Selective Resonance Photoionization of Odd Mass Isotopes

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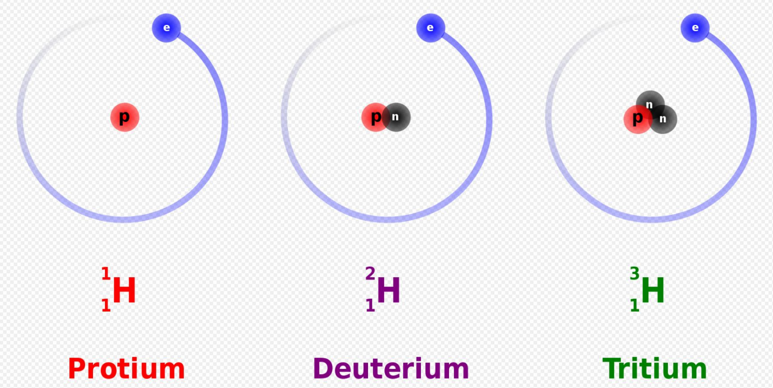
Outline

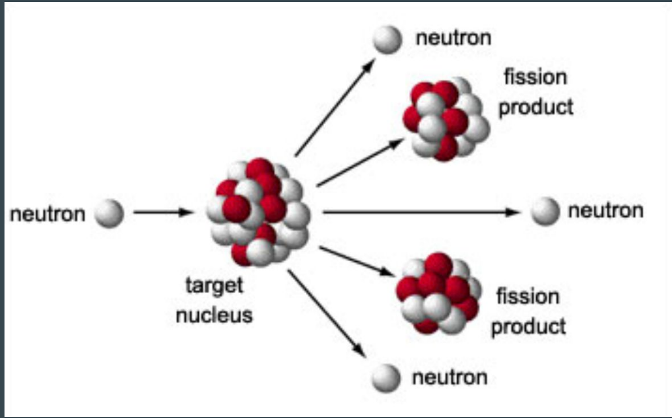
What are Isotopes?

- Same Z, but different mass
- Chemically speaking, all atoms are completely indistinguishable
  - Recently discovered chemical reactions rates may vary (very rare effect)
- Many elements have many different kinds of isotopes
  - Some are stable
  - Some definitely aren't
  - Some that aren't can be very bad for you



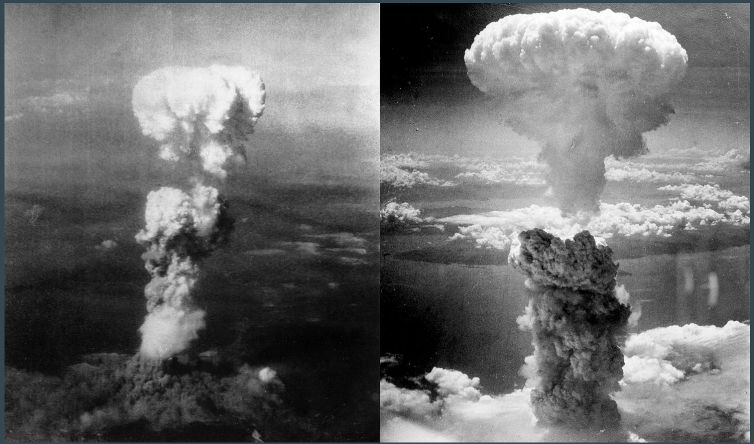
Why do we care?

- The modern world uses isotopes on a fairly regular basis
- Nuclear Fission Energy is a clean form of energy that powers much of the world
  - Specific Isotopes are used as fuels
  - Specific Isotopes are produced as harmful waste
- Medically ~50 kinds of isotopes are used for a variety of medical procedures
  - Imaging
  - Therapies



