# The Lifetime of Carbon-11

D.C. Elton[1, a)] and J. Chia-Yi[b)]
*Stony Brook University*

(Dated: 27 April 2012)

We measured the lifetime of Carbon-11 to be $\tau = 1761.3 \pm 1.4$s corresponding to a half life of $1220.84(97)s = 20.347(16)$ min. Our measured value is in agreement with the accepted half-life of 20.334(24) min.[2] The Carbon-11 was produced via the reaction $^{11}$B + p $\rightarrow$ n + $^{11}$C using 6 MeV protons generated by a tandem Van De Graaff accelerator.

## I. OVERVIEW

Carbon-11 can be produced by bombarding Boron with high energy protons through the following reaction: $^{11}$B + p $\rightarrow$ n + $^{11}$C. The reaction's cross section has a maximum when the energy of the protons is near 6 MeV, so we used that energy in our experiment.[3] (By comparison, the Coulomb barrier for $^{11}$B is 1.62 MeV.[5])

Carbon-11 decays 99.79(4)% of the time via positron emission ($^{11}\text{C} \rightarrow \beta^+ + e^+ + {}^{11}\text{B}$) and .21(4)% of the time via K-capture ($^{11}\text{C} \rightarrow {}^{11}\text{B} + \gamma + e^-_{\text{auger}}$).[6][1]

To measure the lifetime, we used a coincidence circuit to detect gamma rays with energies of 511KeV. These gamma rays are produced by the anihilation of positrons emmitted by the $^{11}$C source. The two gamma rays are emmited in exactly opposite directions to conserve momentum. Two NaI detectors and photomultiplier tubes were wired to discrminators and into coincidence circuit.

## II. PRELIMINARY CALIBRATION

The "resolving time" of the coincidence cicuit, denoted by $\Delta t$, is the time maximum seperation between the leading edge of the first signal and the trailing edge of the second signal whereby the two signals are still considered coincident. For our logic pulses of 50ns, the resolving time was set to 100ns.

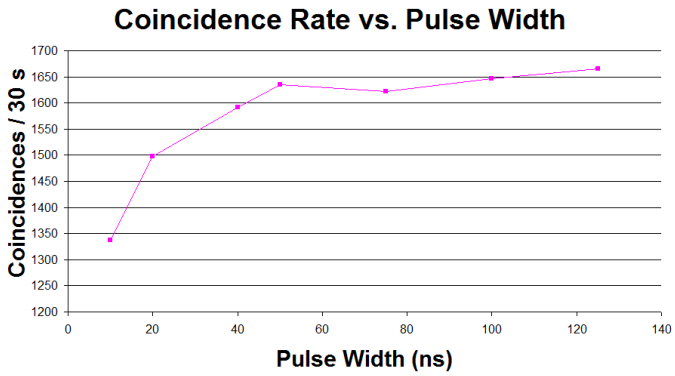


FIG. 1. Data used to determine the optimal pulse width of 50ns.

To test and calibrate our circuit we used a 1 $\mu Ci$ Na-22 source which also decays by positron emmission 90% of the time to $^{22}$Ne.[4] We were able to clearly observe the 511keV signal on the oscilloscope, and set our discriminator threshold accordingly. We also observed lower energy signals from gamma rays which had Compton scattered and higher energy 1.277 MeV gamma rays from the de-excitation of $^{22}$Ne. We next determined that 50ns was the optimal pulse width by varying the pulse width and looking at how the number of coincidences changed (see figure II).

Some of the counts by any coincidence circuit will be "accidentals", due to the possibility of the random overlap of two uncorrelated pulses. The rate of accidentals can be easily derived by considering that during the course of a measurement, the coincidence circuit will be open a fraction of the total time $f = R_1 \Delta t$, where $R_1$ is the rate in channel 1. The rate of accidentals will be:

$$R_{acc} = R_2 f = R_1 R_2 \Delta t \tag{1}$$

We measured our accidental rate exeperimentally by adding a $>$ 100ns delay to one of the lines. We found an accidental rate of 2.8 per minute, corresponding to a resolving time of 200ns $\pm$ 48ns. This is twice larger than our predicted value of 100ns, indicating a larger accidental rate than we would have expected from the equation. (this should have been investigated / explained).

