Cloud Chamber Lab   Phys 128AL   11/1/22

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2:30 pm

A = # nucleons (protons + neutrons) Z = atm. Number (protons)

N = # neutrons

1.2 Alpha Decay

To calculate which atoms are stable vs. unstable use binding energy found via the liquid drop model

For nucleons total mass-energy add following

1.) $Z \cdot m_{proton} + N \cdot m_{Neutron}$ (rest mass)

2.) $- A \cdot 15.8\ MeV$ (Negative binding E from attraction)

3.) $+ A^{2/3} \cdot 18.3\ MeV$ (Nucleons "surface tension")

4.) $+ Z^2 / A^{1/3} \cdot 0.714\ MeV$ (anti binding from charge)

5.) additional quantum mechanical terms.

Consider fixed Z & A will it be one large droplet or split into two smaller droplets.

Surface tension term

$E \propto + A^{2/3}$ single $= + A^{2/3}$

$$\text{split} = \left(\frac{A}{2}\right)^{2/3} + \left(\frac{A}{2}\right)^{2/3}$$
$$= \left(\frac{1}{2}\right)^{2/3} (2(A)^{2/3})$$
$$= \left(\frac{1}{2}\right)^{-1/3} A^{2/3}$$

Takes more Energy to split into two "droplets"

$$+ A^{2/3} < + \left(\frac{1}{2}\right)^{-1/3} A^{2/3}$$

Coulomb term is worse when single (more energy) favors splitting up

Source is ^{210}Pb plated on needle undergoes 3 decays

Beta $\quad {}^{210}Pb \rightarrow {}^{210}Bi + e^- + \bar{\nu}_e$ $\quad \lambda = 22$ years

Beta $\quad {}^{210}Bi \rightarrow {}^{210}Po + e^- + \bar{\nu}_e$ $\quad \lambda = 5$ days

Alpha $\quad {}^{210}Po \rightarrow {}^{206}Pb + {}^{4}He$ $\quad \lambda = 138$ days

MeV KE

1.3 Tunneling

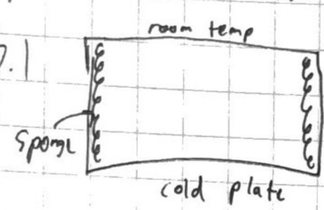
Nucleus to 30 fm is a quantum mechanical potential barrier

Alpha particle must tunnel through barrier

22 years

2.) The Cloud Chamber

2.1



Alcohol evaporates from warm area and sinks down to cold area and into area where saturation vapor pressure is low

This super saturates the air before it can condense.
The super saturated air transitions easily w/ free ions in air which are created by alpha particles.

We will be using Isopropanol for our experiment.

Saturation vapor pressure of Isopropanol

From CRC Handbook of Chemistry & Physics 44th ed

Room Temp. : 40 mm Hg = 5332.9 Pa

-35°C = 1 mm Hg = 133.32 Pa

For 1 cc of saturated gas at room temp. what volume is it at

~~PV=nRT~~   Room temp P = 101,325 . $P_{RT} = 0.0526$ $P_{T-35} = 0.001316$

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2} \quad \frac{(5332.9\,Pa)\,10^{-6}\,m^3}{298\,K} = \frac{(133.32\,Pa)\,V_2}{238}$$

5199.58 Pa oversaturated

1cc · 0.05132

$\boxed{\text{Ea droplet is} \sim 3.39 \times 10^{-5} \text{ cc of isopropanol}}$

$= \boxed{5.132 \times 10^{-2} \text{ cc of alcohol must condense}}$

Assume tracks are 1cm deep
Isopropanol Ionization energy is 10.15 eV

each track ionizes ~ 830 droplets
track Area ~ 0.35 cm² = 0.35cc

2.2 Passage of Particles through matter

How does Alpha particle behave as it travels through the gas
~~A~~ α particle is surrounded by strong $\vec{E}$ field from +2 charge
When passes near a gas molecule it can ionize them, giving the molecule & excised electron some energy, ~~slow~~ slowing down alpha particle
More Ionization the more the α-particle slows down.
Expressed via, energy lost per distance

