A LIQUID HELIUM SCINTILLATION COUNTER FOR USE AS A NEUTRON POLARIMETER

BY

ABDEL-RAOF AWAD AHMED HELALY

B. Eng., B. Phys.

A THESIS

Submitted to the Faculty of
Graduate Studies in Partial Fulfillment
of the Requirements for the Degree of

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ABSTRACT

It has been our purpose, as part of our neutron polarization measurement programme, to build a liquid helium scintillation counter (hereafter referred to as liquid helium polarimeter) that would enable us to measure, by time-of-flight method, the polarization of neutrons of low energy. We have been concerned about improving the efficiency and precision of the scintillation detection. Details of construction and operation are described in this thesis.

Neutrons scattering from the liquid helium produce α-particles which generate scintillations as they are stopped in the helium. These scintillations are conveyed to the top of the polarimeter by a solid quartz light pipe which dips into the liquid helium.

For optimum energy resolution in a liquid helium scintillator, one needs a uniform pulse height response over the entire volume of the scintillator. This response depends on the uniformity of the wavelength shifter and the light collecting geometry. We have attempted to secure optimum resolution with such a counter, and have thus far obtained a resolution of 13% in liquid helium with ^{210}Po alpha source.

An outline of a method of measuring neutron polarization is given in chapter one. The scintillation mechanisms and detection system are also described in that chapter.

In chapter two, a full description of the polarimeter is given. The cryogenic and optical problems are considered and discussed.

In chapter three, the results of testing the polarimeter with an α-source using both liquid argon and liquid helium as scintillating targets are presented.

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CHAPTER 1

MAIN FEATURES OF NEUTRON POLARIMETRY

1.1 INTRODUCTION

For a deeper understanding of the interaction of nucleons with complex nuclei, it is extremely helpful to carry out experiments with beams of polarized particles. It is first useful to define what polarized particles are. The nucleons, as fermions have a spin S=1/2 which is connected with a magnetic moment M_l. In an external magnetic field, there exist two states, with quantum numbers $S_z = \pm 1/2$, respectively, referring to the spin axis pointing parallel or anti-parallel to the field direction. We speak of a fully polarized beam when all of its particles are in only one of these states. If we have a mixture, we define the degree of polarization by the equation:

$$P = \frac{N+ - N_-}{N+ + N_-} \qquad 1\text{-}1$$

where N_+ and N_- specify the fractions of particles in the two states. Fig. 1-1 shows a simple representation of polarization states of an assembly of spin-1/2 particles, by the familiar pictures of N_+ spin-up nucleons and N_- spin-down nucleons (Darden, 1967). Three parameters are required for the specification of the most general state. Two of these are two angles required to specify a reference spin direction, while the third gives the relative numbers of particles, N_+/N_-, in the two pure states. Since this kind of polarization is characterized by a direction and a magnitude, it is really a vector quantity and is referred to as vector polarization. It is, in fact, just the average value of the particle spin, where the average is taken over all of the particles in the beam.

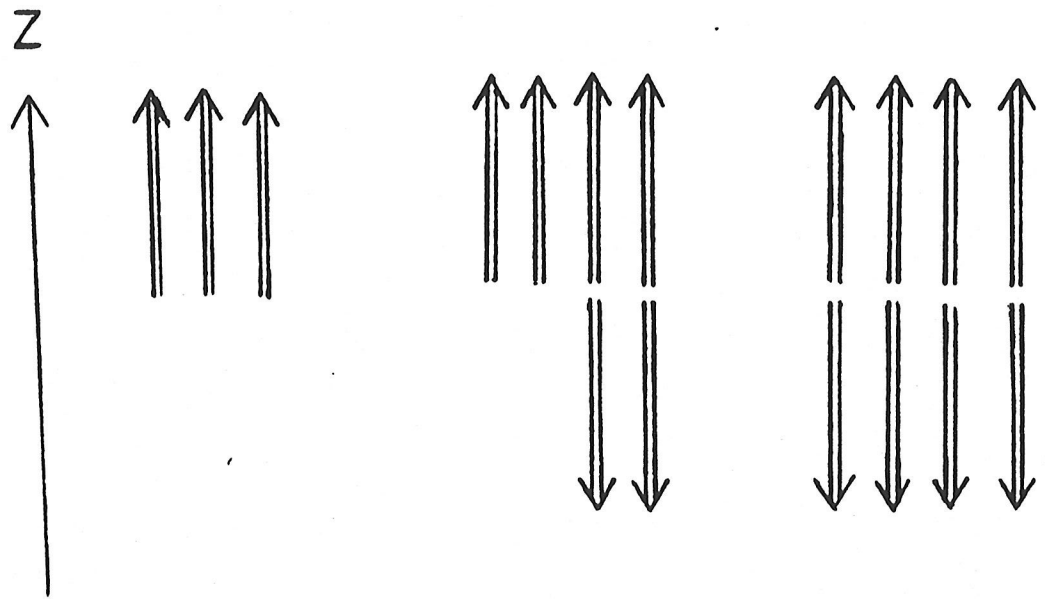


Fig. 1-1 Simple representation of polarization states of an assembly of spin-1/2 particles.

a) Completely polarized system

b) Partially polarized system

c) Unpolarized system

According to the Madison convention (Barschall and Haeberli, 1970), the polarization of beams of particles should be referred to a right-handed coordinate system in which the positive z-axis is along the direction of momentum of particles and the positive y-axis is along $\vec{K}_{in} \times \vec{K}_{out}$ for the nuclear reaction which the polarized particles initiate, or from which they are emerging. In the latter case, it should be explicitly stated whether $\vec{K}_{out}$ is in the c.m. or lab. system. Fig. 1-2 shows a recommended system normally used to describe the polarization of the incident beam.

