Angular Distribution of Neutrons from the Photo-Disintegration of Deuteron

– by Frank Genevese

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A paper on experiment

Paper Club, 22, Feb, 2011

The Outline of the paper

- Motivation
- Apparatus
- Precautions
  - Scattering by Heavy Water
  - Scattering by surroundings
- Experiment method
- Results and Conclusions

Motivation (@ 1949)

- the angular distribution *(or the differential cross section)* of photo-neutron from Deuteron is a difficult task.
  - Low intensity.
- The theory point out that the photon will react with the deuteron in 2 ways
  - Photo-electric effect (electric dipole $H_e = d \cdot E$)
    - Electric absorption cross section σ_{el}
  - Photo-magnetic effect (magnetic dipole $H_m = \mu \cdot B$)
    - Magnetic absorption cross section σ_m

Photo-electric vs Photo-magnetic

- parity selection rule of (EL)electric L-dipole transition is

$$\pi_i = \pi_f\,(-1)^L$$

- parity selection rule of (ML)magnetic L-dipole transition is

$$\pi_i = \pi_f\,(-1)^{L+1}$$

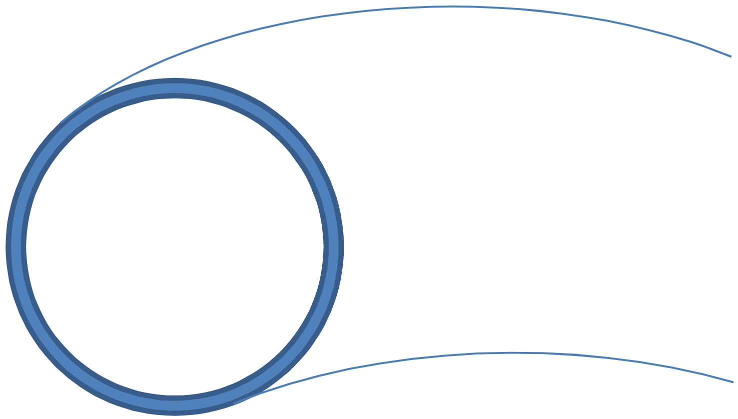
- From S-state to P-state, $L=1$
  - Parity of E1 is – => odd angular distribution
  - Parity of M1 is + => even angular distribution

Apparatus (Source)

- The γ – ray source were prepared by bombardment of Sodium (Na) with deuteron
- The deuteron beam current is 350 μA
  - About 2 x 10^{15} particle per second.
  - 7MeV
  - 6 ~ 8 hours
- The γ – ray has strength 500 mCi (millicurie)
  - 1Ci = 3.7 x 10^{10} decay per second = 3.7 GBq
  - 1.85 x 10^{10} decay per second

Apparatus (Target)