In addition to the accidental rate, there is also a background rate, which is due to things like a cosmic ray passing through both detectors. We measured the background rate to be at $0.783 \pm 0.386$ counts per minute, by removing the source for 1.7 hours. The background rate is neglibly small compared to our coincidence count rate for Na-22.

## III. MEASUREMENT OF $^{11}$C'S LIFETIME

The rate of radioactive decay of $^{11}$C is described by the equation

$$R(t) = R_0 e^{-t/\tau} \tag{2}$$

where $\tau$ is the lifetime, which is closely related to the half-life: $t_{1/2} = \ln(2)\tau$

[a)] Electronic mail: daniel.elton@stonybrook.edu
[b)] Electronic mail: thefairfeather@msn.com

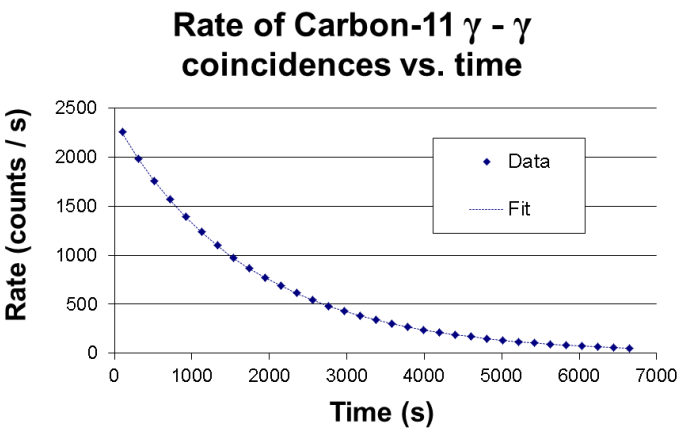


FIG. 2. Data and fit we produced.

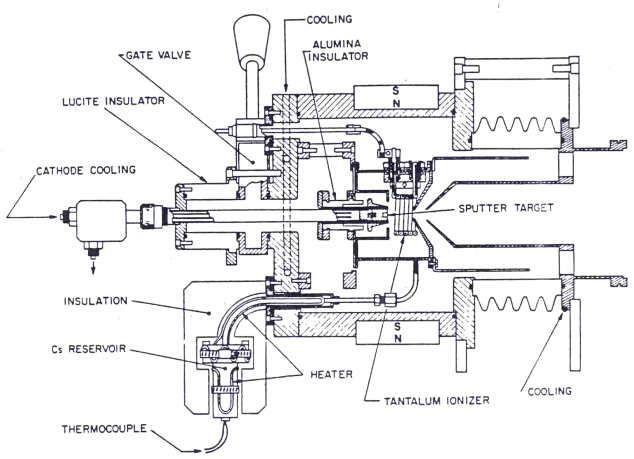


FIG. 3. The General Ionex 860A inverted sputter ion source.

The function we used to describe the rate of decay is:

$$-R(t) = \frac{A}{\tau_1} e^{-t/\tau_1} + \frac{B}{\tau_2} e^{-t/\tau_2} + C \qquad (3)$$

We measured the number of coincidences in time periods of 200s to get our rate data. To perform our fit we integrated equation 3 over each of those time periods and compared to what was measured (see figure 3).

We found the Carbon-11 lifetime to be $\tau_1 = 1761.3 \pm 1.4$s corresponding to a half life of $1220.84(97)s = 20.347(16)$ min. Our fit had a normalized $\chi^2 = 1.32$, corresponding to a p-value of .0984. Our measured valued is in agreement with the accepted value of 20.334(24) min.[2]

We also found that $\frac{B}{\tau_2} e^{-t/\tau_2}$ term had a much smaller amplitude (about 2% of the first term) and that $\tau_2 = 938.65 \pm 55$s. We believe the second exponential decay is due to the accidental rate, which scales as the square of the total rate. Therefore, the lifetime of the accidental rate should be half the lifetime of Carbon-11, as we observed. The relative amplitude of the accidental rate also compares nicely with a measurement of the accidental rate for $^{11}$C we took, where we found $R_{\text{acc}}/R_{\text{total}} \approx .01 \pm .005$ We also found $C = .17(04)\text{min}^{-1}$ which is slightly smaller than the background rate we measured previously. The difference in the background term could be due to a small systematic error in the experiment. Adding a third exponential to the fit equation did not improve the fit, indicating that no other radioactive isotopes with similiar half lifes were interfering with our measurements.