A schematic arrangement for the measurement of neutron polarization is shown in Fig. 1-3. The unpolarized proton beam is incident on a target and partially polarized neutrons from the reaction are observed at an angle Θ. Two neutron detectors, R and L, are located symmetrically to the right and left of a helium cryostat. The neutrons are allowed to fall on the scatterer and the numbers of neutrons scattered from it and registered in detectors R and L are recorded. If $L(\phi)$ and $R(\phi)$ are the numbers of neutrons scattered to the left and right of the beam, then the asymmetry of the scattering is defined as:

$$\varepsilon = \frac{L(\phi) - R(\phi)}{L(\phi) + R(\phi)} \qquad 1\text{-}2$$

The factor relating this asymmetry to the initial beam polarization, P, is known as the analysing power of the scatterer, $A(\phi)$, and is given by (Lam et al., 1968):

$$\varepsilon = A(\phi) \cdot P \qquad 1\text{-}3$$

ε is the experimentally measured quantity. In practice, systematic errors are present in the measurement of ε, in particular, the left

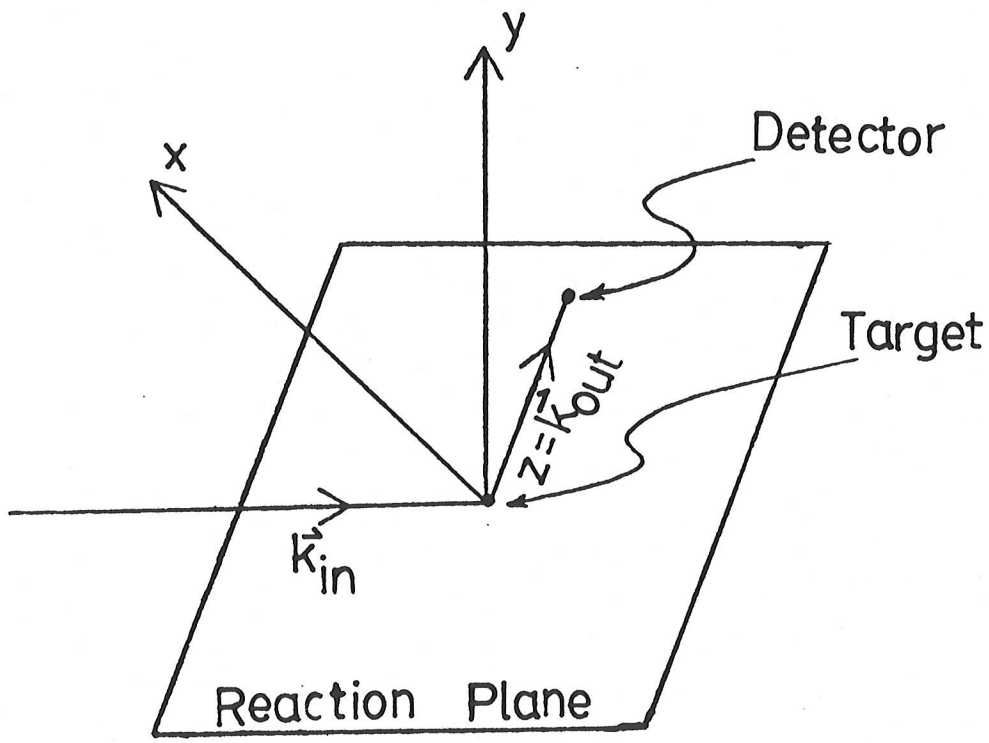


Fig. 1-2 A coordinate system recommended by the Madison Convention. This system is normally used to describe the polarization. Arrows denote vectors.

