Physics 100 – Module 1

Materials Science and Materials Analysis using a Particle Accelerator

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Background:

In the department for 9 years

3rd time teaching Physics 100.

Teach primarily

- Physics 110/111 (Physics for the Life Sciences)
- Physics 120 (Physics for Majors and Engineers)
- Physics 210 (Medical Physics)
- Physics 300 (Modern Experimental Techniques)

Occasionally Teach

- Physics 121/122Lab/123
- Astronomy 50/51 (Introduction to Astronomy/Solar Systems)

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Background continued…

I am a theoretical physicist who works in waveguide theory.

- Production, propagation, and diffraction of x rays (a type of electromagnetic wave) through glass capillary fibers.
- Includes surface roughness and x-ray attenuation effects.

I am also an experimental physicist who runs the particle accelerator.

- Medical and Health Physics issues – Hg in Fish
- Soil contamination – Mud Samples
- Art and Archeometry
- At some point – Forensics/paleontology/medical applications

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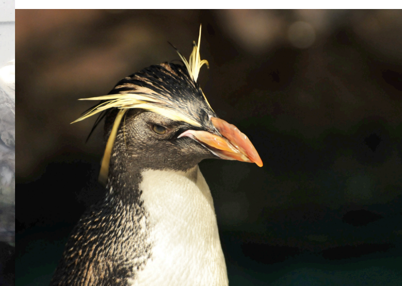
My physics hobbies…

Environmental & Accelerator Physics
Fluid Mechanics
Aerodynamics
Flight and Flight Mechanics
Aircraft Photography

Motion, Gravity & Optics



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Game Plan….

Accelerator – What it is, What it does. Will do some energy and velocity calculations.

PIXE – Basics, Theory and Sample calculations and elemental identification.

Modifications to the PIXE Theory to describe heavier elements.

Perform an experimental PIXE run on the accelerator.

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The Pelletron Particle Accelerator

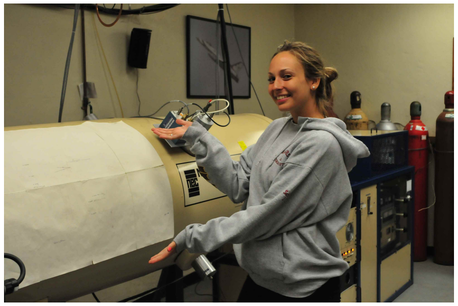
Built by the National Electrostatics Corporation

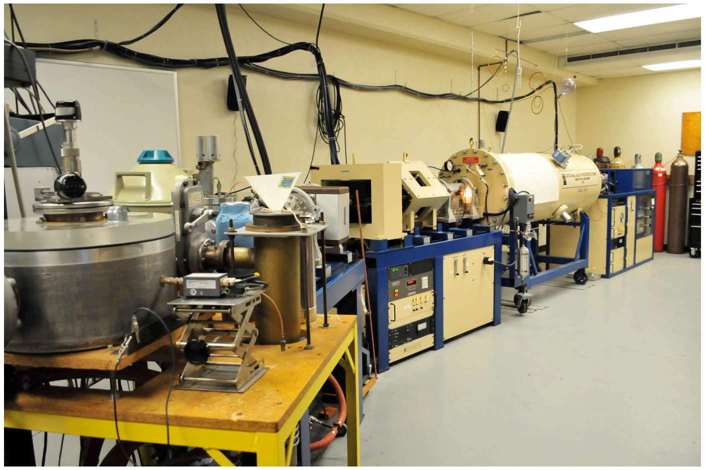
Acquired in 1991

Replaced 450 kV Van-de-Graff accelerator

Our accelerator has 4 main components

- Ion production
- Two-Stage (tandem) ion acceleration
- Steering of ions
- Scattering chambers