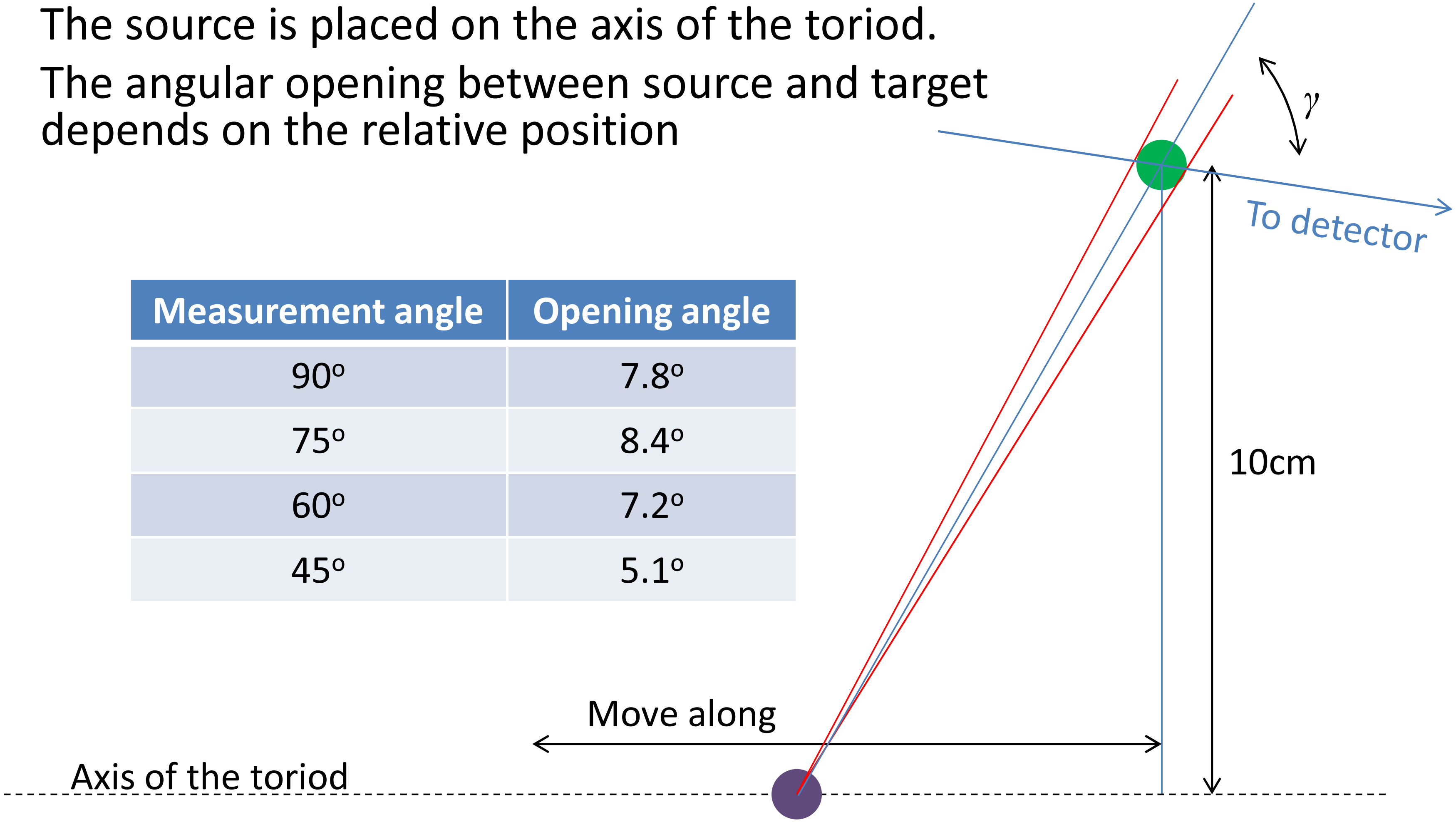
- 3 factors need to be considerate
  - The internal scattering of neutron
  - Departure from point source
  - The angular opening of the γ – ray source
- Invented a Toroid (donut) tube.
  - Radius 100mm
  - External radius is 8.8mm
  - Internal radius is 8mm
  - 30c.c. DO_2



Apparatus (Target & Source)