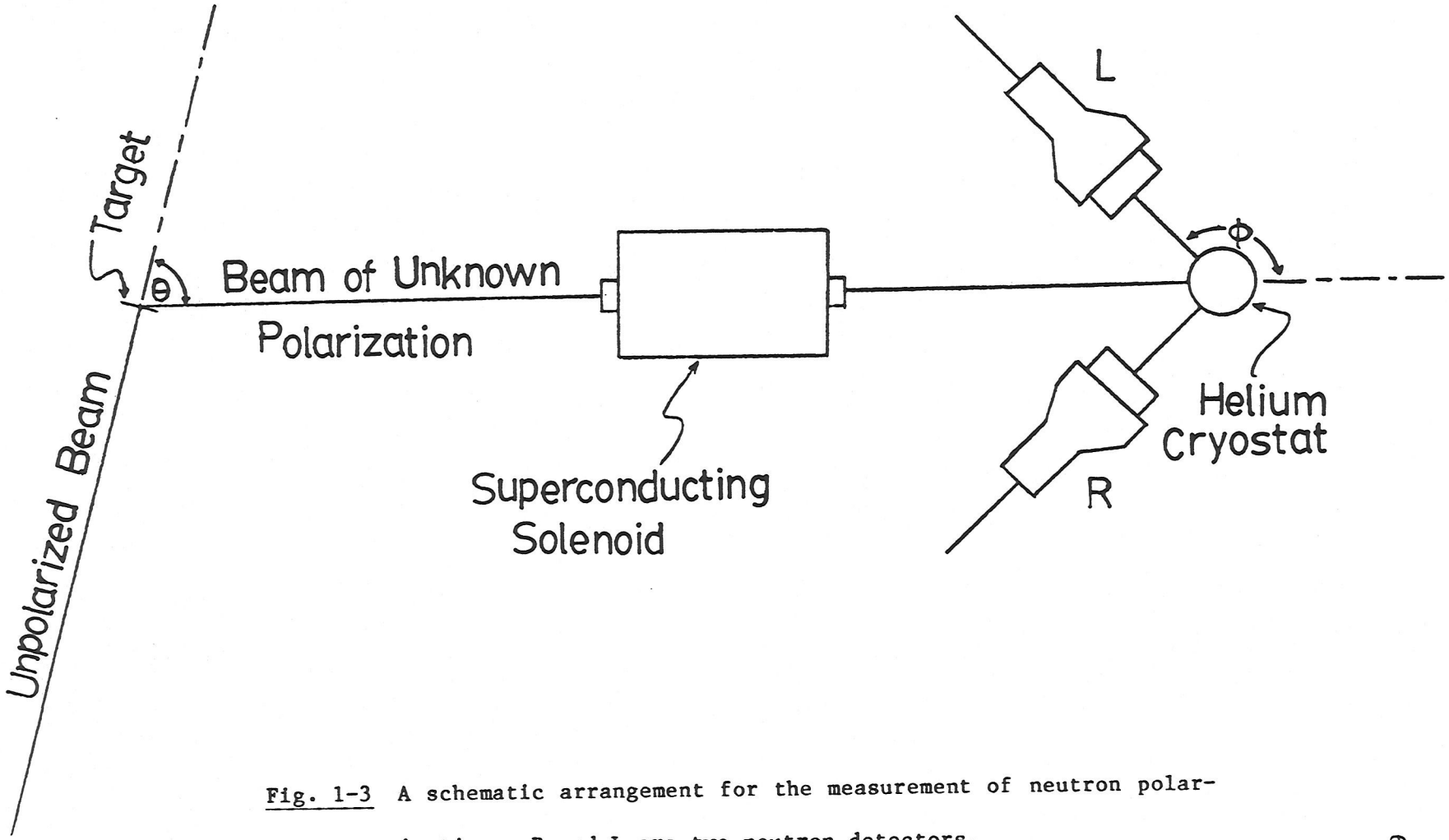


Fig. 1-3 A schematic arrangement for the measurement of neutron polarization. R and L are two neutron detectors.

and right detectors may have different efficiencies for detecting neutrons scattered from the helium cryostat. In order to minimize these errors, a superconducting solenoid is located between the neutron source and the polarimeter. The field produced by the solenoid is parallel to the direction of propagation of the neutrons and precesses the spin of the incident neutrons through 180°, thereby interchanging the roles of the L and R detectors by reversing the sign of P in equation 1-3. Then, if $L'(\phi)$, $R'(\phi)$ are the count rates in the left and right detectors when the neutron spins are precessed through 180°, the scattering asymmetry corrected for first order errors is:

$$\varepsilon = \frac{r - 1}{r + 1} \qquad 1\text{-}4$$

where

$$r = \left[\frac{L(\phi)}{R(\phi)} \cdot \frac{R'(\phi)}{L'(\phi)}\right]^{1/2} \qquad 1\text{-}5$$

If P is to be accurately determined, $A(\phi)$ must satisfy certain conditions. The main conditions are that it should be as large as possible over a reasonable angular range and that it should not change too rapidly with either the energy of the incident neutron or the scattering angle . A further condition is that the scatterer chosen should have a reasonable cross-section for scattering at the angles of highest polarization so that a statistically accurate measurement of the polarization may rapidly be obtained.