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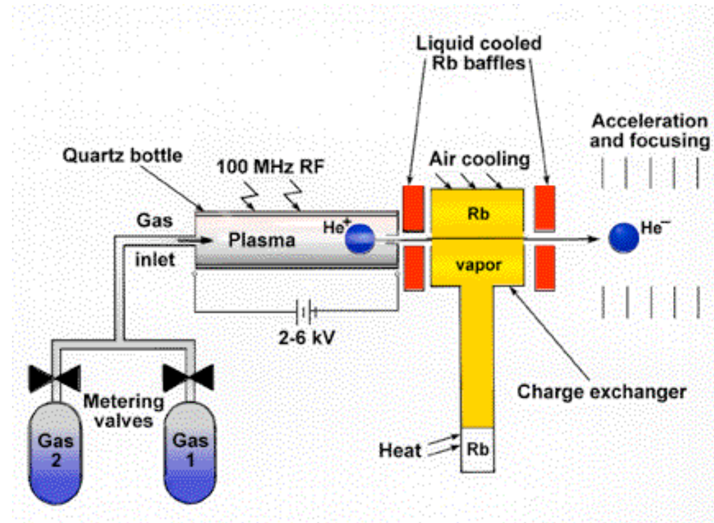
Ion Production

H or He gas is bled into the gas inlet.

100MHz Radio Frequency (RF) electromagnetic energy is dumped into the quartz bottle which produces H^+, He^+, He^{++} and other ions.

A potential difference of about 6kV (for He) or 2kV (for H) is applied across the bottle.

This accelerates the ions out into the charge exchanger.



The H^+ or He^+ charges pass through a Rubidium (Rb) vapor and through collisions pick up an extra negative charge.

The H^- and He^- charges continue on into the accelerator.

Of course there are other ions that are also accelerated.

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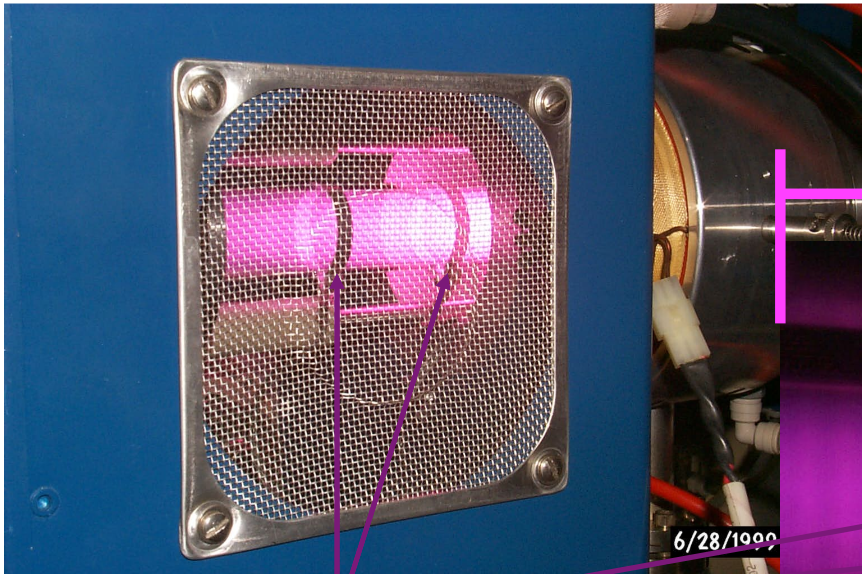
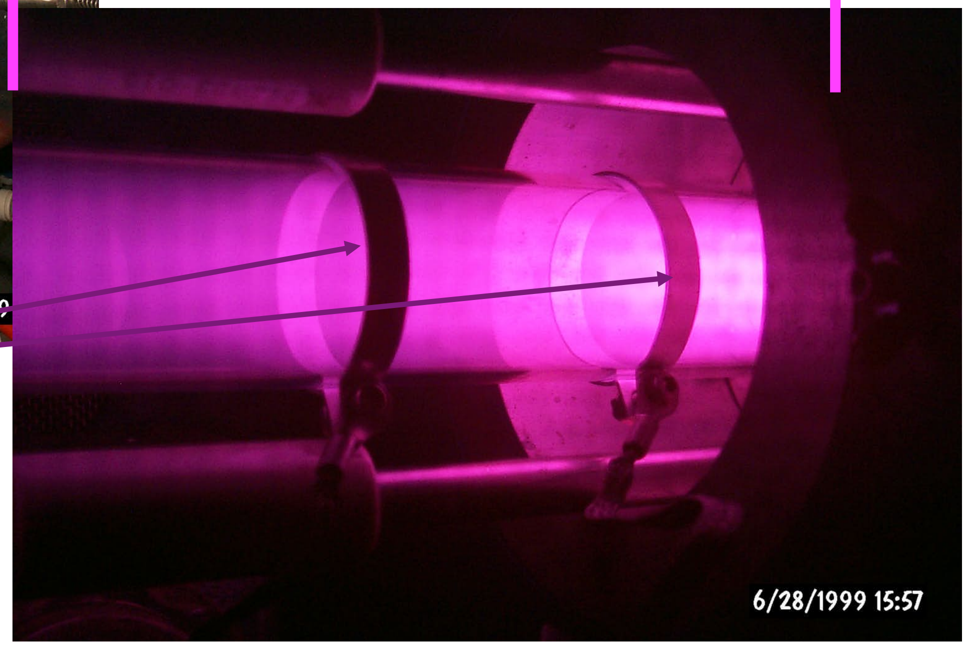
Ion Production and Plasma Source