$\frac{dE}{dx}\left(\frac{MeV}{cm}\right)$ or including density $\left(\frac{dE}{dx}\right)/\rho\left(\frac{MeV \cdot g}{cm^2}\right)$

All materials have ~~a~~ 3×10^{23} e^- per gram difference is usually in density

from Bethe formula $\frac{Z^2}{A^{1/3}}$ term makes $\frac{dE}{dx}$ depend on electron density η so ~~A~~ $\eta \propto -\frac{dE}{dx}$

presence of electrons increases work to form nucleus
this means a higher electron density results in a higher $\frac{dE}{dx}$
i.e. the α-particle gives off more energy per distance.

Energy per unit distance depends on ~~##~~ $1/v^2$
As particle slows down more and more energy is lost per distance

Last "end of track" dense energy loss is called "Bragg Peak"

3. Cloud Chamber Set up

3.1 Turning it on

1. Pour 10-20cc Isopropanol into chamber let soak up sponge ...
2. ~~Cool bottom plate of cloud chamber w/~~ set cooling pump to -10°C let cool for 20 min.
3. Plug in chamber which will cool bottom to -35°C
4. Once cooled where thick condensing fog forms then cloud chamber is ready
5. Put Radioactive ^{210}Pb sample (on needle) into chamber.
6. Connect high voltage banana plug to top of needle to reduce # of ions in chamber.

3.2 Compressed gases

~~Remove source so open at the top~~

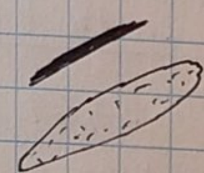
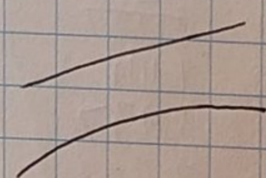
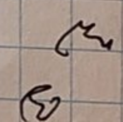
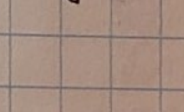
Ended up not being able to use any different gases

Thursday 11/3/22

2:32 pm Cloud chamber is now cooled and the environ is saturated so tracks appear.

Beginning observations to catalogue different phenomena

Catalogue of event patterns Image J scale 51.33̄ px/cm

Number	Description	Sketch	Count Rate
1. ^{210}Pb α	Thick short and dense lines ~2cm emanate radially from source spreads out		w/ sample in 19.4s 52 ct/19.4s 2.68 ± .37 ct/s
2.	Long faint & thin lines ~3-4cm Straight lines or slightly curved		~37 cts in 19.4s 1.90 ± 0.31 ct/s very hard to count/estimate especially w/ camera
3.	Short, faint & thin lines >1cm very squiggly and small		estimation 2-3 ct/s very hard to estimate
4. Gamma ray emitter	Effect/ Increase in small squiggles near source look similar to #3 catalogue above		estimate 2-4 ct/s

Notes/

Without Voltage ion clearing field: Lines are much smaller and fainter and harder to see. Don't create cloud effect of droplets condensing

with Voltage Ion clearing field: Makes a big difference, less droplets in air and particles create thicker, more visible lines. The particles create large clouds of vapor droplets that take about a second to disperse

· Estimate average range of α-particle in cloud chamber

1. Visually using Ruler over 30s ~~[illegible]~~ interval

- I estimated them to be ~2.5 ~~cm~~ ± 0.1 cm visually
- My partner Charley estimated them to be ~2.3 ± 0.1 cm by eye

1.) With Image capture and webcam

Measure 20 α particle

Scale : ~~0.0195 cm/px~~
0.0242 cm/px

uncertainty ± ~~1~~ px in imageJ ~~[illegible]~~ measure length
= ± 0.12 cm uncertainty