When measuring polarization by this method, the only signals of interest in the right and left detectors are those resulting from neutrons actually scattered from the analyser (scatterer). In practice,

the number of neutrons arriving at the side detectors directly from the neutron source may exceed, by an order of magnitude, the number actually scattered from the analyser into the side detectors. If the analyser scintillates, this provides a means of separating the pulses representing legitimate scatterings from the undesired background. Not only does the scintillation accurately fix the time of a scattering event, but the intensity of the scintillation depends on the energy of the recoil nucleus and hence on the energy of the neutron and the angle through which it was scattered. By viewing the scintillations with a photomultiplier it is thus possible to electronically reject those detector pulses not appearing in the correct time interval following a scattering, or not corresponding to a scattering through the known detector angle. This technique of using the recoiling particle to reduce background is called the "associated particle method" and is particularly important in fast neutron work where shielding is very expensive and not completely effective.

Reports of several scintillation counters using liquified noble gases, particularly helium, as a scintillant have appeared since 1959; (Simmons and Perkins, 1961); (Benenson et al., 1965); (Piffaretti et al, 1965); (Miller, 1966); (Lam et al., 1968); (Birchall et al., 1969).

The usefulness of liquid helium as the polarizer-analyzer in the measurement of neutron polarization is well established (Baicker et al, 1960); (Simmons et al., 1961); (Epstein et al., 1964). Its analyzing power is high and well known and varies reasonably smoothly with energy and its scintillation properties allow it to be used as a liquid scintillator. The increased density ($0.125 g/cm^3$) obtained in using liquid

helium relative to gaseous helium offers distinct advantages in time-of-flight experiments where the average current is usually low due to beam pulsing and where the neutron flight path has been increased to obtain higher energy resolution. Also, it offers large benefits from increased counting rates, especially at higher energies where cross-sections are decreasing.

Unfortunately, helium liquifies at 4.2K and boils off very easily. For this reason it was decided to redesign an existing liquid polarimeter (Birchall et al., 1968, 1971) to lower the boil-off rate. The main features of the new modifications were suggested by Videla (1984).

It was also decided to make tests on liquid argon in the new polarimeter. The resolution of argon as compared with that obtained from liquid helium is of interest, as it may be possible to use liquid argon as a substitute for liquid helium on some occasions.

A full description of the new liquid polarimeter is given in greater detail in Chapter 2.

1.2 SCINTILLATION MECHANISMS

Because the mechanism for the production of scintillations is complicated, most information concerning gas or liquid scintillations is empirical.

The scintillation of inert gases excited by alpha particle impact has been interpreted in terms of electron-ion recombination by Northrop and Gursky (1958) and by Esterling and Lipman (1965). On the other hand, Ward (1954) showed that the recombination of ions played no appreciable part in the production of the photons in the range 300-400 nm.

L. Colli (1954) suggested the following mechanism to explain the luminescence emission in the case of argon:-
the metastable atom (A^m) produces, by three-body collisions, an excited argon molecule A_2^* according to:

$$A^m + A + A \longrightarrow A_2^* + A \qquad 1\text{-}6$$

where A denotes a ground state atom. A three-body collision accounts for the conservation of momentum and energy. An UV photon is emitted in the transition fom the excited molecular state of argon to the ground state:

$$A_2^* \longrightarrow A + A + h\nu \qquad 1\text{-}7$$

The emission intensity (I) plotted versus time was experimentally found to be well represented by the formula:

$$I = c \left(\exp\left[-\frac{t}{\tau_A} \right] - \exp\left[-\frac{t}{\tau_M} \right] \right) \qquad 1\text{-}8$$

where τ_A is the time constant for the formation of the molecule A_2^* and τ_M is the life time of the molecular state, which is an important

property of the scintillator from the view-point of suitability as a nuclear radiation detector.

In the case of helium, the excitation of helium atoms can take place by alpha particle impact. In this collision process, the energy of the alpha particle can be transferred to one of the helium atoms, resulting in the formation of a metastable atom (He^m). The scintillation of helium can then be explained by de-excitation of the excited molecule formed by a three-body collision of a metastable atom with two ground state atoms according to (T. Takahashi, 1966):

$$He^m + He + He \longrightarrow He_2^* + He \qquad 1\text{-}9$$

$$He_2^* + He \longrightarrow 3He + h\nu \qquad 1\text{-}10$$

where He^m and He_2^* denote the metastable atom and the excited molecule.

1.3 PHYSICAL PROCESSES INVOLVED IN SCINTILLATION COUNTING

We can somewhat arbitrarily break down the process of scintillation counting into three main parts:

(1) The kinetic energy of the radiation incident upon the luminescent material must be converted as efficiently as possible into energy of excitation and ionization of the atoms or molecules of the scintillator.

(2) The de-ionization and de-excitation of the molecules should result in the emission of fluorescent radiation and this radiation should be transmitted as freely as possible through the luminescent material. The radiation should be of such wavelengths as to match well with the known spectral characteristic curve of the photomultiplier.

(3) Assuming the spectral distribution of the fluorescent radiation matches the spectral sensitivity curve of the tube, so that the maximum emission of photo-electrons is secured, these photo-electrons in turn must be efficiently collected and directed on to the first dynode. Finally the multiplication of these in number should be as high as is consistent with stable and uniform performance of the photomultiplier itself.