$\Delta V = 2kV – 6kV$



Looking into the back end bottle. The metal bands are what couples the RF source to the bottle.

Characteristic glow of a hydrogen plasma.

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The Low Energy End of the Accelerator

Ion Source or Low-Energy end of the accelerator showing the Rubidium furnace and cooling system. The H^+ plasma is the faint pink glow.

Wide view of ion source. This also has a *Faraday cup* in view. The faraday cup is designed to count the number of charges and determine the beam current.

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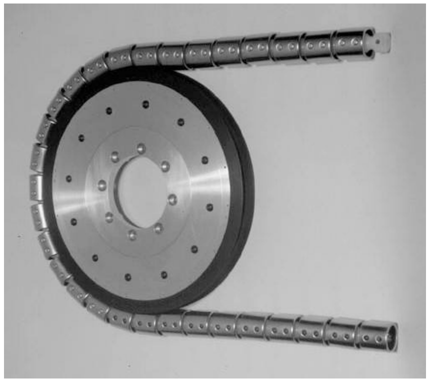
Tandem acceleration of ions

The negative ions are accelerated toward the center of the pressure tank by a 1.1 MV difference in potential.

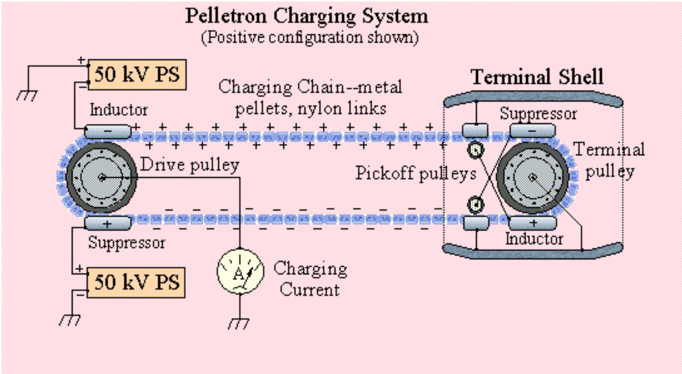
The center of the pressure tank is made positive with respect to the charge exchanger.

The potential difference is developed by the Pelletron Charging system, which consists of metal pellets and insulating connectors.

The terminal is charged by induction and is a very stable and reliable system.



Pelletron Chains



Pelletron Charging System by NEC

The Accelerator

The chain is housed inside of this tank.

The terminal is in the center.