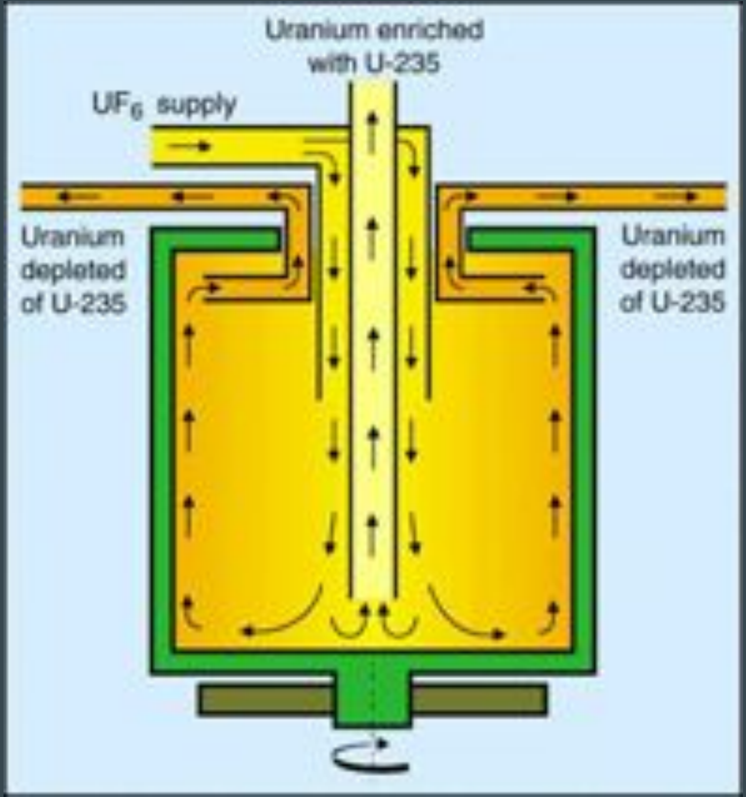
How have we been separating isotopes?

- Many techniques hypothesized and developed in the late 1930's early 1940's
  - Mostly meant to prepare enriched U-235 materials for atomic weapons
  - Cold War, it appears techniques were just used, not developed
    - Classified Information?
- Main Techniques from this era are:
  - Centrifugal Separation
  - Electromagnetic Separation
  - Gaseous Diffusion
  - Liquid Thermal Diffusion



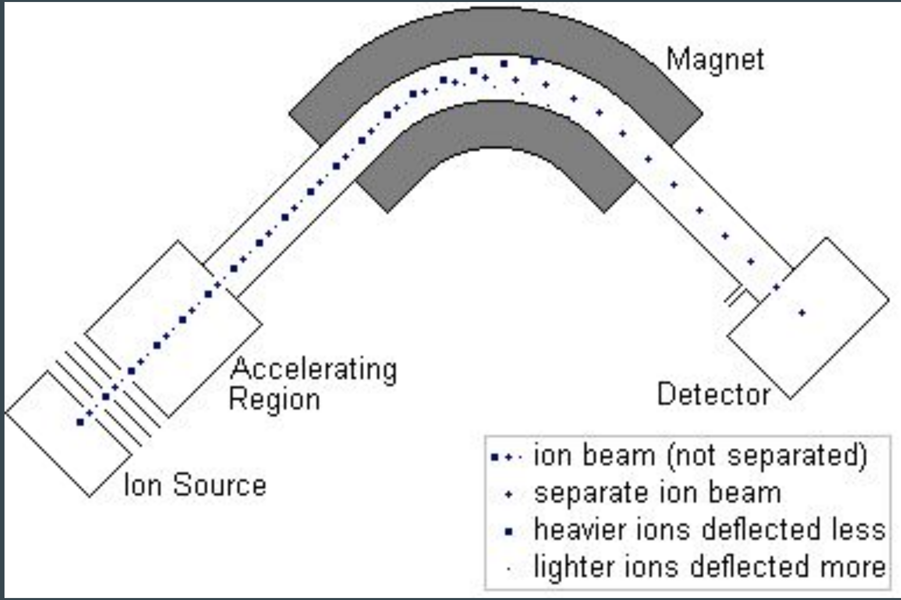
Centrifugal Separation

- The isotope is put into a vapor form
- Fed into spinning cylinder
- Higher mass tends to edge and is removed
- Low mass tends to center and is collected