The ability of a scintillation counter to indicate the energy of the incident nuclear particle rests on the fact that, for a given type of nuclear particle, the number of optical photons produced is proportional, or nearly proportional, to the energy of the particle and that the size of the output pulse from the multiplier is proportional to the number of photons which strike the photocathode. Energy spectrometry

can, therefore, be carried out simply by measuring the height of the output pulses from the scintillation counter.

The pulse of charge q arriving at the anode of the photomultiplier tube due to the stopping of a charged particle of kinetic energy E in the scintillator, can be quantified as: (Smith, 1965; Curran, 1953)

$$q = \left(\frac{EK}{W}\right) (TG)\ SFMe \qquad 1\text{-}11$$

Where K is the conversion efficiency of the scintillator.

W; the mean photon energy of the luminescent radiation.

$\left(\frac{EK}{W}\right)$; the mean number of photons of the luminescent radiation produced in the scintillator.

T; the transparency factor of both the scintillating medium and the light pipe.

G; the geometrical factor of the light collection system.

(TG); the fraction of photons which reach the cathode of the photo-multiplier.

S; the fraction of photons reaching the cathode which eject electrons into the space between the cathode and the first dynode.

F; the fraction of the photo-electrons reaching the first dynode.

M; the gain of the tube.

e; the electron charge.

Fig. 1-4 is a schematic diagram of a scintillation counter.

Hence, the pulse of electrons arriving at the anode charges the capacitance C between anode and earth to a potential difference:

$$V = q/C \qquad 1\text{-}12$$

The charge then leaks away through the anode load resistance R at an exponential rate determined by the time constant RC.

It is obvious that a large pulse corresponding to each incident particle can be observed easily and its amplitude is proportional to the energy of the incident particles (provided the current pulse in the photomultiplier is not so large that the potentials applied to the dynodes change. This "saturation" is avoided by limiting the gain of the photomultiplier).