From right edge of the photo to the terminal is where 1.1MV is applied.

A Nitrogen gas is bled from the left end of the photo to the terminal to pull off the added electron in anther charge exchange collision.

The resultant positive particle is accelerated away from the terminal back down 1.1MV towards the left edge and thus produces the tandem acceleration.

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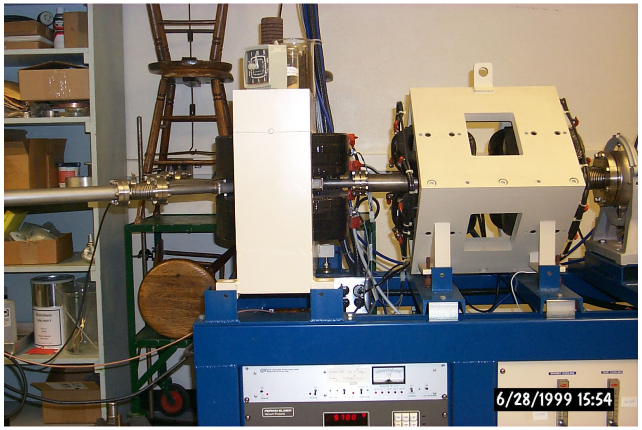
Steering of Ions

The steering magnets are a momentum filter.

A momentum filter is a device which separates charged particles based on their momentum (or energy).

When a charged particle passes through a magnetic field with a component of its velocity perpendicular to the magnetic field, the charge will feel a force and it will move in the direction of the applied force.

The magnetic force is given by $\vec{F} = q\vec{v} \times \vec{B}$



Side view of steering and quadrapole magnets

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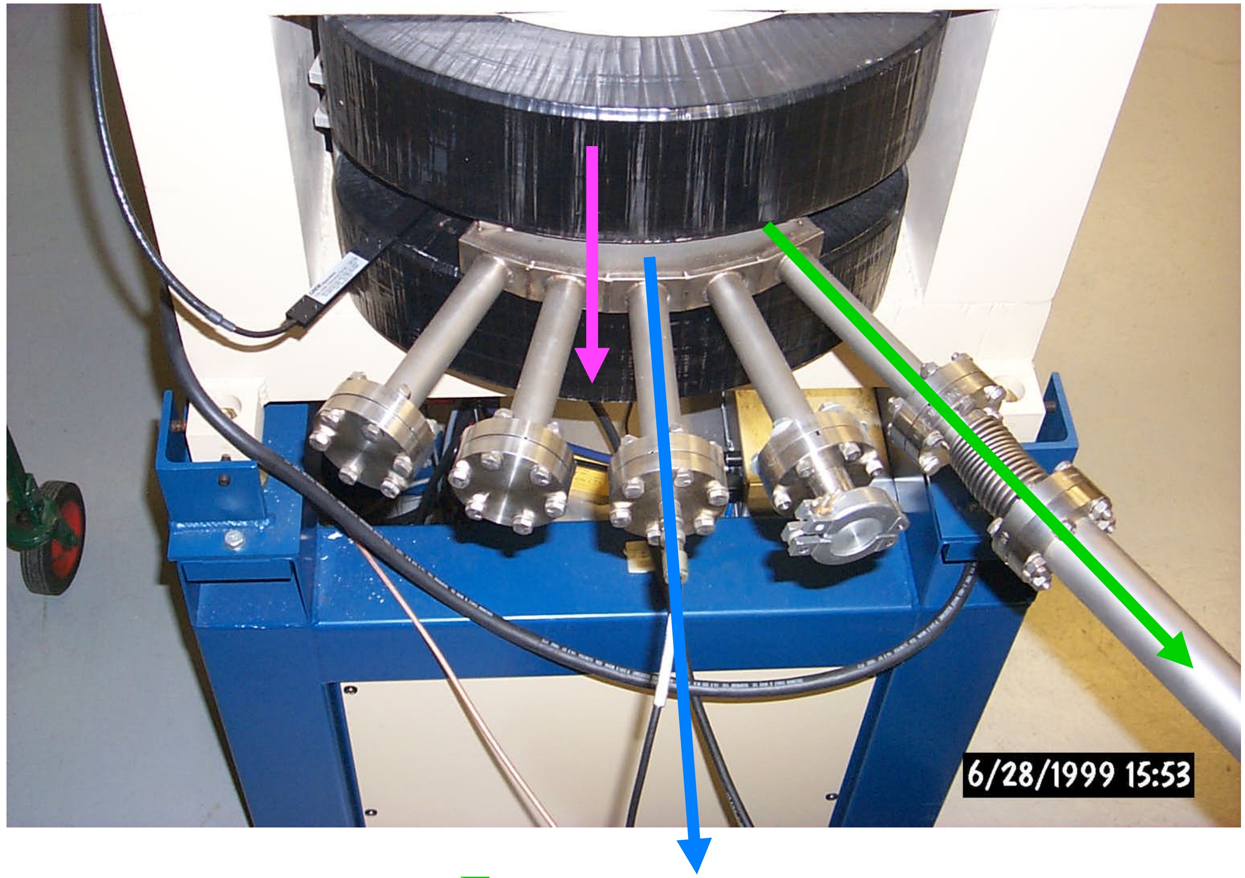
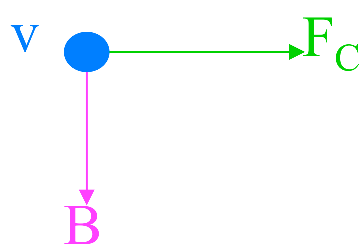
Steering of Ions