## ACKNOWLEDGMENTS

Thanks to Richard Lefferts for his time spent guiding us through the experiment and explaining the workings of the accelerator.

## Appendix A: Experimental methods

### 1. Ion source

We used a General Ionex 860A inverted sputter negative ion source, a diagram of which is shown in figure A 1. It works by first creating cesium ions and then accelerating towards a piece of titanium hydride. The Cesium ions are created by boiling off cesium using a 40 Watt heater into the vaccum chamber. The cesium atoms are ionized when they come into contact with a coil of tantalum wire which is heated to 1200 °C. Tantalum has a work function of 4.25 eV while cesium has an ionization potential of 3.89 eV, so it is energetically favorable for the neutral cesium atoms to give an electron to the tantalum. The resulting $Cs^+$ ions are acceleratored towards the sample holder via a potential between -3 to -5 kV. Negative hydrogen ions are produced in the sputtering process that results when the $Cs^+$ ions slam into the titanium hydride. Negative ions produced by the sputtering are accelerated out of the sample chamber by a voltage of 15 kV. In addition to $H^-$ ions, many other types of ions are produced. However, the $H^-$ ions are filtered out using the inflection magnet.

### 2. Accelerator

The Van De Graaff accelerator that we utilized is a model FN-8 built by the High Voltage Engineering Corporation in 1966. The Van De Graaf is enclosed in a 25m long pressure vessel filled with 10 tons of $SF_6$ gas, to prevent arcing. $SF_6$ was chosen because it chemically stable, has a high dielectric strength, slow diffusion rate and a high recombination rate. A 12m laddertron (charging belt) mechanically transports up to 250 $\mu A$ of charge to the center of this tank. The lad-

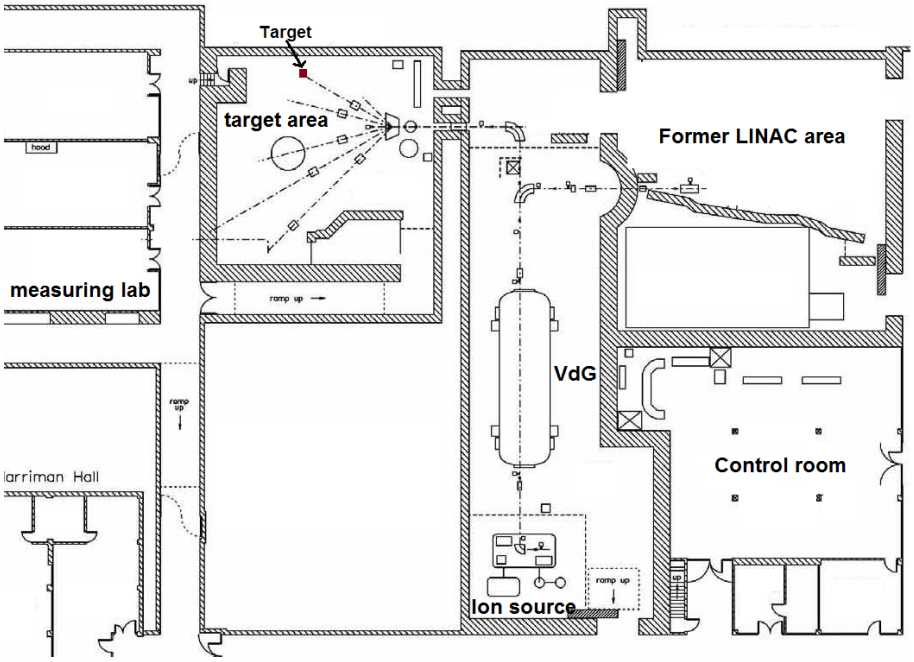


FIG. 4. The layout of the Stony Brook Nuclear Structure Laboratory.