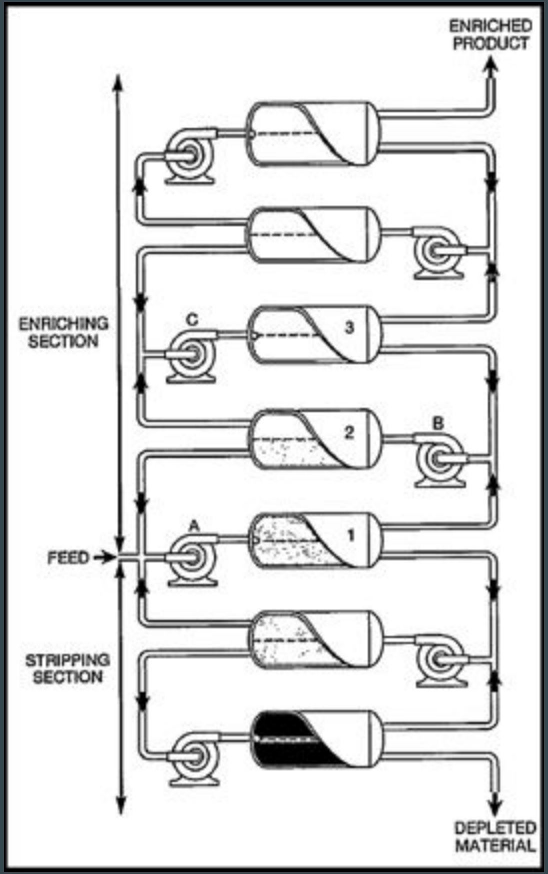
Electromagnetic Separation

- Use strong electric field to ionize atoms
- Accelerate newly ionized atoms into magnetic field
- Heavy atoms tend to not bend path
- Light atoms tend to bend path
- Appropriate Isotopes collected



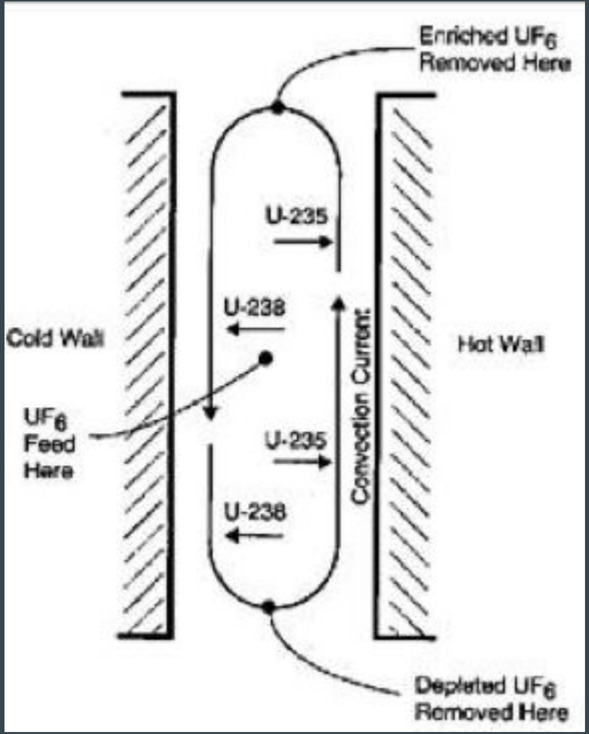
Gaseous Diffusion

- Isotopes are turned into a vapor and inserted into feed
- Each tank has a porous barrier
- Light atoms tend to propagate through the barriers
- Run through multiple barriers
- Remove enriched product



Liquid Thermal Diffusion

- Isolate liquid form of isotope
- Put under immense pressure
- Create a temperature differential
- Convection current forms
- Light isotopes tend to hot end of differential
- Collect the appropriate isotope