B points straight down to the floor

v of the charges is coming out of the machine at you.

This bends the charges to your right and down the beamline.





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A Couple of Quick Calculations

How fast is the proton traveling when it leaves the ion source?

$$W_i = q\Delta V = 1e \times 2.2kV = 2.2keV$$

$$W_i = \Delta KE$$

$$W_i = 2.2keV \times \frac{1.6\times10^{-19}J}{1eV} = 3.52\times10^{-16}J = KE_f - KE_i = KE_f$$

$$3.52\times10^{-16}J = \frac{1}{2}m_p v_p^2$$

$$\therefore v_p = \sqrt{\frac{2\times3.52\times10^{-16}J}{1.67\times10^{-27}kg}} = 6.49\times10^5 \tfrac{m}{s}$$

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A Couple of Quick Calculations

What is the kinetic energy of the proton after it leaves the accelerator?

$$W = q\Delta V = 1e \times 2.2MV = 2.2MeV$$

$$KE_f = 2.2MeV + 2.2keV = 2.202MeV \approx 2.2MeV$$

$$\therefore KE_f = 2.2MeV \times \frac{1.6\times 10^{-19}J}{1eV} = 3.52\times 10^{-13}J$$

What is the speed of the proton after it leaves the accelerator?

$$KE_f = \frac{1}{2}m_p v_p^2 \rightarrow v_p = \sqrt{\frac{2KE_f}{m_p}} = \sqrt{\frac{2\times 3.52\times 10^{-13}J}{1.67\times 10^{-27}kg}} = 2.05\times 10^{7}\,\tfrac{m}{s}$$

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A Couple of Quick Calculations

Comment:
Generally one needs to worry about the speeds of these particles and how they compare to the speed of light.

Need to include Relativistic effects?

In other words does the measured speed of the proton equal the theoretical speed of the proton?

This is hard to do… so, we set a limit… and we define a relativistic limit to be when the velocity of the object is less than *one-tenth* the speed of light ($c \sim 3x10^8$ *m/s*) then we do not have to worry about relativistic effects.

Here the velocity is 2.05×10^7 m/s which is *0.069* times the speed of light, less than the limit, so no relativistic effects.

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A Couple of Quick Calculations

So, we've accelerated the proton and calculated its energy and speed.