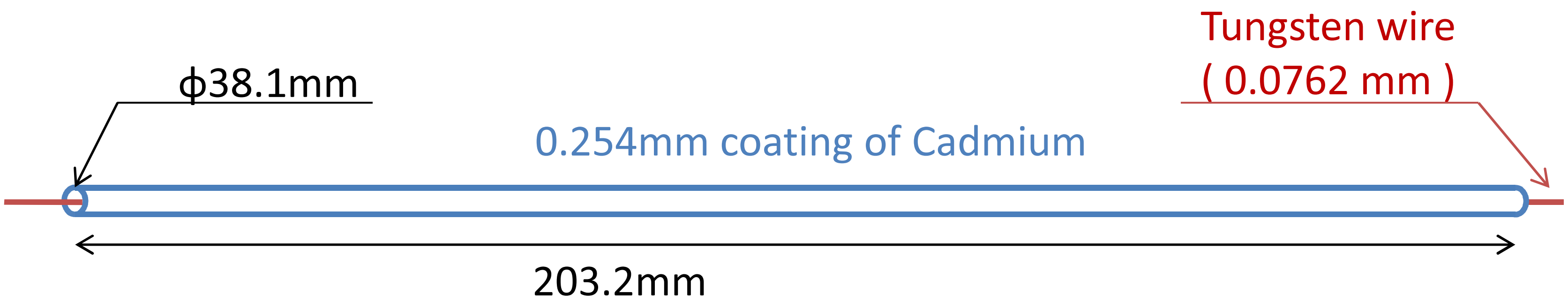
- The source is placed on the axis of the toriod.
- The angular opening between source and target depends on the relative position

Measurement angle	Opening angle
90^o	7.8^o
75^o	8.4^o
60^o	7.2^o
45^o	5.1^o



Apparatus (Detector)

- A cylindrical proportional counter
  - BF_3 at ⅓ atm.
  - 96% of Boron is B^{10}, for neutron capture
- Operation voltage is 2100 V
  - 10% of Ar at 99.6 purity. (why?)



