION

The knowledge of the features of the transmission and absorption of low, intermediate and high energy protons in elemental materials is of great importance for the experimental methods in nuclear and atomic physics. It is also useful in understanding the interaction of particles with matter. The heavy charged particles like proton interact with matter primarily through coulomb forces between positive and negative charge of the orbital electrons within the absorber atoms [3]. Thus we performed a study on the stopping power of proton in different materials. This is done using an object oriented toolkit named GEANT4 which is developed for fast and accurate Monte Carlo simulations of the passage of particles through matter.

It has been initially created for high energy applications up to 100 TeV and now allows for very low energy applications below a few eV[2]. It contains complete toolkit for modeling of the particle trajectories and interactions: definition of the geometry of the system, materials, particles and interactions, and generation of the primary events, particle trajectories and detector response[2]. This makes Geant4 good and flexible for wide range of applications in high energy, nuclear and accelerator physics, as well as studies in medical and space science.

***Stopping Power***

In passing through matter, fast charged particles ionize the atom or molecule which they encounter. Thus, the fast particles gradually lose energy in many small steps. By stopping power we mean the average energy loss of the particle per unit path length designated by -dE/dx and measured[3]. The stopping power depends on the type and energy of the particle and on the properties of the material it passes. Since the production of an ion pair (usually a positive ion and a negative ion (electron) requires a fixed amount of energy, the density of ionization along the path is proportional to the stopping power of the material. Stopping power refers to the property of the material while energy loss per unit path length describes what happens to the particle[3]. But numerical values and units are identical for both quantities.

## II.CALCULATIONS OF STOPPING POWER:

### *A. Niels Bohr formula*

In 1913, Niels Bohr derived an explicit formula for the stopping power of heavy charged particles. Bohr calculated the energy loss of a heavy charged particle in a collision with an electron then averaged over all possible distances and energies. The Bohr formula for heavier particle is given by [3]:

$$-\frac{dE}{dx} = \frac{4\pi n z^2 k_o^2 e^4}{mv^2} \ln\left(\frac{2mv^2}{I}\right)$$

n= number of electrons per unit volume in the stopping material.
m= electron rest mass, v=velocity of the particle.
Z=charge of the particle, e= electron charge
ko = $1/4\pi\varepsilon_o$, I=mean excitation energy of the medium

### *B. The Bethe- Bloch formula*

Using relativistic quantum mechanics Bethe derived the following expression for the stopping power of a heavy charged particle[3]:

$$-\frac{dE}{dx} = \frac{4\pi n z^2 k_o^2 e^4}{mv^2} \left[ln\frac{2mv^2}{\mathrm{I}} - \ln\left(1-\frac{v^2}{c^2}\right) - \frac{v^2}{c^2}\right]$$

## III.RESULTS

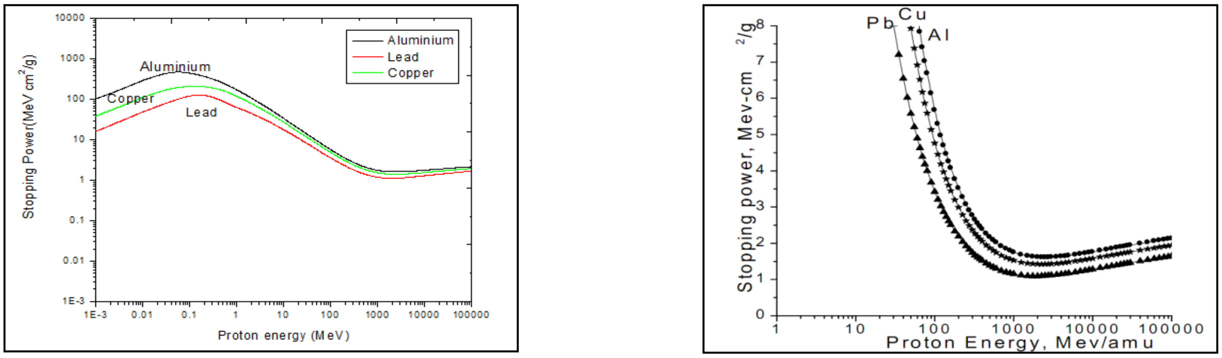


**Fig.1 Left:** Simulation result for Stopping power of proton versus energy for Al, Cu, and Pb using Geant4.
**Right:** Stopping power of the proton energy for Al, Cu and Pb taken from Literature Abebe Getachew, "Stopping power and range of Protons of various energies in Different materials"- March 2007, Depart. Of Physics, Addis Ababa University [3]

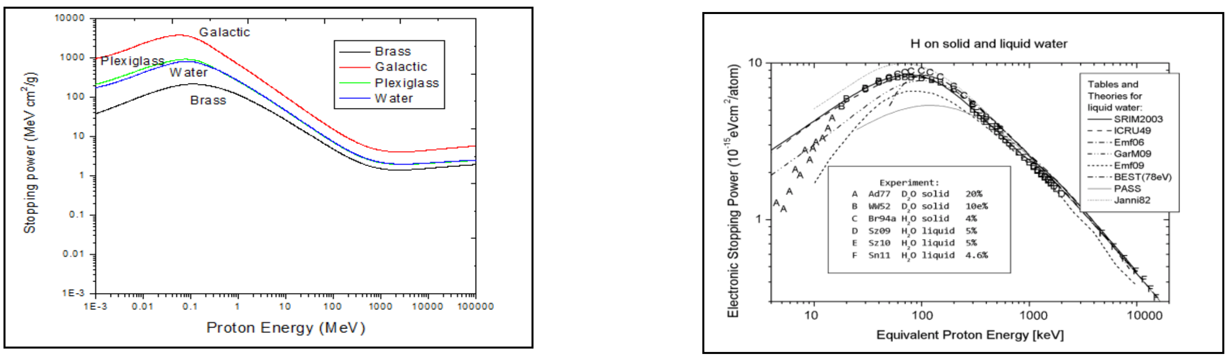


**Fig .2 Left:** Simulation result for Stopping power of proton versus energy for Brass, Galactic, Plexiglass, Water using Geant4
**Right:** Stopping power of the proton energy for Water taken from Literature by H.Paul, "Reference stopping cross section for hydrogen and helium ions in selective elements" – Nuc.Inst.Methods in Physics.res.d61(1991)261[4]

The measurements of stopping power of proton in Brass, Al, Cu, Pb, Water, Plexiglas, Galactic materials in the energy range from 0.01 to $10^5$ MeV is done using Geant4 toolkit. We can observe the dependence of stopping power on proton energy from Fig 1 and 2. Based on a approximate theory i.e. the Thomas Fermi model of atom[3], Bohr suggested that for high energies above 100 keV region, the stopping power decreases as the particle velocity approaches the velocity of light. When the velocity of the particle is comparable with speed of light, the normal spherical field becomes distorted in the direction of motion of the particle expanding laterally and in the perpendicular direction shrinking. This leads to higher energy loss at higher energies.

## IV.CONCLUSION

A good evidence has been obtained and also observed on measuring the stopping power of proton beam for various materials using Geant4 simulation toolkit. The stopping power of proton in matter is obtained as it has useful applications for the study of biological effects, radiation damage dosage-rates and energy dissipation at various depths of an absorber. It has also useful applications in the design of detection systems, radiation technology, semiconductor detectors, shielding and choosing the proper thickness of the target.

## V.References

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