# α	Length (cm)	
1	~~1.262~~	1.570
2	~~1.595~~	1.984
3	~~1.767~~	2.198
4	1.419	
5	1.937	
6	2.363	
7	3.394	
8	1.602	
9	1.416	
10	1.618	
11	2.175	
12	2.704	
13	1.153	
14	1.527	
15	2.692	
16	1.144	
17	1.804	
18	1.674	
19	2.373	
20	1.398	

Average Length 1.92 ± 0.12 cm

Beth-Bloch Energy Loss Formula

$$-\left\langle \frac{dE}{dx} \right\rangle = \frac{4\pi}{m_e c^2} \cdot \frac{n z^2}{\beta^2} \cdot \left(\frac{e^2}{4\pi\varepsilon_0} \right)^2 \cdot \left[\ln\left(\frac{2 m_e c^2 \beta^2}{I \cdot (1-\beta^2)} \right) - \beta^2 \right]$$

electron density: n

$$n = \frac{N_A \cdot Z \cdot \rho}{A \cdot M_u}$$

$\beta = \frac{v}{c}$

z = Charge (2+)

I : target mean excitation Energy

Terms a that depend on target properties are electron density n and Mean excitation energy, I, for air inside chamber

$$n \propto \rho \quad n \propto \frac{Z}{A} \qquad I \approx (10\,eV)\cdot Z \qquad -\frac{dE}{dx} \propto n \qquad -\frac{dE}{dx} \propto \ln\left(\frac{1}{I}\right)$$

Target properties depend on density, Atomic mass, and how easily target is ionized

α particles should travel farther in less dense gas

From NIST for 5.407 MeV α particle

Target	Total Stopping Power $\left(\frac{MeV\,cm^2}{g}\right)$	Projected Range $\left(\frac{g}{cm^2}\right)$	Track length$_{cm}$ $\left(\frac{range}{density}\right)$
Air	7.207×10^2	4.88×10^{-3}	$\rho = 1.482 \times 10^{-3}$ g/cm³ @ -35°C 3.295 cm
Hydrogen	2.109×10^3	1.535×10^{-3}	ρ: 1.018×10^{-4} g/cm³ @ -35°C 15.078 cm
Aluminum ~~Argon~~	~~5.069×10^2~~ 5.748×10^2	~~7.174×10^{-3}~~ 6.437×10^{-3}	~~$\rho = 2.02 \times 10^{-3}$ g/cm³ @ -35°C~~ $\rho = 2.712$ g/cm³ 2.37×10^{-3} cm

Clearly density plays a major factor in how far particles will travel. Even for vastly different materials like above the projected range (g/cm²) is very similar. The only difference causing the difference in particle track length is density

Note: As of November 8th the CF_4 tank still has not been refilled so we have not yet had a chance to measure the range in a medium besides air. Hopefully they will refill the tank by thursday so we can test this in lab.

Simplified Bethe Block Formula
for $\beta \ll 1$ $\quad v \ll c$

$$-\frac{dE}{dx} = \frac{4\pi n z^2}{m_e v^2}\left(\frac{e^2}{4\pi\varepsilon_0}\right)^2\left[\ln\left(\frac{2 m_e v^2}{I}\right)\right]$$

$$= \frac{4\pi n z^2}{m_e}\left(\frac{e^2}{4\pi\varepsilon_0}\right)^2\left[\ln\frac{2 m_e v^2}{I}\right]\cdot\frac{1}{v^2}$$

Simplify constant terms: assume material is air at -35°C

$m_e = 9.1093837 \times 10^{-31}$ kg

$e = 1.60217663 \times 10^{-19}$ C

$\varepsilon_0 = 8.854187 \times 10^{-12}$ F/m

$z = +2$ (alpha particles have +2 charge)

$$n = \frac{N_A \cdot Z \cdot \rho}{A \cdot M_u}$$

$N_A = 6.02214 \times 10^{23}$ $\quad$ $A = 28.96$ for air $\quad$ $M_u = \frac{1g}{mol}$ $\quad$ $A \cdot M_u = 0.02896$