1:1 scale

1 mil = 0.001 inches

1 inches = 25.4mm

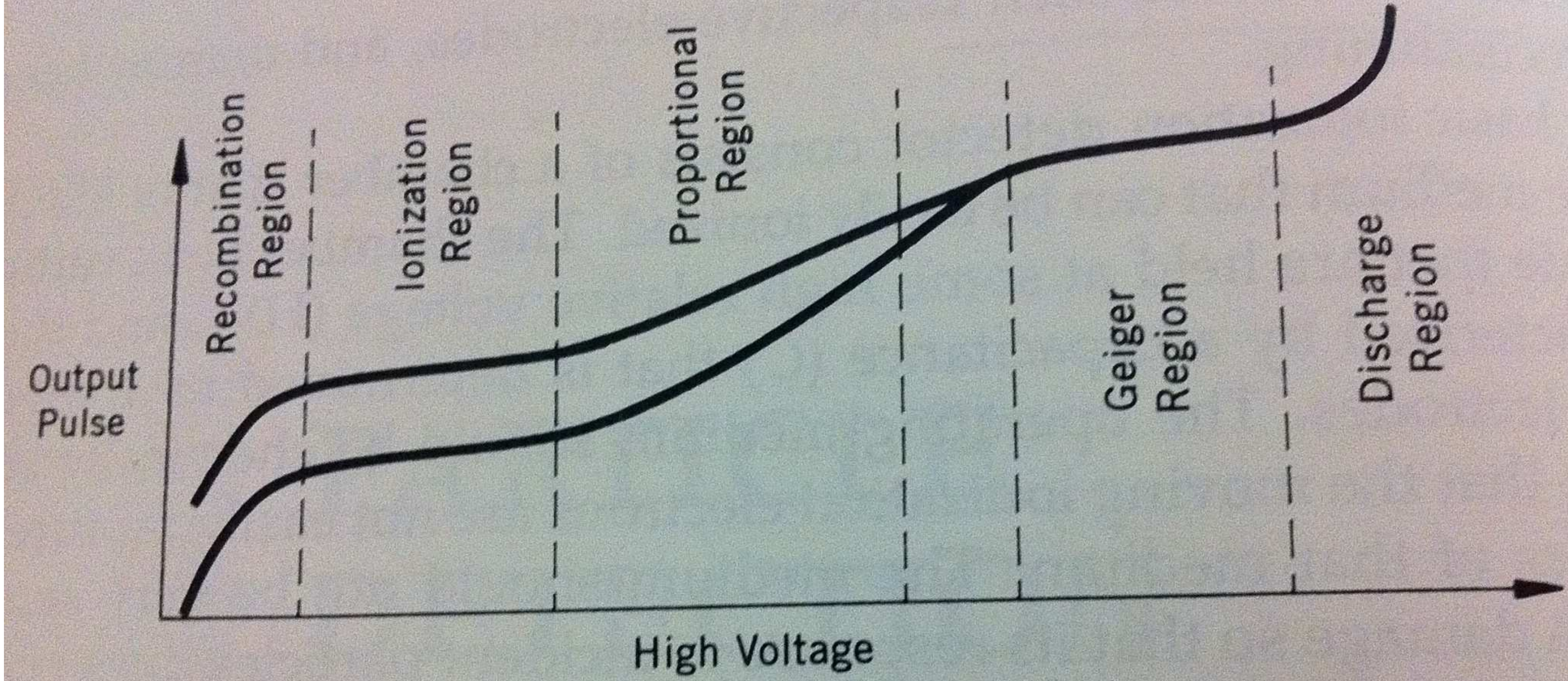


Figure 7.2 Signal response to ionization loss as a function of imposed voltage for heavily ionizing (top curve) and minimum ionizing particles (lower curve). In the Geiger region, the output does not depend on HV, nor on the amount of deposited energy or initially produced ionization.