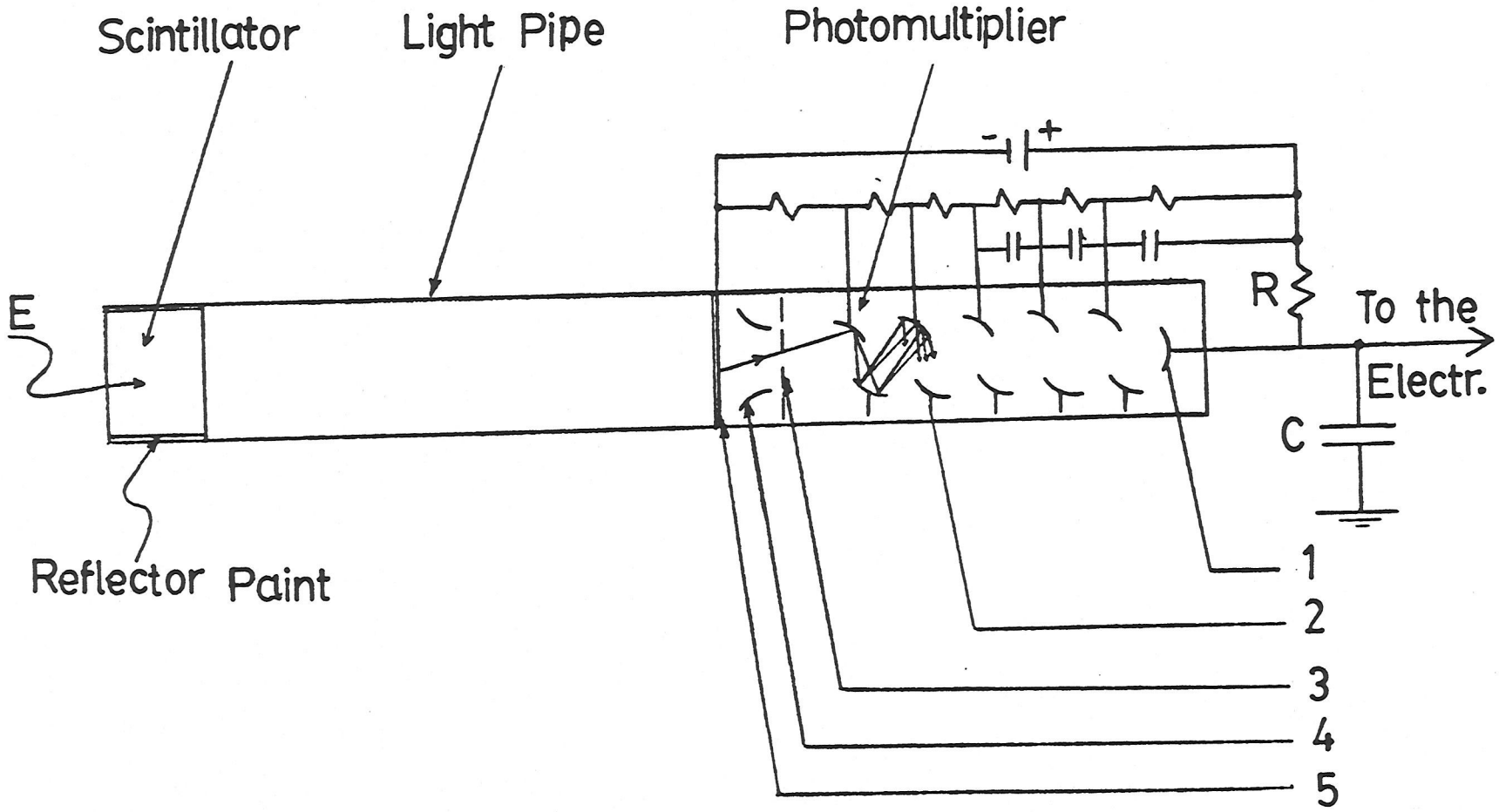


Fig. 1-4 A schematic diagram of a scintillation counter.

1 - anode, 2 - fourth dynode, 3 - acceleration electrode, 4 - focussing electrodes, 5 - photocathode

CHAPTER 2

THE POLARIMETER

2.1 INTRODUCTION

In building a liquid helium polarimeter, one has to take the following considerations into account:

(a) The cryostat should maintain an adequate level of liquid scintillator to allow several hours of continuous running. This is desirable, not only from the economic point of view, but also because the low count rates in neutron experiments imply long running periods.

(b) A compromise has to be made between maximizing neutron detection efficiency (by increasing the size of the scintillation volume) and decreasing the volume so as to minimize the spread in time of travel of light from the scintillation point to the photomultiplier. In addition, some care has to be taken to keep to a minimum the amount of material surrounding the liquid scintillator cell, so that there is a relatively low probability of scattering before the neutron reaches the scintillator.

(c) The scintillation light should be collected in the most efficient manner. This is by far the most important problem to be faced and it is treated in detail in Section (2.3).

2.2 DESIGN CONSIDERATIONS

In the original version of the polarimeter (Birchall, 1969), the main sources of heat-leak were:

(a) conduction down the light-pipe.

(b) conduction down the cylinder around the light-pipe.

(c) conduction down the filling/boil-off tubes.

(d) radiation.

These sources have been reduced considerably in the present design by:

(a) Doubling the length of the light-pipe (76.2 cm).

(b) Placing a liquid nitrogen thermal clamp 10 cm from the top of the light-pipe to assure a low temperature gradient below the clamp. Fig. 2-1 shows a view of the thermal clamp as depicted by Videla (1984). This thermal clamp is a cooled helium gas clamp covering a 2.54 cm long section of the light-pipe. The distance between the light-pipe and the supporting stainless steel tube is 0.5 mm.

(c) Making the helium filling/boil-off tubes longer (80.7 cm). Also, reducing the number of those tubes from three to two.

(d) Wrapping a blanket of superinsulation (12 layers) around the cryostat and the scintillation volume.

A cross-section of the polarimeter is shown in Fig. 2-2. The scintillating liquid is located in a brass isoangular volume (0.485 litres) and in a reservoir located above the scintillation volume. The total capacity is about 1.4 litres.

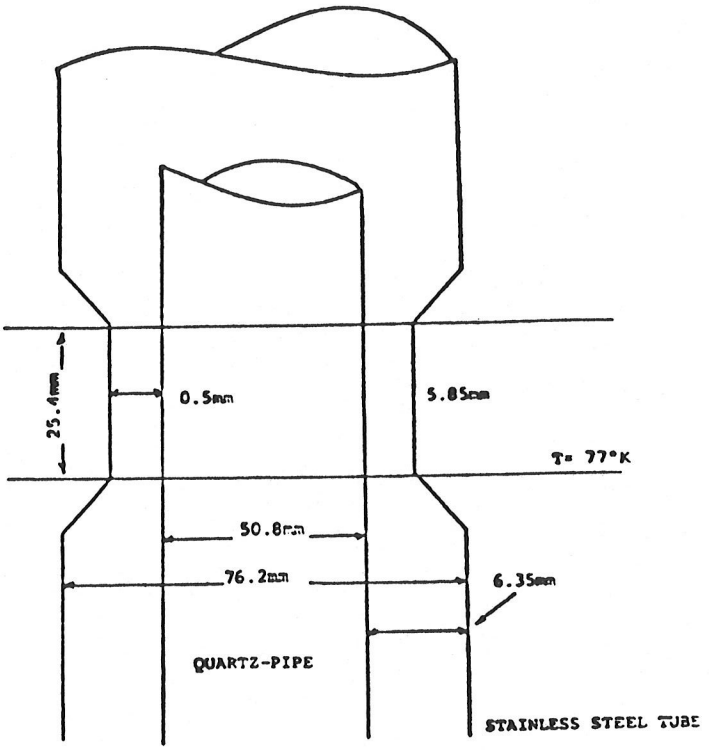


Fig. 2-1 A view of the thermal clamp used in the liquid polarimeter.

