Determining the relationship between the energy of a π^- meson beam and its ability to penetrate and react with a carbon-based, non-biological material to determine the viability of "pion therapy" — an alternative Method for cancer treatment

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Introduction

Finding effective safe cancer therapy has been a issue of priority in the medical community. Two out of five individuals get diagnosed with cancer at least once in their lifetime[1]. The most common treatment options available today are chemotherapy, surgery, and radiation therapy[2]. These methods of treatment come with their own side-effects. Chemotherapy is extremely painful and known to cause fatigue and nausea, while radiotherapy can lead to skin problems, irreversible hair loss, and sterility[3]. Surgery is not possible for all stages of cancer and thus does not necessarily eliminate all cancerous cells.

Last year, our school team submitted a proposal outlining a new, less invasive method of cancer therapy — π^- meson therapy. While our proposal was shortlisted last year, we felt there was scope to develop it further after realising the shortcomings of our previous proposal. We have now come up with ways of quantifying our results and plotting graphs to make direct comparisons between proton beam therapy and pion beam therapy. Furthermore, we emulate skin tissue using graphite oxide to understand, to a greater extent, the effects that pion beam therapy has on human tissue.

Overview and Background Information

Negative pions are being considered as an alternative to proton therapy as they contain properties similar to heavily charged particles, like protons, that are traditionally used in therapy. However, pions being lighter than protons have a greater scattering potential, and can scatter up

[1] "Cancer Statistics." *National Cancer Institute*, www.cancer.gov/about-cancer/understanding/statistics.
[2] "Types of Cancer Treatment." *National Cancer Institute*, www.cancer.gov/about-cancer/treatment/types.
[3] "Option D: Medicinal Chemistry." *Chemistry: Course Companion*, by Sergey Bylikin et al., Oxford University Press, 2014, p. 766.

to three times more than protons, thus also increasing their potential to destroy cancer cells. Negative pions, when captured by hydrogen atoms, replace the electron in its orbit. When this atom gets close to a heavier element like carbon, oxygen, or nitrogen in the tissue, the pion is transferred to the heavier atom due to lower final binding energy. The pion is moved into the nucleus due to strong attraction, in a time that is shorter than its lifetime. It gets destroyed upon reacting with the nucleus, and 140 MeV of this total energy provides the fragments of the nucleus and neutrons with kinetic energy, while the rest is used to overcome binding energy.[4] However, due to heavily ionizing fragments close to the nucleus, the Bragg Peak should theoretically be enhanced. Examples of such fragments include:

$$\begin{aligned} \pi^{-} + {}^{16}O &\rightarrow {}^{12}C + p + 3n \\ &\rightarrow 3\alpha + p + 3n \\ &\rightarrow {}^{14}N + 2n \\ &\rightarrow {}^{10}B + \alpha + 2n \end{aligned}$$

Negative Pion Beams and Cancer Therapy, M.R. Raju

This is how the beam disrupts the cell from functioning — by changing the chemical composition and releasing energy.

For our experiment, we need a material that emulates body tissues and is non-biological in origin. This allows the experiment to mimic real-life therapies to a great extent. The non-biological substance must contain elements that are largely present in biological tissue, primarily carbon, oxygen, and hydrogen. With these principles in mind, we set out to find the ideal substance that might emulate cellular membranes — graphite oxide. Carbon, oxygen and hydrogen are the most abundant elements in the body, and the compound of Graphite Oxide also includes carbon, oxygen, and hydrogen in 50.1%, 44.81%, and 2.69% quantities respectively[5].

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[4] Raju, M R. *Negative Pion Beams for Radiotherapy*. Los Alamos Scientific Laboratory.
[5] "Carbon Nanostructures Reduced from Graphite Oxide as Electrode Materials for Supercapacitors." *Modern Electronic Materials*, Elsevier, 2 Dec. 2015, www.sciencedirect.com/science/article/pii/S2452177915000043.