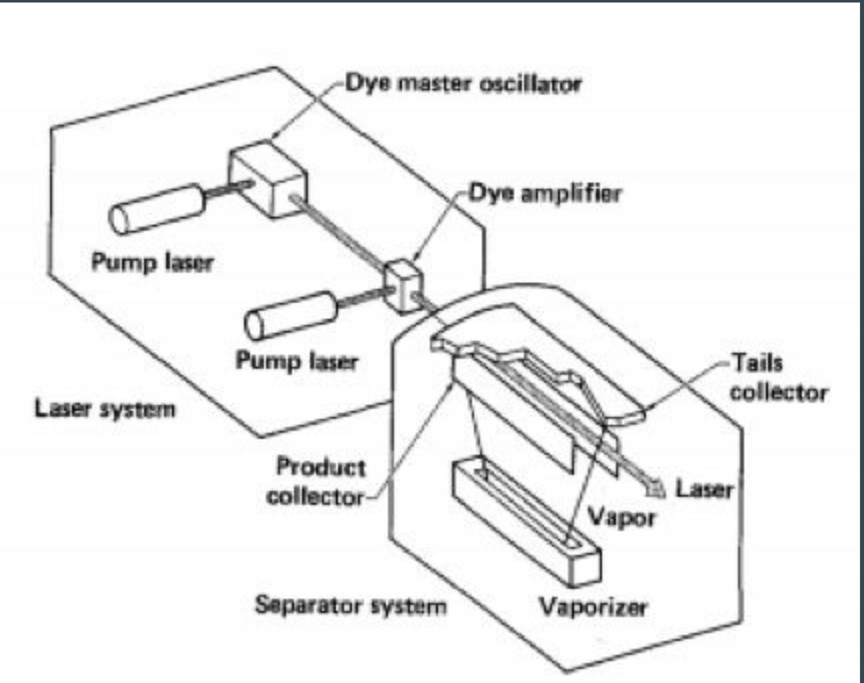
What was wrong with these?

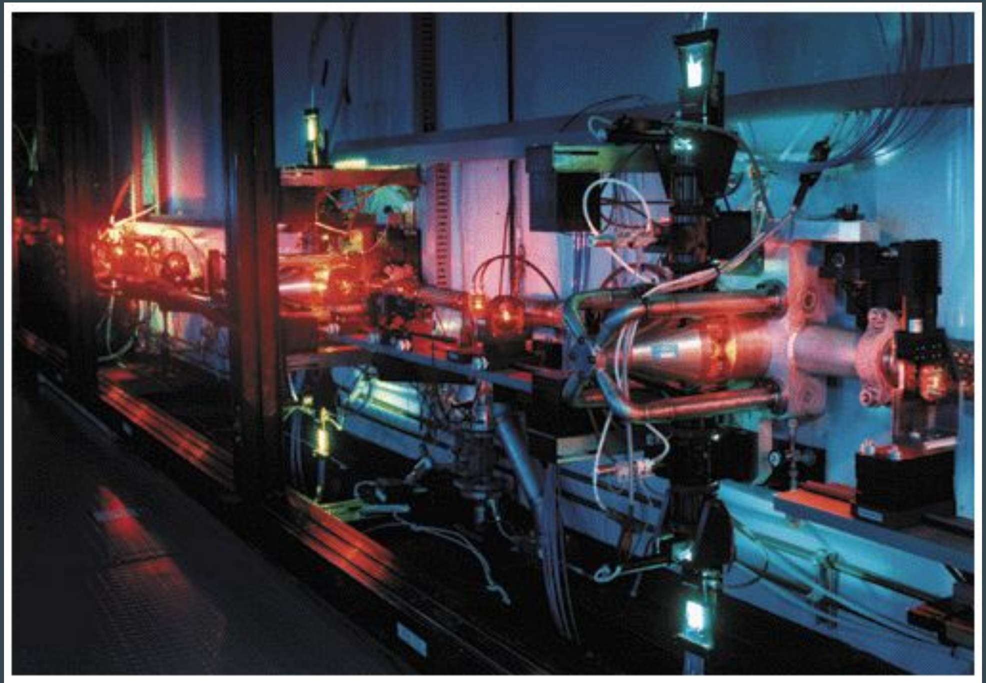
- Slow
- Low enrichment ratio
- Large Facilities Required
- Most processes require atomic vapor, or atomic gas
    - These are usually highly corrosive and require special materials for the devices
- Huge Amounts of Power Used
- Money….. Lots of Money
- Require huge mass differences to be effective (this is bad if Isotope spacing is not large)

The Next Rung Up

- Atomic Vapor Laser Isotope Separation (AVLIS)
- 1970's plan proposed to ionize isotopes by exploiting hyperfine structure and the isotope shifts
- Experiments over the next few years showed promising results
- Requires very narrow bandwidth lasers
- Incredibly cost effective
  - 1985 awarded technology research grants so that it would supply U-235 to nuclear power plants in US by D.O.E.