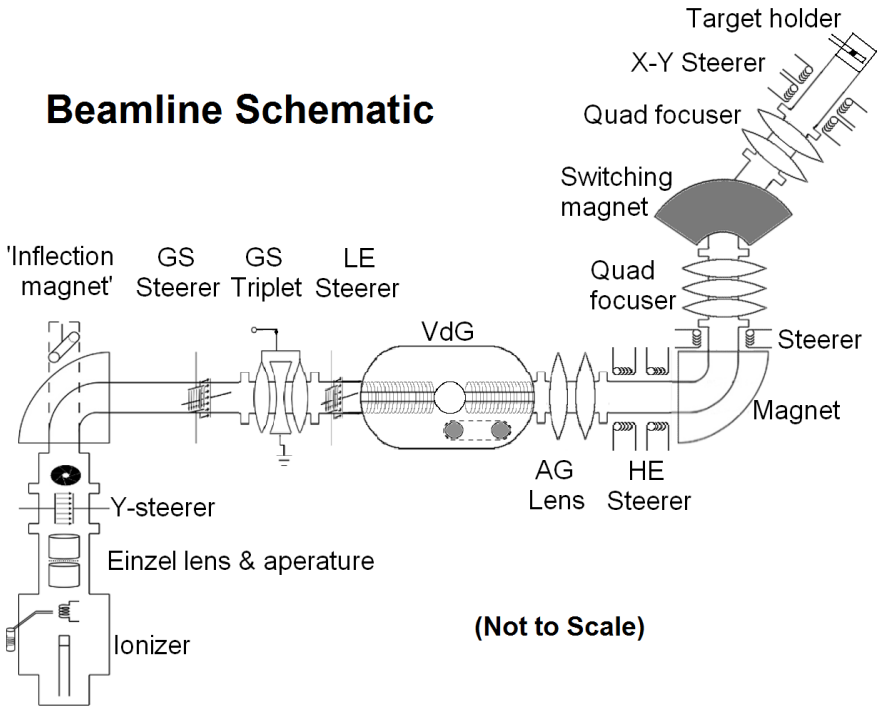


FIG. 5. A schematic diagram showing the beamline components.

dertron travels at 12 m/s. Charge is held on metal bars, which are seperated by plastic resistors. The laddertron picks up positive chage on the low voltage side and transports it to the center, where it is deposited on a smooth metal shell. The laddertron also picks up negative charge from the center and transport it back. Charge is transfered onto the belt by a device called an "inductor", which requires voltages around 50kV. The built up charge travels to ground through three 'columns' which are broken into 200 segments. Adjacent segments are

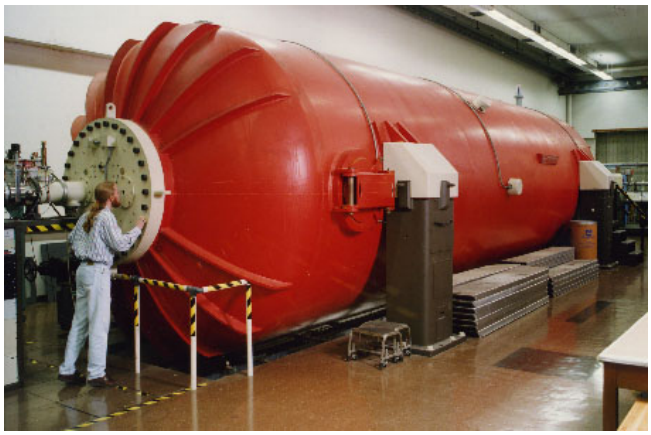

FIG. 6. The Van de Graaf accelerator we used.

connected by 800 MΩ resistor assemblies, creating a total column resistance of 80 GΩ. Assuming neglible losses through the beampipe and that the control circuit takes 10 $\mu$A, then 47.5 $\mu$A of Laddretron current will result in $V = IR = 37.5 \times 10^{-6} \times 80 \times 10^{9} = 3 \times 10^{6} V$. The beampipe passes through the center of the Van de Graaf and contains special "spiral inclined field tubes" which help maintain a constant electric field inside the tube, keep the beam focused and create inclined fields to expell any ions emanating from other sources.