$\rho = 1.482$ kg/m³ (density of air at -35°C from engineeringtoolbox.com)

$Z = [(0.78 \cdot 2 \cdot 7) + (0.21 \cdot 2 \cdot 8) + (0.00934 \cdot 18) + (0.0003 \cdot 22) + (0.01 \cdot 10)$
(weighted atomic number of air)

$Z = 14.555$ $\qquad$ $I = 85.7$ eV $= 1.37307 \times 10^{-17}$ J

$n = 4.4854 \times 10^{26}$

$\frac{4\pi n z^2}{m_e} = 2.47505 \times 10^{58}$ $\quad$ $\left(\frac{e^2}{4\pi\varepsilon_0}\right)^2 = 5.323 \times 10^{-56}$

$\frac{2 m_e}{I} = 1.32686 \times 10^{13}$

$$-\frac{dE}{dx} = (2.47505 \times 10^{58})(5.323 \times 10^{-56}) \cdot \ln(1.32686 \times 10^{13}\, v^2) \cdot \frac{1}{v^2}$$

without magnets we cannot measure the velocity of the alpha particles accurately.
Instead we rely on the ASTAR database for our energy loss ~~data~~ data

Particle Range: Measure from source to end of track.
$\delta x = \pm 0.1\,cm$ $\rho_{air} @ 35°C = 0.001482\ g/cm^3$

#	Range (cm)	Range (g/cm^2)
1	2.637	3.908e-3
2	2.770	4.105×10^{-3}
3	3.144	4.659×10^{-3}
4	3.330	4.935×10^{-3}
5	2.688	3.984×10^{-3}
6	3.581	5.307×10^{-3}
7	2.836	4.203×10^{-3}
8	3.166	4.692×10^{-3}
9	4.117	6.101×10^{-3}
10	2.978	4.413×10^{-3}
11	2.356	3.492×10^{-3}
12	2.634	3.904×10^{-3}
13	3.120	4.624×10^{-3}
14	3.470	5.143×10^{-3}
15	2.251	3.336×10^{-3}
16	2.838	4.206×10^{-3}
17	3.881	5.752×10^{-3}
18	4.015	5.950×10^{-3}
19	2.562	3.797×10^{-3}
20	2.998	4.443×10^{-3}
21	3.491	5.174×10^{-3}
22	3.057	4.530×10^{-3}
23	2.652	3.930×10^{-3}
24	2.336	3.462×10^{-3}
25	2.668	3.954×10^{-3}
26	2.141	3.173×10^{-3}
27	3.593	5.325×10^{-3}
28	2.395	3.549×10^{-3}
29	3.106	4.603×10^{-3}
30	3.758	5.569×10^{-3}

Avg Range (cm): 3.019 cm

stdev range = 0.5372 cm

30

Standard Error = $\frac{stdev}{\sqrt{30}}$ = 0.098 cm ✓

Avg Range $\left(\frac{g}{cm^2}\right)$ = $4.474 \times 10^{-3}\ g/cm^2$

stdev Range = $7.961 \times 10^{-4}\ g/cm^2$

Standard error = $1.453 \times 10^{-4}\ g/cm^2$

Range (cm) = 3.019 ± 0.5372 cm

Range $\left(\frac{g}{cm^2}\right)$ = $4.474 \times 10^{-3} \pm 7.961 \times 10^{-4}\ g/cm^2$

For Our α-Range of 3.019 ± 0.537 cm

or $4.474 \times 10^{-3} \pm 7.961 \times 10^{-4}$ g/cm^2

compare to NIST-ASTAR charts for stopping power & MeV using Projected Range for Air, Dry near sea level