Now can we steer it in the magnetic field? If so, what is its orbital trajectory, or radius?

The proton feels a force given by $\vec{F} = q\vec{v} \times \vec{B}$.

This makes the particle travel in a circle of radius *r* due to the centripetal force it feels.

$$F_B = F_C \rightarrow qv_p B = \frac{m_p v_p^2}{r}$$

$$r = \frac{m_p v_p}{qB} = \frac{1.67\times10^{-27}\,kg\times2.05\times10^{7}\,\frac{m}{s}}{1.6\times10^{-19}\,C\times0.6214T} = 0.344m = 34.4cm$$

Once the charges leave the magnetic field the force vanishes and they continue in a straight line toward the scattering chambers.

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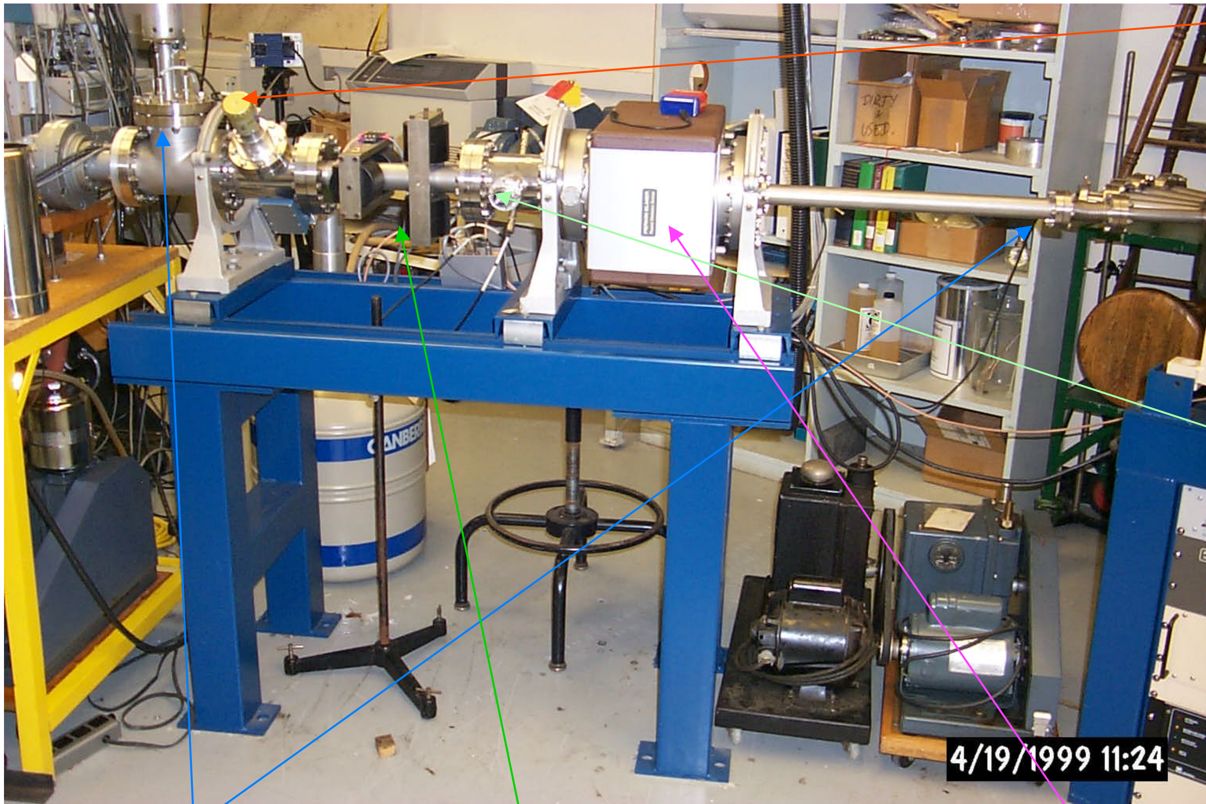
A few odds and ends….