Apparatus (Detector)

- B^{10} can capture slow neutron by reaction
  - $B^{10}(n,\alpha)\ Li^{7}$
- A paraffin form was used to slow down the fast neutron
  - 55mm thickness is found to be optimum condition
- Side view can maximized the counting
- For matching the target azimuthal symmetry, it was made like this:

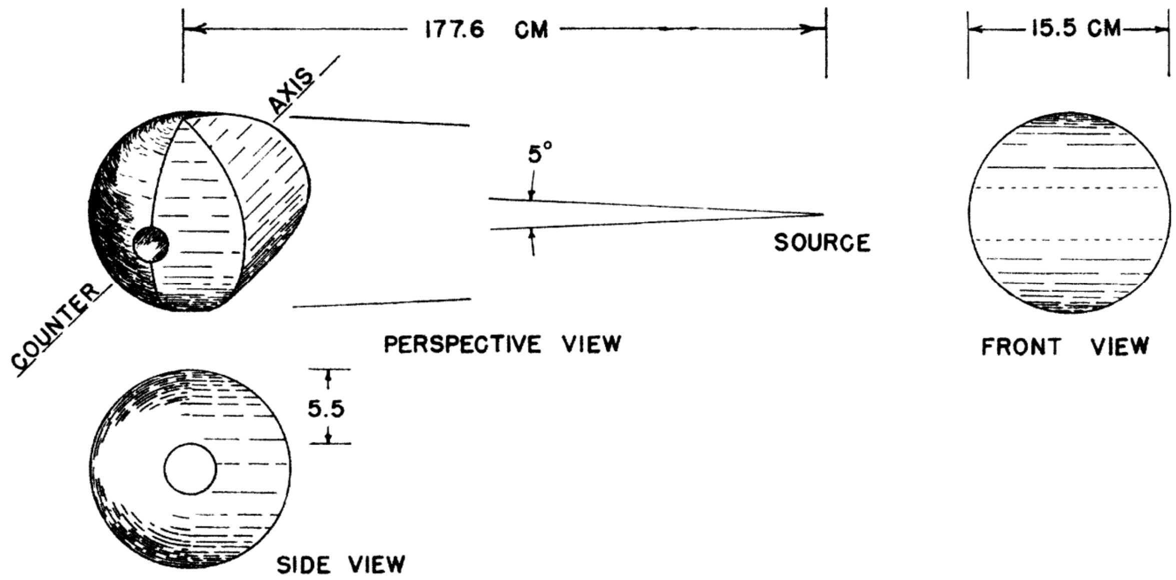
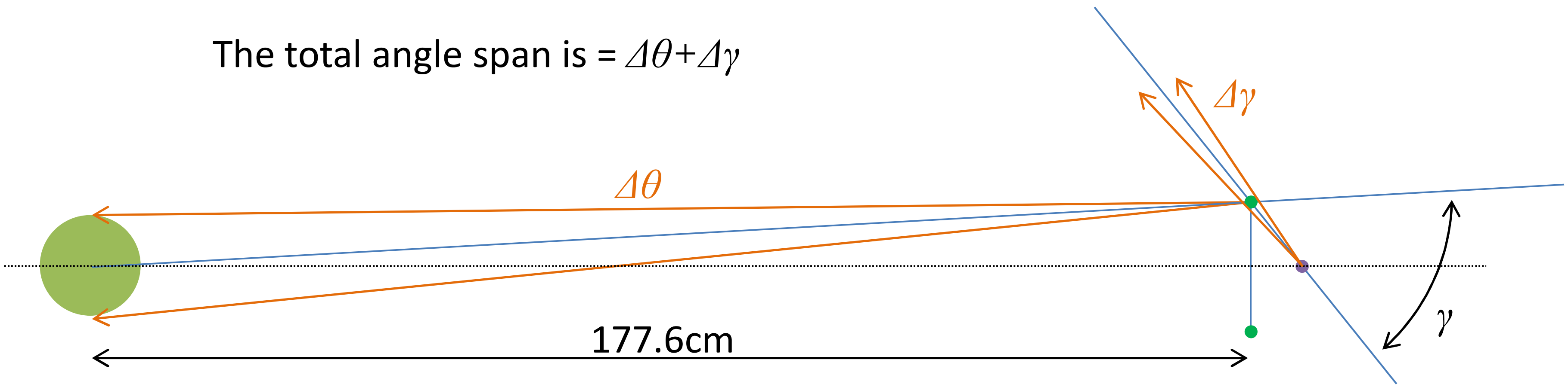