	Range (g/cm^2)	Total Stopping Power (MeV cm^2/g)	KE (MeV)
min.	~~3.736~~ 3.678×10^{-3}	$8.206 \times 10^{+2}$	4.484
center	4.474×10^{-3}	$7.499 \times 10^{+2}$	5.108
max	5.270×10^{-3}	$6.961 \times 10^{+2}$	5.683

Total stopping power: $7.499 \times 10^{+2}$ MeV cm^2/g

$= 1.111$ MeV/cm

~~Rang~~ Range of stopping power $6.961 \times 10^{+2} - 8.206 \times 10^{+2} = 1.245 \times 10^{+2}$ MeV cm^2/g

$= \pm 62.25$ MeV cm^2/g

Kinetic Energy = 5.108 MeV

Range of KE : $5.683 - 4.484 = 1.199$ MeV $= \pm 0.60$ MeV

Expected Values are 5.407 MeV & 7.207×10^2

Our uncertainty includes the expected values so that is good!

Stopping power & KE are not linear to range as expected

Correlation between droplet density & $\frac{dE}{dx}$

Assume tracks 1cm deep

Measure area of tracks w/ Image J

~530 droplets per track = 5.407 MeV / 10.15 eV ionization energy of isopropanol

droplet density = $\frac{\cancel{5530}\ KE/10.15eV}{\text{track area} \cdot 1cm}$

Compare w/ Value for $\frac{dE}{dx}$ for track range

α	Track Range (cm)	Track Area (cm^2)	Range (g/cm^2)	Total stopping power ($MeV\ cm^2/g$)	KE
1	3.130	0.223	4.638×10^{-3}	7.377×10^2	5.230
2	3.299	0.116	4.889×10^{-3}	7.202×10^2	5.413
3	2.704	0.187	4.007×10^{-3}	7.888×10^2	4.749
4	2.596	0.128	3.847×10^{-3}	8.038×10^2	4.621
5	2.807	0.106	4.160×10^{-3}	7.754×10^2	4.868
6	3.484	0.278	5.163×10^{-3}	7.026×10^2	5.608
7	3.518	0.473	5.214×10^{-3}	6.994×10^2	5.644
8	3.050	0.217	4.520×10^{-3}	7.464×10^2	5.143
9	2.764	0.237	4.096×10^{-3}	7.809×10^2	4.819
10	2.287	0.309	3.389×10^{-3}	8.521×10^2	4.242

α	Stopping Power $\frac{MeV}{cm}$	Droplet #	Droplet density #/cm^3
1	1.093	515	2309.4
2	1.067	533	3650.7
3	1.169	468	2502.7
4	1.191	455	3554.7
5	1.149	479	4518.9
6	1.041	553	1989.2
7	1.037	556	1175.5
8	1.106	507	2336.4
9	1.157	475	2004.2
10	1.263	418	1352.8

$\delta SP = \pm 0.11 \times 10^2\ \frac{MeV\ cm^2}{g}$

$\delta SP = \pm 1.64 \times 10^{-2}\ \frac{MeV}{cm}$

$\delta Area = \pm .01\ cm^2$

$\delta KE = \pm 0.1\ MeV$

$\frac{\delta \rho}{|\rho|} = \sqrt{\left(\frac{\delta A}{A}\right)^2 + \left(\frac{\delta KE}{KE}\right)^2}$

$\frac{\delta \rho}{|\rho|} = 0.0508$ Max. Uncertainty?

Graphing Droplet Density vs $\frac{dE}{dx}$ (stopping power)
there is an upward trend but the uncertainty in the droplet density is large, ~15%, that it renders the analysis practically useless for any direct correlation

The uncertainty is so large for droplet density because of the reliance on the NIST charts to convert range to KE & for the stopping power

Because the relation between range and KE / $\frac{dE}{dx}$ isn't linear it led to higher values of uncertainty for higher ranges