Fig. 2-2 A cross-section of the polarimeter;

1 - quartz pipe

2 - copper heat shields

3 - isoangular scintillation volume

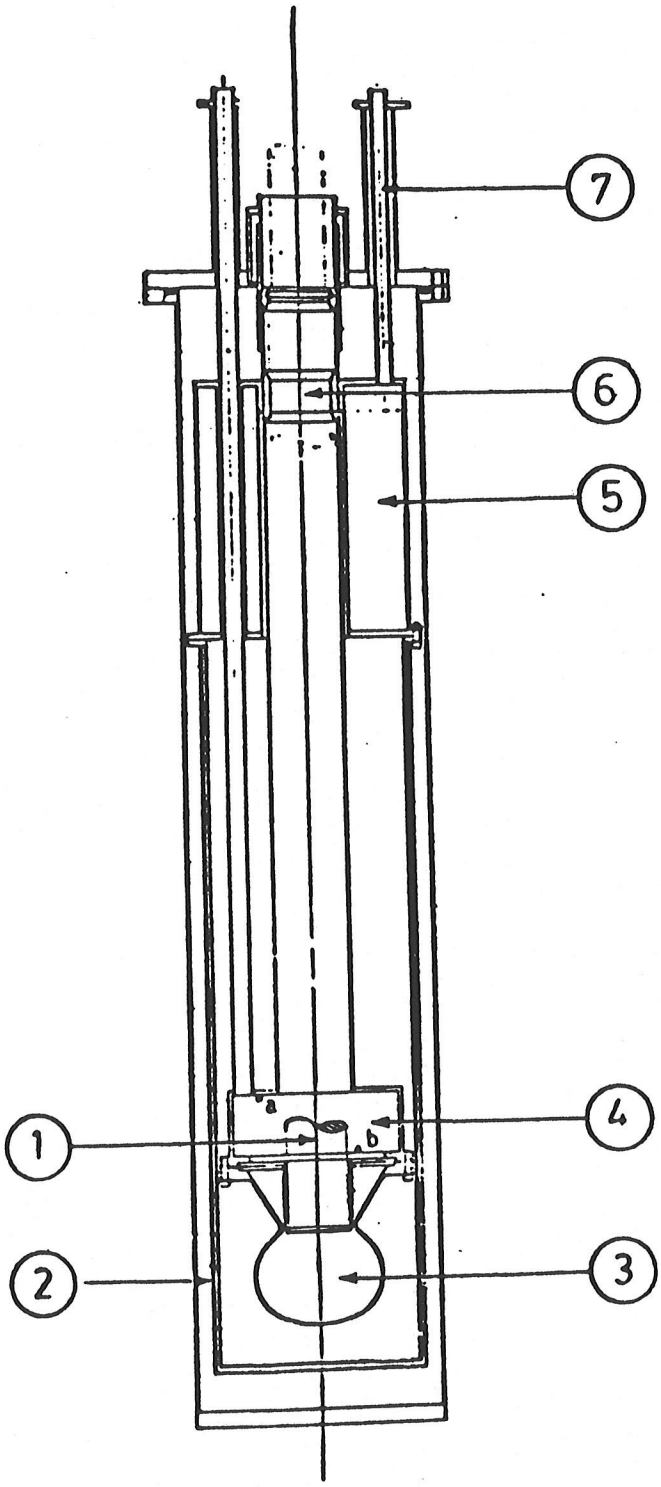
4 - helium reservoir

5 - nitrogen reservoir

6 - thermal clamp

7 - filling and boil-off tubes

a, b are two carbon resistors


7
6
5
4
1
2
3
a
b

The boil-off can be minimized by ensuring that the space surrounding the scintillation volume is maintained at a vacuum of approximately 10^{-5} pascal. The scintillation volume is also surrounded by copper radiation shields maintained at liquid nitrogen temperature (77K) to decrease thermal radiation influx to the liquid reservoir. The temperature of the upper end of the helium filling/boil-off tubes should then be lowered considerably. Also, the tubes are 1.6 cm in diameter in order to avoid the high boil-off produced by thermal oscillations. This name is given to the periodic movement of helium gas in a narrow tube having a high longitudinal temperature gradient (Hoare, Jackson and Kurti, 1961). The undesirability of this effect has been demonstrated by Wexler (1951) who showed that thermal oscillations can increase the boil-off rate of a helium storage dewar by a factor of 1,000.

Two carbon resistors, marked (a) and (b) and shown in Fig. 2-2, are used to measure the temperature. One of these (a) is located almost at the top of the liquid scintillation reservoir, and the other (b) on the bottom of the reservoir. When these two resistors are immersed in liquid helium the resistance increases from 100Ω and 300Ω to about 1K and 3K respectively. The change in the value of the resistance provides information about the liquid level and acts as a level indicator rather than as a temperature gauge.

A narrow rod passes through a rubber "O" ring in the top flange of the cryostat and into the helium reservoir. On the end of the rod is fitted a ^{210}Po alpha source. The source can be positioned below the light guide or be moved away from the guide, allowing us to measure the response of the scintillation volume as a function of the alpha source position.