FIG. 1. Paraffin moderator.

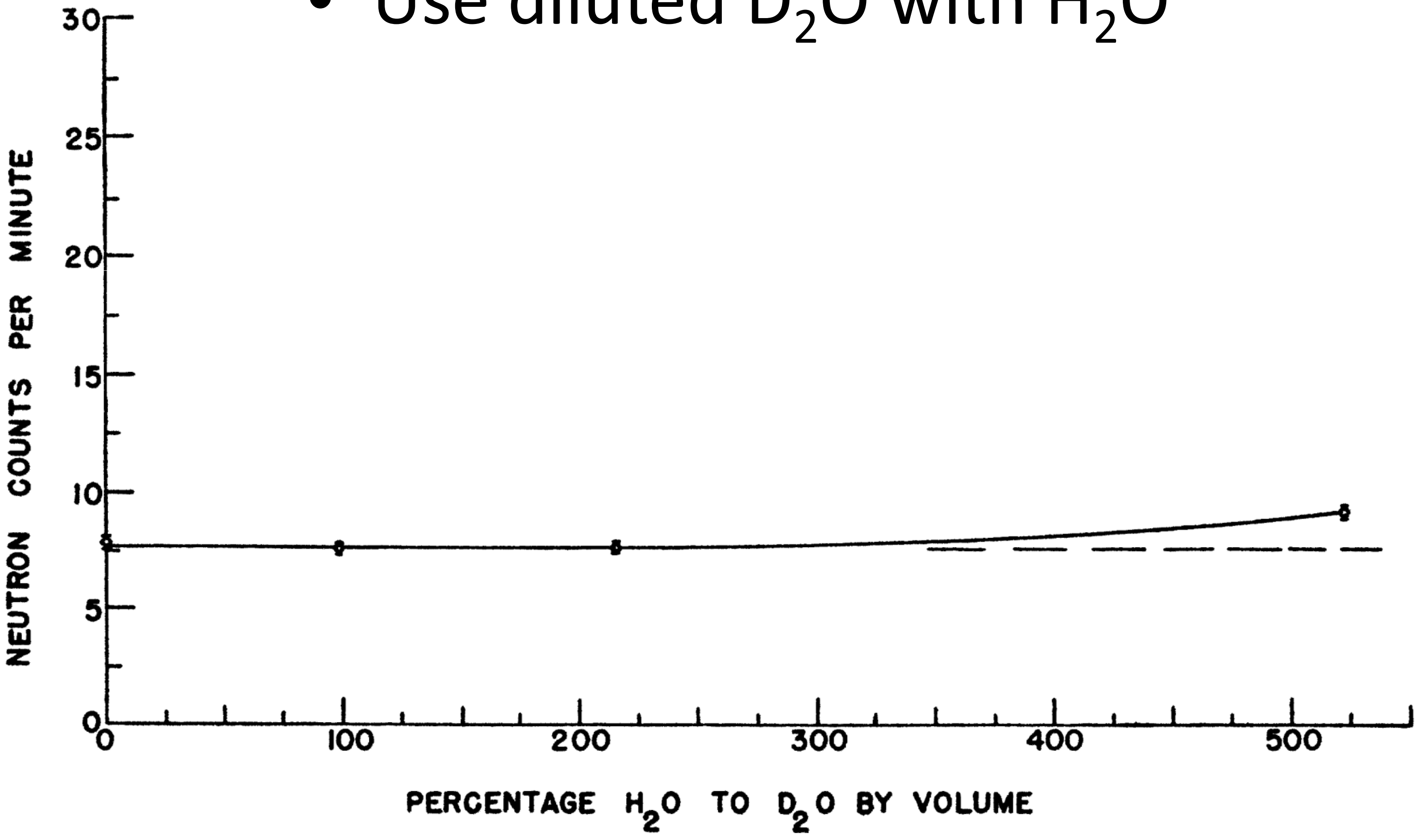
Apparatus (Whole system)