AVLIS


Dye master oscillator
Dye amplifier
Pump laser
Pump laser
Laser system
Tails collector
Product collector
Laser
Vapor
Separator system
Vaporizer



Yet Another Rung Up

- Narrow bandwidth lasers are highly complex pieces of equipment
- AVLIS still tends to favor high mass differences due to how narrow the bandwidth has to be in comparison to transitions frequencies between the different isotopes
- Selective Resonance Photoionization comes in
- Instead of focusing on one transition, use multiple transitions to isolate the desired isotopes, or remove the unwanted isotopes

What did the experimenters do?

- Wanted to separate 93-Zr and 95-Zr from even mass Zr isotopes
  - Both products of nuclear fission fuels common in nuclear power plants (U-235)
  - Long half-life
  - Dangerous radiation

$$^{235}_{92}U + ^{1}_{0}n \longrightarrow ^{236}_{92}U \longrightarrow ^{90}_{38}Sr + ^{144}_{54}Xe + 2\ ^{1}_{0}n$$

$$^{235}_{92}U + ^{1}_{0}n \longrightarrow ^{236}_{92}U \longrightarrow ^{87}_{35}Br + ^{146}_{57}La + 3\ ^{1}_{0}n$$

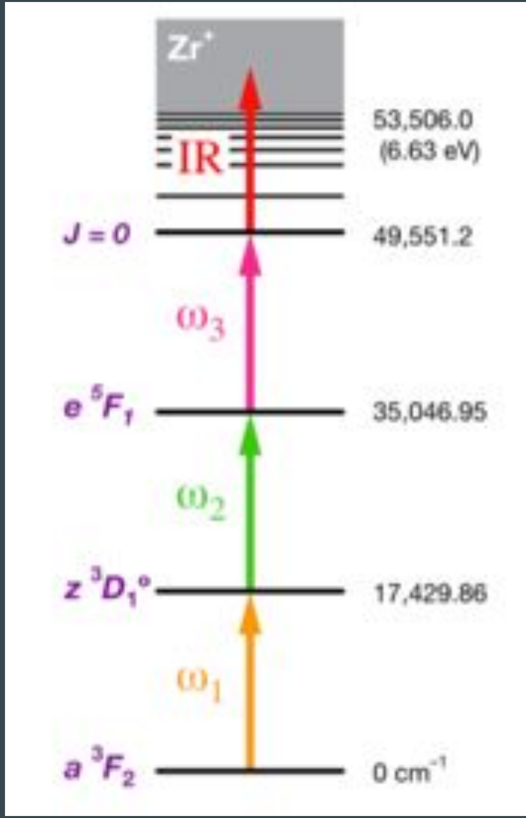
$$^{235}_{92}U + ^{1}_{0}n \longrightarrow ^{236}_{92}U \longrightarrow ^{96}_{37}Rb + ^{137}_{55}Cs + 3\ ^{1}_{0}n$$

$$\boxed{^{235}_{92}U + ^{1}_{0}n \longrightarrow ^{236}_{92}U \longrightarrow ^{137}_{52}Te + ^{97}_{40}Zr + 2\ ^{1}_{0}n}$$

$$^{235}_{92}U + ^{1}_{0}n \longrightarrow ^{236}_{92}U \longrightarrow ^{141}_{56}Ba + ^{92}_{36}Kr + 3\ ^{1}_{0}n$$