Precise voltage control of the Van de Graaff is achieved with a special corona discharge circuit. Sharp needles are placed at the end of a metal rod, which is moved close enough to the center of the Van de Graaff so as to draw $20\mu A$ of current. Control of this current is achieved using a vaccum triode tube. The vaccum triode grid voltage is controlled by either of two ways. Normally it is controlled by a generating voltmeter (GVM) circuit which was specially invented for high-voltage measurements. In our case however the grid voltage was regulated by a feedback circuit which monitors the beam as it passes between two metal plates. The feedback circuit insures that the beam passes directly through the slit, by monitoring current 'picked off' the edge of the beam by the plates.

### 3. Beam tuning & control

What we neglected to mention in the previous section is that the entire ion source is on a table which is held at a potential of -.4MV. This high voltage is generated a 170 kV high voltage power supply connected to two CockcroftWalton like generators.

We used the Van de Graaff as a tandem accelerator, meaning that the high voltage potential is utilized twice. The $H^-$ ions hit a thin carbon foil in the center of the Van de Graaff and are converted into $H^+$ ions, which are then accelerated again.

The entire system, including the ion source, Van De Graaf, and bending and focusing magnets are controlled by LabView software, with the exception of the Van de Graaff 'inductors' and voltage readout.

A schematic diagram of the beam path is shown in figure 5. After emerging from the ionizer, the beam first passes through an Einzel lens, which uses electrostatic fields to focus the beam. Then the beam passes though a steerer and then the inflection magnet which selects out the proper mass with a precision of $\Delta m/m \approx 1/130$. Additionally, the vertical magnetic field of the magnet works to help focus the beam.

Next the beam passes through another steerer and electrostatic triplet lens. A triplet configuration ensures the system is anastigmatic. The beam then passes through the Van de Graaf and the "analyzing magnet" directs the beam towards the target chamber. The beam then passes through a steerer and another focusing triplet. The beam then passes through a large layer of concrete (to provide radiation protection) into the target room. The correct beamline is selected by the "switching magnet". Our target was a small chunk of boron suspended in an aluminum frame. Before the target there is a magnetic quadrapole focuser and another X-Y steerer. We can tell that the target is being hit because then the current measured on the "frame" around the target is maximized and the current measured after the target is near zero.

There are also four Faraday cups (not shown in figure 5) which can be inserted pneumatically to stop the beam at four strategic locations. Each Faraday cup consists of a metal cup attached to an electrometer which can read the current of the beam hitting the cup. Also not shown is the beam profile monitor, which is capable of displaying the beam cross section while interfering minimally with the beam. The beam profile monitor consists of a thin grounded helical wire connected to a drive motor. The rotating wire passes through the beam horizontally and vertical during each rotation. A cylindrical collector around the wire/beam picks up electrons which are knocked off the wire by the beam. The resulting current signal can be translated into a 2D cross section of the beam.

## REFERENCES


[1] K.W.D. Ledingham R.W.P. Drever R.W.P. J.L. Campbell, W. Leiper. The ratio of k-capture to positon emission in the decay of 11c. *Nuclear Physics A*, 96:279287, 1967.

[2] Brookhaven National Laboratory. Nudat 2.6 database, March 2012.

[3] David J. Schlyer Mahmoud L. Firouzbakht and Alfred P. Wolf. Yield measurements for the $^{11}b$(p,n)$^{11}c$ and the $^{11}b$(d,n)$^{11}c$ nuclear reactions. *Nuclear Medicine & Biology*, 25:161–64, 1998.

[4] Adrian C. Melissinos. *Experiments in Modern Physics*. Academic Press, Orlando, Fl, 1966.

[5] (Nuclear Reaction Video project. Q-value calculator, March 2012.

[6] J. Scobie and G.M. Lewis. K-capture in carbon 11. *Philosophical Magazine*, 2:1089–1099, 1957.