The total angle span is = $\Delta\theta + \Delta\gamma$



Precaution – Scattering by D_2O

- Use diluted D_2O with H_2O



Precaution – Scattering by Surrounding

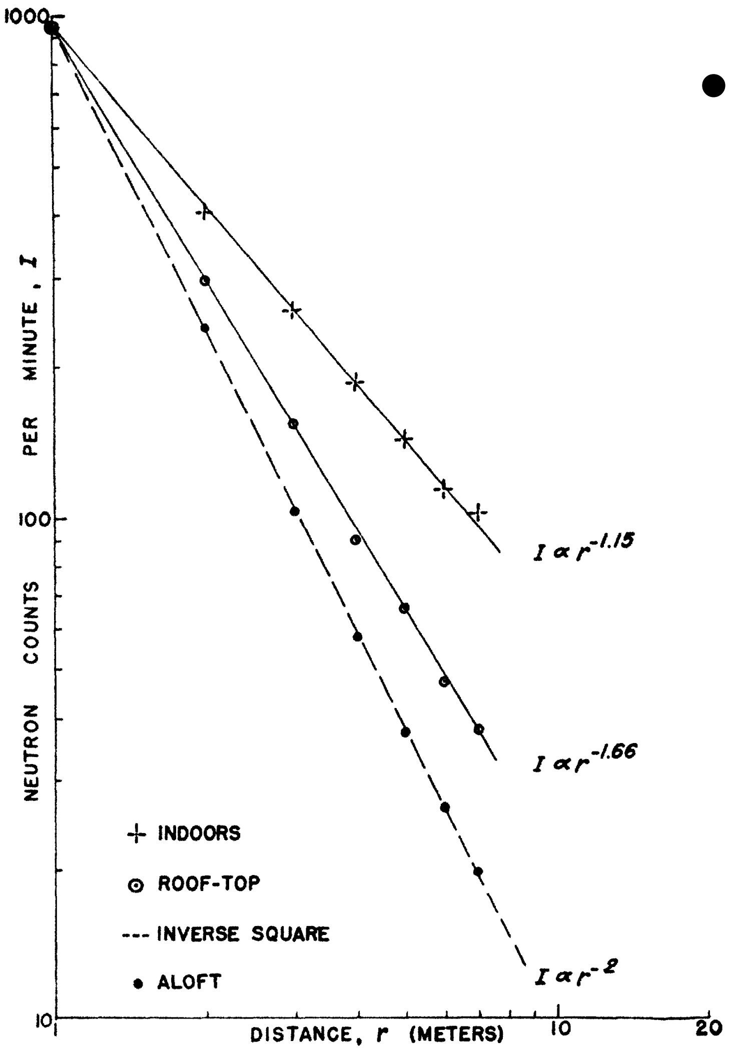
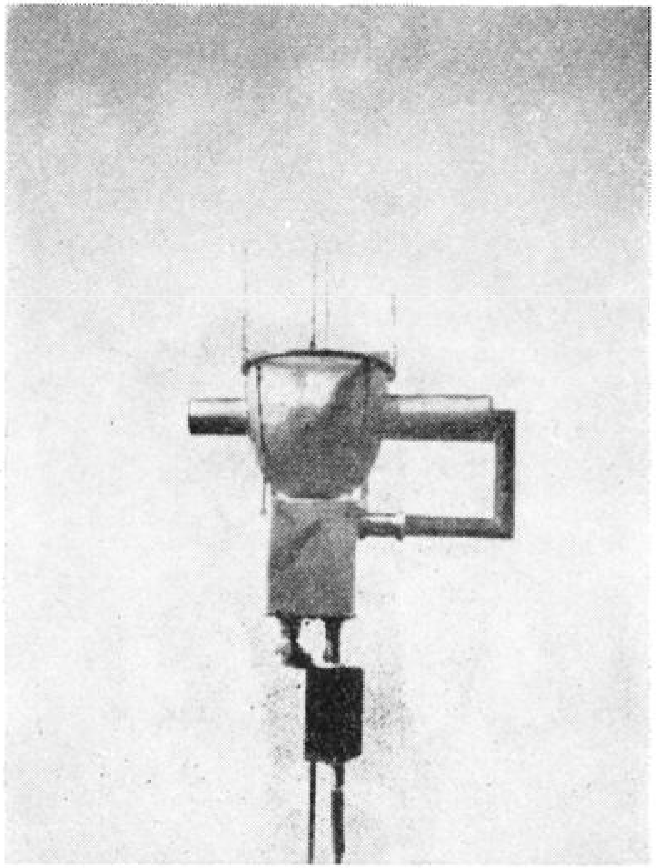


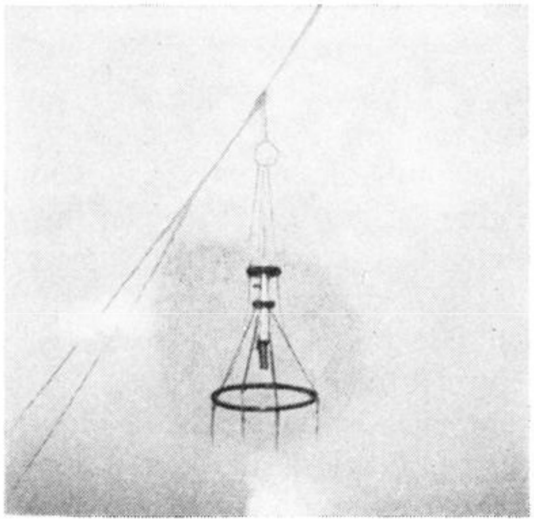
FIG. 5. Photo-neutron background.

