Accurate High Voltage Measurement for Laser Spectroscopy

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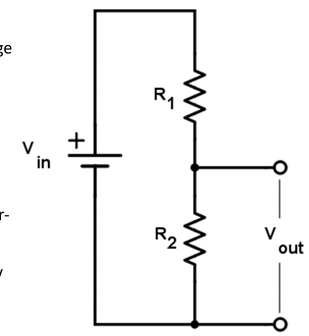
Introduction

- This project was performed at the BEam COoling and LAser Spectroscopy (BECOLA) facility at the Facility for Rare Isotope Beams (FRIB).
- BECOLA'a s main undertaking is to determine the fundamental properties of radioactive nuclei such as charge radii (the proton distribution inside a nucleus) using laser spectroscopy techniques. This is essential in attempting to advance our understanding of nuclear forces and benchmark nuclear theories.
- Laser resonant fluorescence measurements are carried out on an ion beam of radioactive nuclei at an energy of approximately 30 keV. The accurate knowledge (at a few ppm level) of the beam energy i.e. the high voltage potential applied to the ion beam is critical to deduce very small nuclear structure information from the fluorescence spectrum.
- In this project, I built a high voltage divider (because our old one stopped working properly), which scales down the high voltage applied to it, to accurately determine the high voltage. The high voltage divider is comprised of a long chain of high precision resisters connected in series between the high voltage and the ground. The small voltage drop (less than ~10 V) across the last resistor from the high voltage (30 kV) is read out using a typical voltmeter. The applied high voltage is then deduced by knowing the resistance ratio of the last resistor to the entire resistor chain.
- I designed and assembled the high voltage divider and performed the ratio measurement against a reference voltage divider. I will present details of the construction of this divider, and the ratio determination.

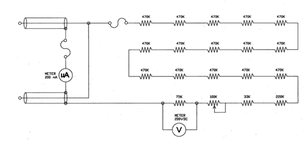
How does a high voltage divider work?

- Voltage division is the result of distributing the input voltage among the components of the divider. A simple example of a voltage divider is two resistors connected in series, with the input voltage applied across the resistor pair and the output voltage emerging from the connection between them.
- A high voltage divider is a passive linear circuit that produces an output voltage (Vout) that is a fraction of its input voltage (Vin).
- A passive element is an electrical component that does not generate power, but instead dissipates, stores, and/or releases it.
- A high voltage divider can therefore be used to scale down a very high voltage so that it can be measured by a volt meter. This is because it is very difficult to measure a high voltage directly with accuracy. The high voltage is applied across the divider, and the divider output—which outputs a lower voltage that is within the meter's input range—is measured by the meter.

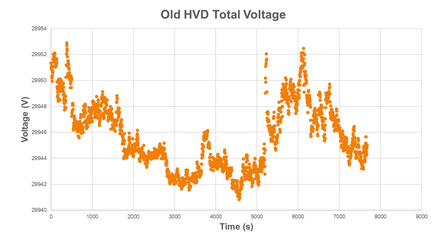
$$V_{out} = \frac{R2}{R1 + R2} \cdot V_{in}$$



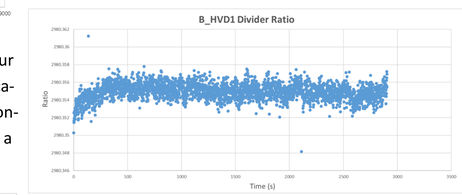
HIGH VOLTAGE DIVIDER & METER



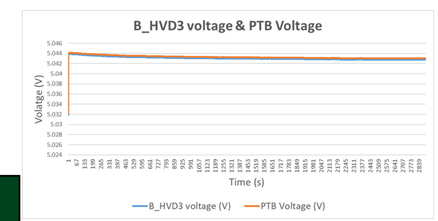
Results



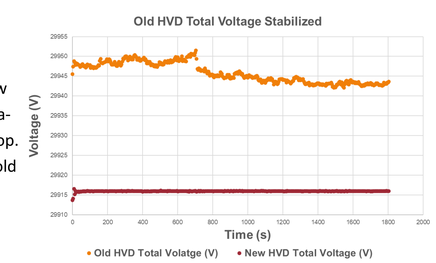
- This is a plot of the total voltage against time of our old High Voltage divider. The erratic spread of the voltage is problematic because it means we have no way to accurately determine the voltage applied and therefore determine the beam energy.



- This is the Divider ratio plotted against time of our new divider. It's relatively straight shape is an indicator that the divider is performing well because a constant voltage was applied and we therefore expect a constant ratio.



- Here is a plot of the voltage of the last resistor of our Divider with the reference Divider from PTB. The graphs are virtually coincident, which is an excellent result because it means our divider is performing how it's supposed to.



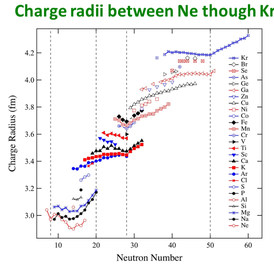
- This is a comparison of our old Divider with our new divider when both are stabilized, that is, minor fluctuation in their output are corrected using a feedback loop. The voltage of our new Divider is constant while the old one has large fluctuations.