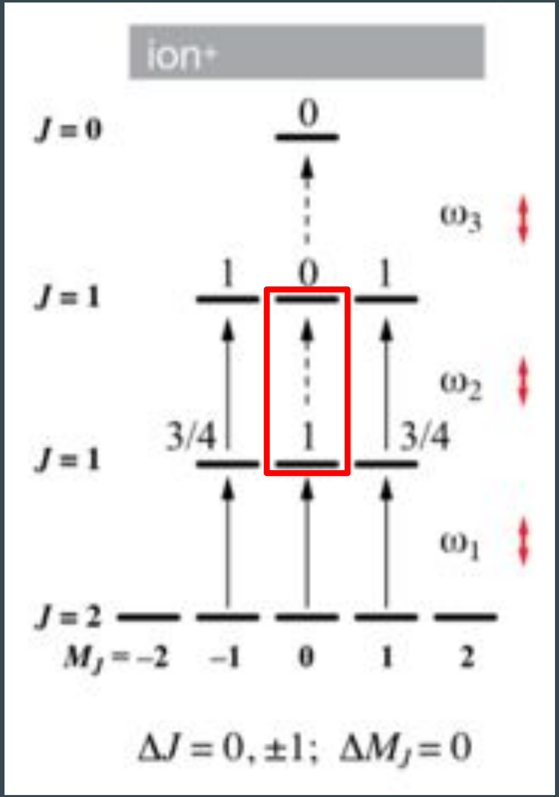
What the scheme looks like

- Proposed J = 2 -> 1 -> 1 -> 0 -> Ionized scheme



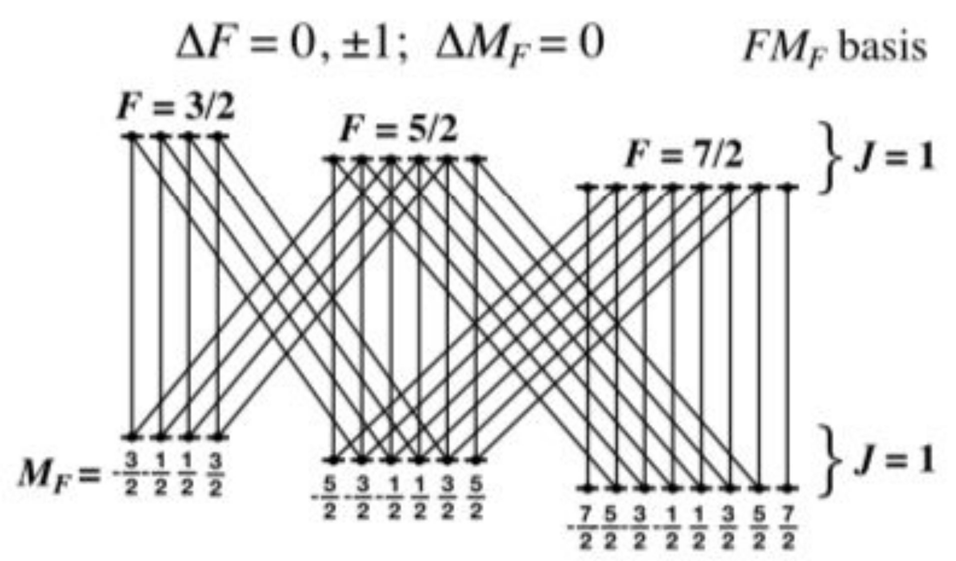
Even Mass Isotopes

- All non-radioactive
- Certain Transitions not allowed
  - We focus on the |1,0> to |1,0> transition
  - This violates the J transition rules
  - Even Mass Isotopes can't go to the next level
  - Even Mass Isotopes won't be ionized