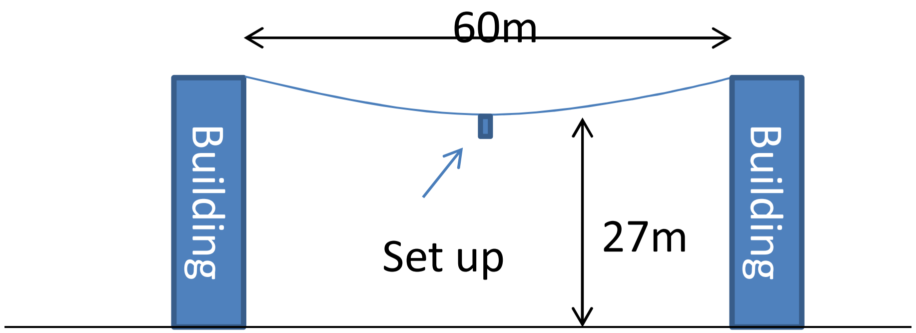
- Use the inverse-square law

Measurement

- The whole set-up was hanged in the middle of air.







Results & Conclusions

$$\bar{I}(\gamma) = \frac{\int_{\gamma_1}^{\gamma_2} (a + b\sin(\gamma))\sin(\gamma)\,d\gamma}{\int_{\gamma_1}^{\gamma_2} \sin(\gamma)\,d\gamma}$$

$$\bar{I}(\gamma) = a + b\left(1 + \frac{1}{3}(\cos^2(\gamma_1) + \cos(\gamma_1)\cos(\gamma_2) + \cos^2(\gamma_2))\right)$$

$$\frac{\sigma_m}{\sigma_{el}} = \tau = \frac{3}{2}\frac{a}{b} = 0.295 \pm 0.028$$

$$\sigma_m = a\int_o^{\pi} \sin(x)\,dx = 2a$$

$$\sigma_m = b\int_o^{\pi} \sin^3(x)\,dx = \frac{4}{3}b$$

a = # of neutron projected into unit solid angle at $\gamma = 90^o$ by •magnetic effect

b = # of neutron projected into unit solid angle at $\gamma = 90^o$ by •electric effect

Questions

1. What nuclear structure will be revealed by this cross section ratio?
2. How are conservation laws in these reaction?
   - What transition inside the Deuteron?

Deuteron (modern view)

- Deuteron was discovered on 1931 by Harold Urey at Columbia University.
- The ground state energy is 1876.13MeV
- The blinding energy is 2.22MeV
- It has no excited state
  - Partially due to small blinding energy
- By Parity consideration. ($j^{\pi} = 1^{+}$)
  - Total spin in 1 (Odd –Odd nucleus)
  - The L can only be 0 or 2, symmetric
  - The spin angular momentum S can only be 1

Nuclear Reaction $D(\gamma,n)p$

- *Conservation of energy*
  - The photon energy is just higher the blinding energy
  - neutron and proton has similar mass
  - neutron gains 27MeV, moving at 24 cms^{-1}
- *Conservation of momentum*
  - Same as cons. Of energy
- *Conservation of angular momentum and Parity*
  - The photon is spin 1
  - neutron and proton is spin ½
  - ^3S to ^3P transition will take place for photo-electric effect
  - ^3S to ^3S transition will take place for photo-magnetic effect

Nuclear Reaction $D(\gamma,n)p$

Not sure

<table>
<tr><th></th><th>D</th><th>γ</th><th>n</th><th>p</th></tr>
<tr><td>L</td><td>0 (S-state)</td><td>0</td><td>0</td><td>0</td></tr>
<tr><td>S</td><td>1</td><td>1</td><td>½</td><td>½</td></tr>
<tr><td>J</td><td colspan="2">0 , 2</td><td colspan="2">0, 1</td></tr>
<tr><td rowspan="2">Parity (electric)</td><td>+</td><td>(-)</td><td>+</td><td>+</td></tr>
<tr><td colspan="2">(-)</td><td colspan="2">+</td></tr>
<tr><td rowspan="2">Parity (magnetic)</td><td>+</td><td>(-)</td><td>+</td><td>+</td></tr>
<tr><td colspan="2">(-)</td><td colspan="2">+</td></tr>
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