- In conclusion, our new High Voltage Divider performance was excellent. It consistently maintains a constant voltage reading and divider ratio for a fixed applied high voltage and this means we can use it in our spectroscopy experiments with confidence that we can accurately adjust the velocity of the ion beam and produce a precise laser spectra.

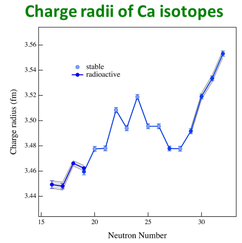
How does Laser Spectroscopy Work?

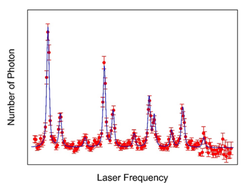
- The objective at BECOLA is to determine the shape and radius of radioactive isotopes
- Essentially, we shoot a laser at a high velocity beam of ions, the ions absorb the energy from the laser at discrete frequencies and release it as electromagnetic (EMF) radiation. The frequencies absorbed are measured and a spectrum produced. This is then compared to other isotopes of the element to determine its radius.
- Lasers produce monochromatic light, this means light of only one wavelength and thereby one frequency. In order to produce a spectrum, we need to scan a range of frequencies, not just one. There are two ways to do this. We can change the frequency of the laser itself, which turns out to be very difficult while maintaining stability, or we can make use of the Doppler Effect and adjust the velocity of the sample we are investing to achieve the same effect. We use the later.
- If you shoot laser light at a moving object, in this case the ion beam, the ions observe a different laser frequency from the laser because of the Doppler Effect (the same way the frequency of the sound of an ambulance changes as it passes you). By varying the velocity of the beam, we can scan a wide range frequencies and produce a spectrum.
- In order to determine the Doppler Shift (which is what we use to produce the laser spectrum), we need to know the velocity of the ions very precisely. That is why we need to know the voltage very precisely and hence why we need a High Voltage Divider to accurately determine the value of the high voltage.

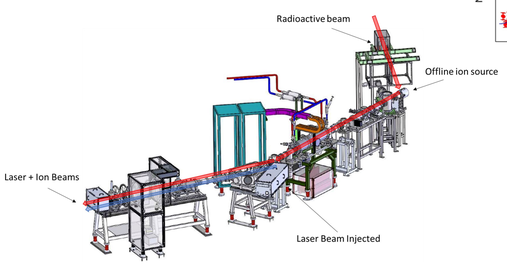
Charge radii between Ne though Kr



Charge radii of Ca isotopes

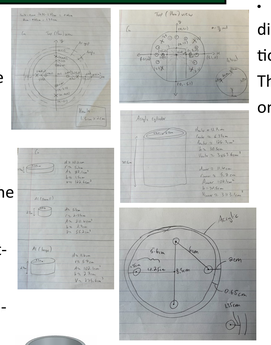


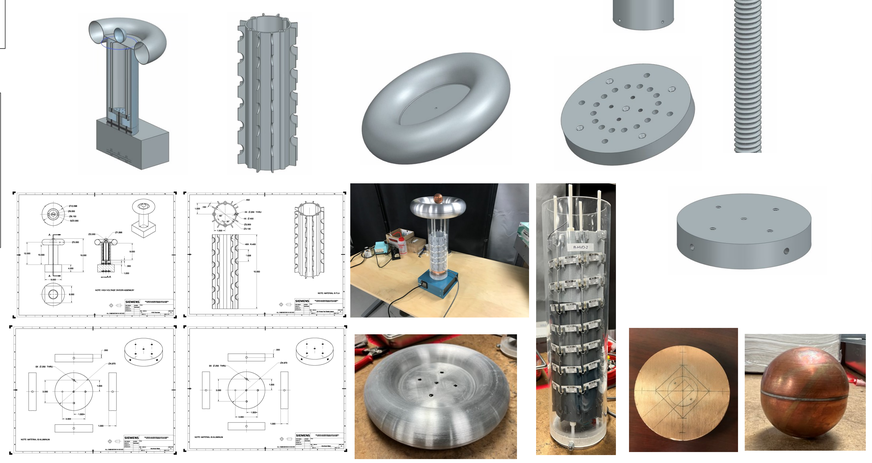




Methods

- The National Metrology Institute of the Federal Republic of Germany (PTB) was kind enough to provide us with a High Voltage divider that we based ours off of and used as a reference to compare performance.
- I started with rough sketches as shown to the right to dimension all the parts for the 3d Computer-Aided Design (CAD) models.
- I then made the CAD models and produced technical drafts of each of the components and the entire assembly as shown below.
- My collogues and I ordered the parts, including a custom made 3D printed support for the resistors, and assembles the divider
- I combined the drafts, information on suppliers, pricing and assembly instructions into a document so the High Voltage divider can be reproduced and used in other facilities at FRIB, which has occurred.
- We ran multiple tests on the divider and I analyzed the data to determine the divider ratio, that is, the scale factor that is multiplied by the voltage reading of the last divider to determine the total voltage applied.





References

- [1] Repetto, D., 2015. *A very quick and dirty introduction to Sensors, Microcontrollers, and Electronics*. [online] Ieec.uned.es. Available at: <http://www.ieec.uned.es/investigacion/Dipseil/PAC/archivos/How%20sensors%20and%20actuators%20work%20and%20how%20to%20hook%20them%20up%20to%20a%20microcontroller.pdf> [Accessed 31 March 2022].

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