Beam profile monitor

Energy controller

Faraday cups

H and V steering magnets

Ion pump

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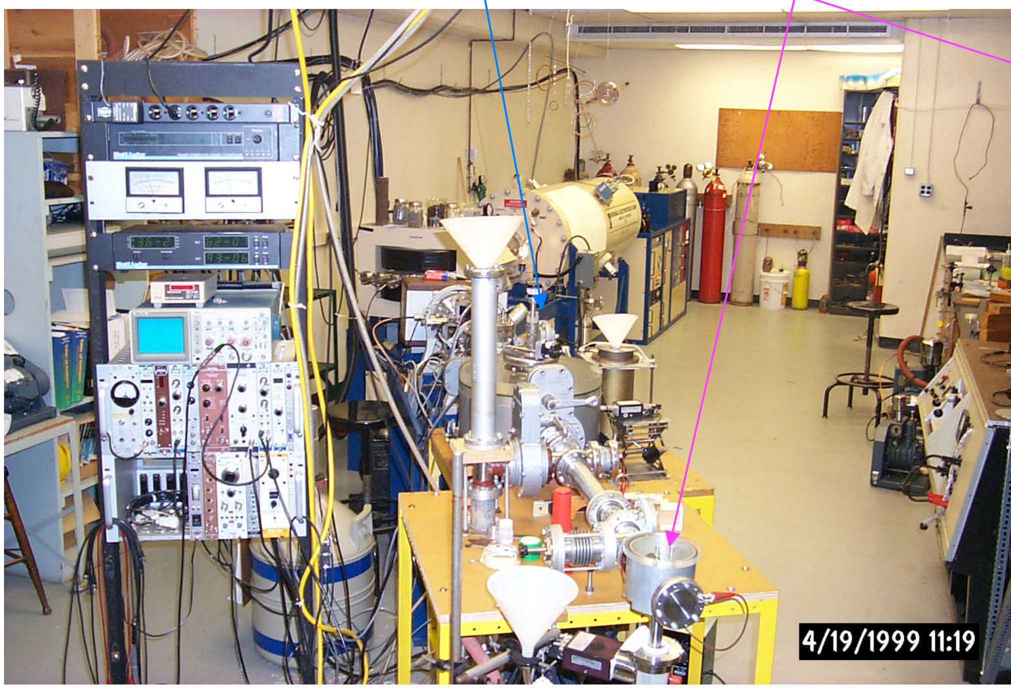
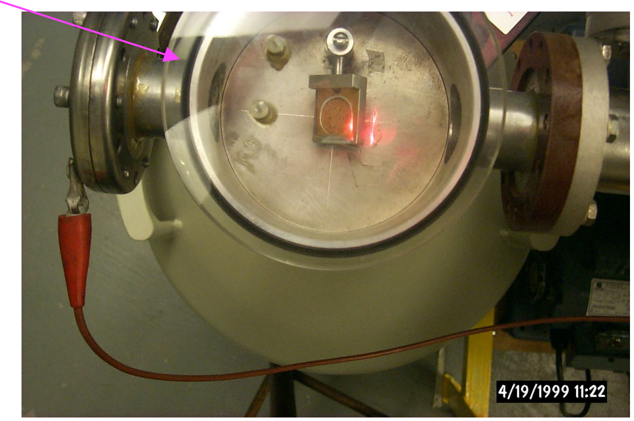
The scattering chambers…

This is where the experiments are done.

We have two; one large (you used this for RBS)

and one small (which we'll use for PIXE.)





This is the small chamber with a sample mounted.

The beam enters from the right.

The glow is the camera flash.

A faraday cup is at the very left.

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Uses of a particle accelerator

Materials Analysis

Mass spectrometry

Nuclear reactions

Nuclear structure

Biochemistry

Paleontology

Forensic science.

Art restoration and archeometry

On Friday, we'll start looking at proton induced x-ray emission spectroscopy, or PIXE.

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