L.4: Demonstration of radioisotope generation using laser accelerated proton and deuteron beams

Short lived radioisotope ^{11}C and ^{18}F have important applications in Positron Emission Tomography (PET). It is a non-invasive diagnostic imaging technique which measures the metabolic activity of cells in human body. Short lived positron emitting isotope is injected into the body which further gets concentrated in tissue of interest. PET then construct the three dimensional image of the body by tracing the radioisotope that was injected in form of medicine. PET isotopes have half-life of few tens of minutes, therefore required to be produced close to the place of application. Conventionally, ion beam from cyclotrons or linear accelerators are used to produce PET isotopes. This requires considerably large infrastructure in terms of accelerator cost and massive shielding. In recent times, protons/ions acceleration using ultra-short, intense laser plasma interaction is seen as a potential way of developing compact accelerators. We have carried out an study on demonstration of ^{11}C isotope using laser accelerated proton and deuteron beam through $^{11}B(p,n)^{11}C$ and $^{10}B(d,n)^{11}C$ reactions.

Experiment was performed using 25 fs, 150 TW Ti:Sapphire laser. The laser pulse is focused onto the thin foils using a 30° off axis parabolic mirror resulting an intensity of ~10^{20} W/cm^2. Foils of different materials and thickness e.g., 1.5 µm Ni,1 µm Cu, 0.75 µm Al, CD_2 coated Ni foil, 8 µm plain CH foil, and 8 µm CD_2 etc. were used as target. The process of proton/ion acceleration in high intensity laser foil interaction is understood to be through Target Normal Sheath Acceleration (TNSA) mechanism. Briefly, in TNSA the high intensity laser pulse is absorbed into the plasma and plasma electrons are accelerated to very high energies. These accelerated electrons penetrate through the foil material and reaches at target rear surface and form a huge sheath field (TV/m). The atoms present at target rear surface are ionized and accelerated by the sheath field. Protons (H^+) are generated from hydrocarbon contaminants, and being lightest and having highest charge to mass ratio are preferentially accelerated. Along with protons, carbon ions of different charge state are also accelerated. In the case of plain CD_2 and CD_2 coated Ni foil targets, high flux of deuterium ions was also present along with other ion species. The accelerated ion beam was characterised using in-house developed Thomson Parabola Ion Spectrograph (TPIS). Stack of Radio Chromic Films (RCF) were used to record the proton beam profile. Protons up to 8 MeV and deuterium ions up to 5 MeV could be accelerated. A 2 mm thick and 99.9% pure natural boron palette (natural boron composition: 80% ^{11}B and 20% ^{10}B) was irradiated with the proton/deuteron beam. The experimental schematic is shown in Figure L.4.1(a).

The (B,p) reaction channel generates ^{11}C isotope. The activity of the generated ^{11}C was recorded using High Purity Germanium Detector (HPGe). The ^{11}C decays into $^{11}C \rightarrow {}^{11}B + e^+ + \nu_e$. The positron annihilates with background electron and gives two gamma photons of 511 keV. The gamma spectrum recorded using HPGe detector shows a strong peak at 511 keV (Figure L.4.1(b)), indicating the substantial generated ^{11}C activity in the boron sample. The measured half-life of the ^{11}C isotope was found to be 20 min., close to the value 20.3 min. reported in the literature (inset of Figure L.4.1(b)). In optimized conditions, the produced activity per shot was estimated to be 3.5 ×10^3 Bq (for Cu 1 µm target and through $^{11}B(p,n)^{11}C$ reaction). We found that the use of deuteron beam could further enhance the overall activity of ^{11}C isotope because of the low energy threshold of the reaction $^{10}B(d,n)^{11}C$.

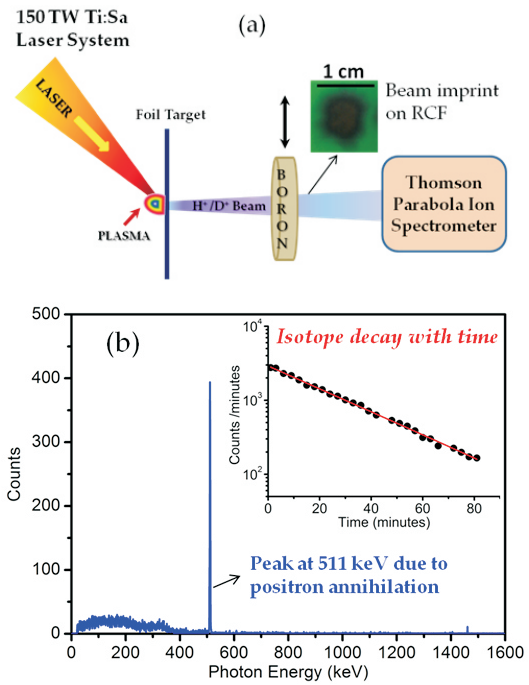

Fig. L.4.1: (a) Experimental set up, and, (b) gamma spectrum and half-life measurement using HPGe detector.

Although the observed activity is less than the necessary dose for PET applications (200 MBq), the primary limitation comes from the present day laser technology. Our study offers a compact source of PET isotope generation on table-top. With further advancement of laser technology, e.g., a laser operating at 100 Hz, the cumulative activity can reach up to 210 MBq in 600 seconds.

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