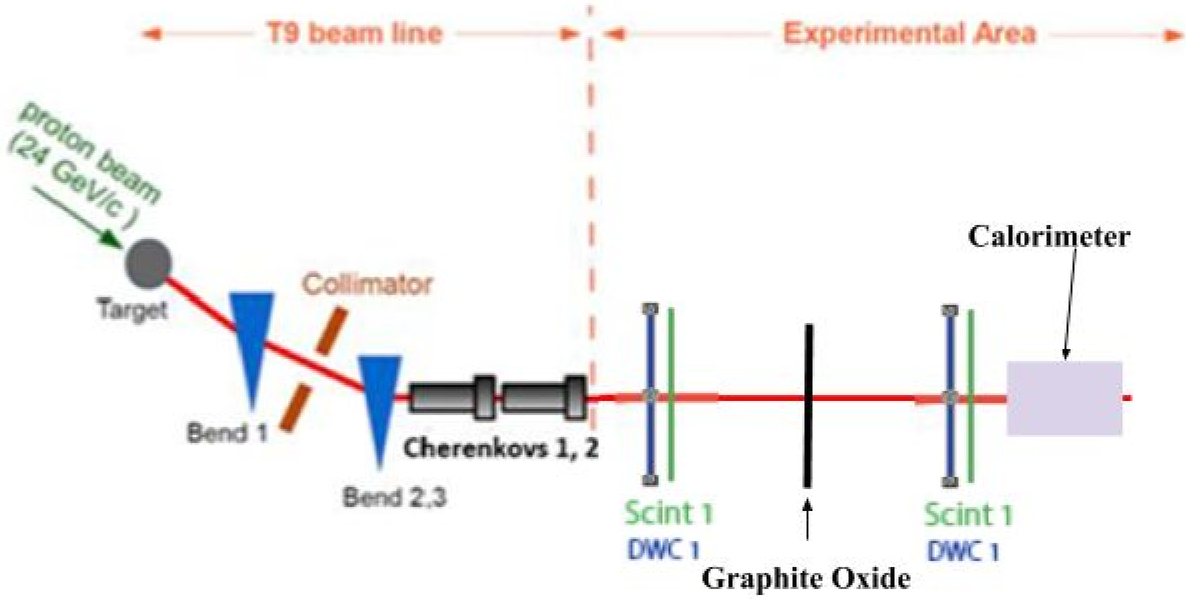
Experimental Setup

The goal of this experiment is to obtain data in order to plot a Bragg curve for using negative pion beams in cancer therapy. This can be repeated for the proton beam. Upon comparing the curve for pion therapy to the curve for proton therapy, we will be able to determine whether or not pion beam therapy is a viable alternative, based on the intensity of the peak, and the depth it occurs at.

With this in mind, we based our dependent and independent variables off the axes that exist in a bragg curve: the depth and energy dissipated per unit depth. The independent variables will be the depth and incoming energy of the negative pion beam, while the dependent variable will be the energy lost due to passing through the graphite oxide. The depth can be varied by measuring the thickness of the actual graphite oxide, and using different depths which can be plotted along the x-axis of the bragg curve. The energy lost can be calculated by subtracting the energy leaving the material (detected by calorimeters) from the energy of the pion beam entering the material. The energy lost can be equated to the amount dissipated into the material, which can be tested and different depths (thicknesses) of graphite oxide. The depth and energy dissipated can be plotted into a graph, and the derivative of this graph (which would show the depth against the energy dissipated per unit depth) will form the Bragg Curve. As such, obtaining this data will give enough information to plot a complete Bragg peak using pions. This will be repeated with pion beams with varying incoming energy to compare and find the most effective incoming energy.

To ensure we can make a direct comparison with the pions and the protons, the same procedure should be repeated using proton beams. This way, variables like chemical composition and density of the material both the beams are passing through is controlled.

Diagram of Experimental Setup:



The dataset for using a pion beam can be collected by using the following experimental setup: The proton beam (24 GeV/c) is directed at a piece of metal (beryllium or aluminium), creating an assortment of subatomic particles. Then, we use the quadrupole magnets and the collimating slits to adjust the size, composition and momentum of the beam to around 0.87 GeV/s, a value that the synchrotron can handle with ease. At this point, the beam should contain only negative pions; this can be confirmed by the Cherenkov detector which allows identification of particles. The beam now is in the experimental area where it encounters a scintillator, which counts the number of incoming particles. To assist in calculating the change in energy, we have placed a second scintillator and calorimeter after the graphite oxide sample, to count the negative pions and energy upon exit.

To enhance post experiment analysis, we can use infrared spectroscopy to gain a deeper understanding on the exact chemical changes that firing a beam of pions incurred. These chemical changes can give a greater idea about possible hazards that accompany this form of therapy, along with how effective it is compared to proton therapy.

Limitations:

One of the limitations regarding the method of collecting data, are the discrete data points. A more continuous dataset would provide a more accurate graph of energy dissipated. This would in turn lead to a more accurate plotting of the Bragg Curve. This error can be minimised by reducing the interval between independent variable: the thickness of the graphite oxide.

Graphite oxide only emulates skin cells to a certain extent. The data collected from this experiment cannot be used directly in cancer therapy. However, it would still be able to provide an accurate comparison between proton therapy and negative pion therapy. If the experiment proves to be effective, it can be later repeated with organic material to see the actual effects of the pion therapy on cancer cells.

There is contamination within the pion beam even after separating the negative pions from the rest. Due to the short lifespan of the pions themselves, they will partially decay before they can reach the Graphite Oxide. This decay will introduce contaminants and will thus interfere with the results. However, this happens consistently through every use of pion beams, and would have the same effects when used for cancer therapy. Therefore, although it does not provide an accurate view of the reactions that take place when only pions are used, it would show what happens when the same pion beams are used on human cells.

It can be hypothesized that while passing through the scintillator, there would be some loss in energy. This loss in energy will impact the results. This, however, can be dealt with by theoretically calculating energy loss due to the scintillator and accounting for this.

What we hope to take away:

Coming back from an experience like this would allow us to spread greater depth of knowledge and passion for physics within the international community we live in, and encourage participation in not just our astronomy club (through which this years members have gathered together to create this proposal) but in all areas of science. In a broader sense, we hope to promote the ideology that every person can make a difference to both the scientific community and the lives of many, whether as a school student, university student, or a professional in the field. In fact, this would not be where our scientific journey ends at all. The greatest thing we could take away from this experience would be to never stop seeking answers.

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