Multiple Scattering

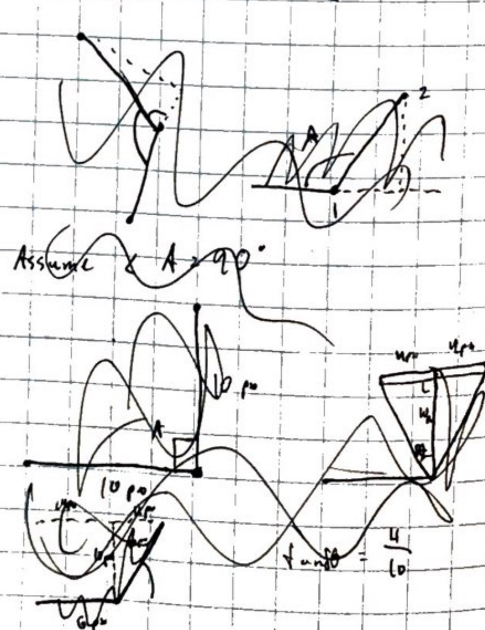
Measure angle of α particles after collision

α	Angle (°)
1	176.49
2	156.37
3	176.269
4	176.84
5	164.55
6	175.582
7	179.053
8	171.203
9	179.745
10	178.858
11	178.127
12	178.556
13	178.499
14	179.66
15	161.458
16	176.84
17	165.763
18	178.431
19	174.674
20	174.098

~~Error in 2 measurements~~

~~each pt. of 3 could be off by ± 4 px~~

last 2 pts determine ∠



Deviation from 180° = 8.83° ± 0.9°

For uncertainty measured a straight line 10 times
record stdev as uncertainty

Trial	1	2	3	4	5	6	7	8	9	10
$\angle$	179.61	177.55	178.526	178.35	179.13	179.08	176.76	178.90	179.59	179.59

$\sigma = 0.9$ $\quad\delta\theta = 0.9^\circ$

deviation $= 8.83^\circ \pm 0.9^\circ$

Scattering formula

2std $= 17.66^\circ \pm 1.8^\circ$

$\cancel{N(\theta) = \frac{N_i \rho \, Z^2 k^2 e^4}{4\, KE^2 \sin^4(\theta/2)}}$

$\cancel{N_i = 20 \quad \rho = 1.482\ kg/m^3}$

$\cancel{r = 3.019\ cm = 0.03019\ m}$

$\cancel{Z = 14.555}$

$\cancel{k = 8.987551 \times 10^9\ Nm^2/C^2}$

$\cancel{e = 1.60217663 \times 10^{-19}\ C}$

$\cancel{KE = 5407\ eV = 8.66297e{-16}}$

$\cancel{N(\theta) = 3.36121 \times 10^{-34} \cdot \sin^{-4}(\theta/2)}$

$$\theta_0 = \frac{13.6\ MeV}{\beta c p} z \sqrt{\frac{x}{X_0}} \left(1 + 0.038 \ln(x/X_0)\right)$$

$$\beta c p = m_\alpha \cdot v^2 = 2 KE_\alpha = 11.408\ MeV$$

$x/X_0 = 48.5$ from pdg particle passage through matter

$\theta_0 = 19.05^\circ$ $\quad$ our value $= 17.66^\circ \pm 1.8^\circ$

meaning 95% of particles should be within 19.05° of straight (180°)

This matches our data as all points are between $160.95^\circ - 180^\circ$

Discussion:

The results of our experiment gave us fairly good data and our values matched the expected values within our uncertainty

	Measured	Expected
Range	3.0 ± 0.5 cm	3.3 cm
scattering	$2\sigma = 17.88° \pm 1.8°$	$2\sigma = 19.05°$

For Droplet density vs Energy loss per distance the correlation we measured was inconclusive. Although the data showed an upward trend as expected the exact correlation couldn't be determined

One thing that could have helped would be taking more data points to hopefully lower our uncertainty and allow for a more accurate correlation

If I were to do this lab again I would like to perform more of the advanced experiments like using a different gas or magnets to determine the particle velocity.