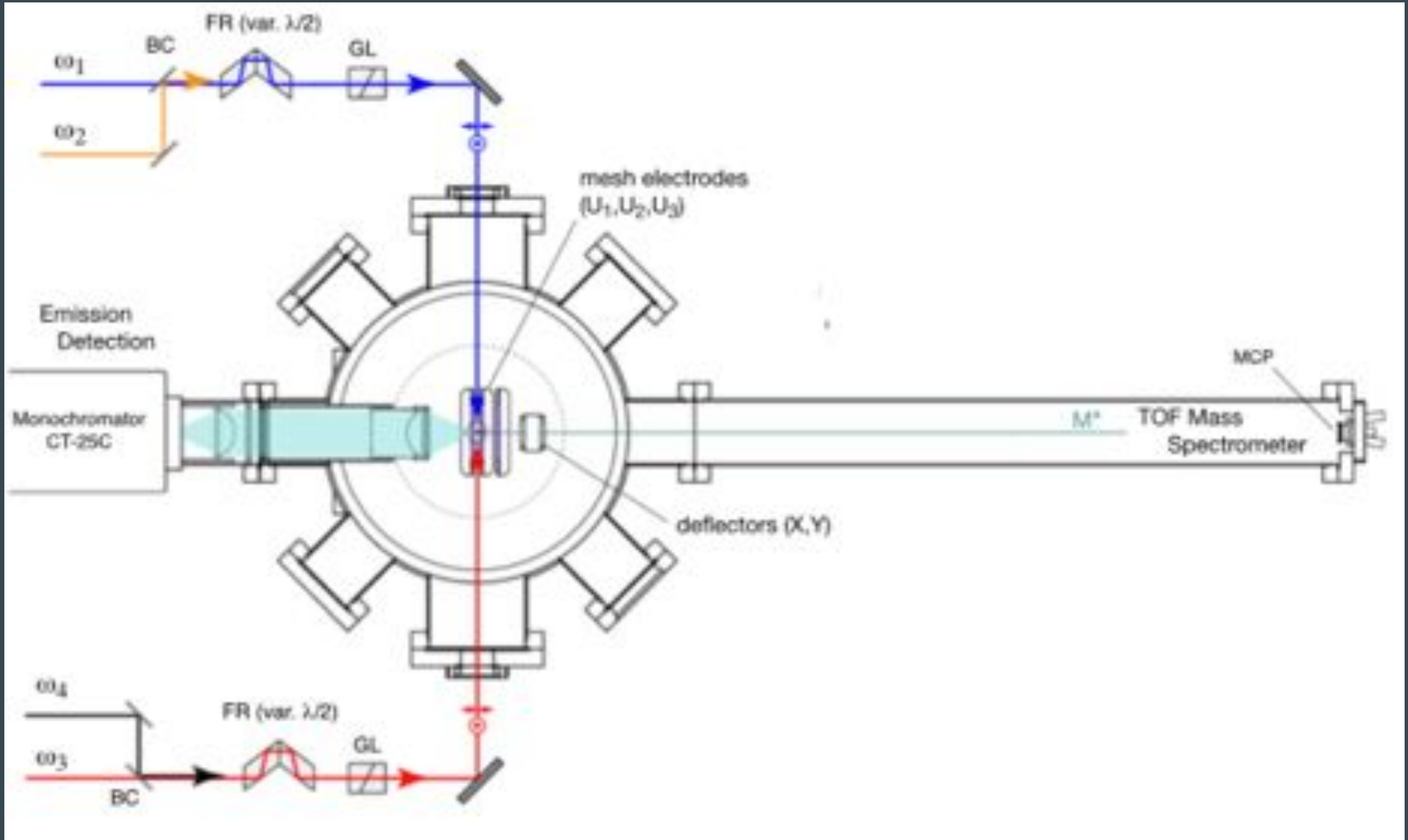


Odd Mass Isotopes

- For Odd Mass Isotopes we must consider nuclear spin in transition calculations
  - F = I +J
- This is how the J = 1 -> 1 transition can look for odd mass isotopes



Experimental Apparatus



Results

3rd intermediate state (cm^{-1})	$^{91}\beta$	relative yield		lifetime (ns)	cross-section (cm^2)
		^{91}Zr	$\sum^{2m}$ Zr[a]		
$J = 2\text{-}1\text{-}1\text{-}0 + \mathrm{IR}$					
52 605.01[b]	266	1	1	1450(50)	$1.8(2) \times 10^{-16}$
	~70[c]	—	—	—	—
	>10[d]	—	—	—	—
52 343.66	310	3.8	3.3	174(5)	$\ll 2.7(2) \times 10^{-19}$
51 848.17	575	30	<13.8	182(5)	$4.9(2) \times 10^{-16}$
51 801.65	490	4.2	3.6	885(20)	$4.2(2) \times 10^{-16}$
51 154.00	1480	16.6	<3.0	110(2)	$1.2(2) \times 10^{-16}$
49 551.31	2460	17.1	1.8	86.7(14)	$3.7(2) \times 10^{-16}$
49 136.64	1630	17.2	2.8	450(10)	$1.7(7) \times 10^{-15}$

Conclusion

- Researchers succeeded in finding a more efficient separation method for odd mass isotopes
- This opens up a new way of separating isotopes of previously difficult to separate isotopes
- All that has to be done is finding the appropriate ionization schemes for each element for optimal separation

References

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