2.3 THE OPTICAL SYSTEM

The optical system consists of the following:

(1) a light-guide and, optically coupled to it, a photomultiplier.

(2) the scintillation volume (see Fig. 2-2).

(3) a film of wavelength shifter evaporated in vacuum on the inside of the scintillation volume, or onto the end of the light-guide, or both.

In order to make the polarimeter optical system more efficient, two requirements were to be met:

(a) maximum light collection.

(b) optimization of the energy resolution of the scintillator.

2.3.1 The light guide:

We tried to fulfill condition (a) by the use of the cylindrical light-pipe (76.2 cm long). Its refractive index is such that any rays entering the pipe can be totally reflected at the wall of the cylinder. The transmission coefficient of the light-guide depends on:

(1) the smoothness and cleanness of the walls.

(2) reflection of light at the ends.

(3) absorption of light by the material of the light-guide.

It is therefore important to keep the light-guide clean, and to ensure efficient optical coupling to the photomultiplier.

Since the wavelength of the helium scintillation light is in the range 80-160 nm, which is below the cut-off of a conventional photomultiplier detection system (200-300 nm), a wavelength shifter, such as p, p'diphenylstilbene (hereafter referred to as DPS) brings the wavelength

of the scintillation light from the far ultraviolet to the ultraviolet region (200-400 nm). The material of the light pipe must therefore be chosen with care. The most suitable materials are quartz and acrylics (hereafter referred to as perspex). Despite its very much greater cost, quartz is superior in all respects for the wavelengths involved. Quartz transmits wavelengths down to 200 nm whereas the corresponding figure for perspex is of the order of 300 nm. According to the above argument, one can see that quartz is better suited to the spectral distribution of the DPS emission.

The main factor involved in choosing the length of the light-pipe is the maximum temperature gradient which can be maintained along it, without unduly cooling the photo-cathode of the photomultiplier or allowing helium to boil off at an unreasonable rate.

The usual arrangement for liquid helium polarimeters is to have the photomultiplier and the light-pipe situated below the scintillation volume, to facilitate refilling operations. This method has the advantage that the light-pipe can be made shorter, because it does not pass through the liquid helium reservoir above the scintillation volume. Nevertheless, it has the major disadvantage that the scintillations must be transmitted through a window between the scintillation volume and the light-pipe. Since the optical coupling at liquid helium temperatures is poor, this results in a considerable loss in efficiency.

We have no such problem in our case, because the photomultiplier and the light-guide are located above the scintillation volume.

2.3.2 The scintillation volume:

If the reflector paint on the inner wall of the scintillation volume were 100% reflecting and if self absorption in the liquid scintillator were zero the shape of the scintillation volume would not matter as all the light would reach the light-pipe eventually regardless of the position of the scintillation. In practice, however, this is not true and the pulse height is least dependent on position when the shape of the scintillation volume is such that the circular end of the light-pipe subtends the same solid angle at every point on the reflector. We have therefore attempted to meet requirement (b), mentioned at the beginning of section (2-3), by giving the scintillation volume a so-called iso-angular shape (Ramsay, 1980) so that any point of the wavelength shifter (100 ug/cm^2 thick) deposited on the wall of the volume sees the exit window with the same solid angle.

If the distance from the point to the exit window is very large compared to the diameter of the window, then the obliquely viewed circular window can be approximated by a normally viewed ellipse. The solid angle is then calculated as the area of the ellipse divided by the square of the distance. The solid angle given by this "elliptical approximation", at a point P on the inside wall of the scintillation volume, as shown by Birchall (1969) is:

$$\Omega_p = \pi a^2 h(b^2+h^2)^{1/2} \Big/ (b^2+h^2-ab)^2 \qquad 2\text{-}1$$

where, is the radius of the light-pipe

h; the vertical distance of the point P from the end of the light-pipe

b; the horizontal distance of the point P from the axis of the light-pipe.

Fig. 2-3 shows an angle subtended by a point on the scintillation volume at the end of the light-pipe. Using the idea of Gardner and Carnesale (1969), Ramsay (1980) calculated the radius (a) as a function of height (h) such that a circular window of unit radius subtends a constant solid angle of 0.322 sr. Fig. 2-4 shows a 3" diameter scintillation volume and a 2" diameter light-guide.

A thin layer of DPS (30 ug/cm^2 thick) is added to the light pipe end. It is transparent to the light emitted from the DPS on the wall, but still intercepts the primary scintillation light from the bulk of the scintillation volume.

2.3.3 Wavelength shifters:

A wavelength shifter is a fluorescent material which absorbs and re-emits the luminescent radiation at a longer wavelength. This emission spectrum may be in a region more appropriate to the spectral response curve of the photomultiplier cathode.

A good fluorescent converter should have:

(1) a good photofluorescence quantum efficiency which is independent of the wavelength of ultraviolet excitation.

(2) a fluorescence emission spectrum which is a good match to the photomultiplier response.

(3) a thickness ($\sim$ 30 ug/cm^2) which is adequate to absorb completely the ultraviolet radiation, and yet is transparent to its own fluorescence emission.

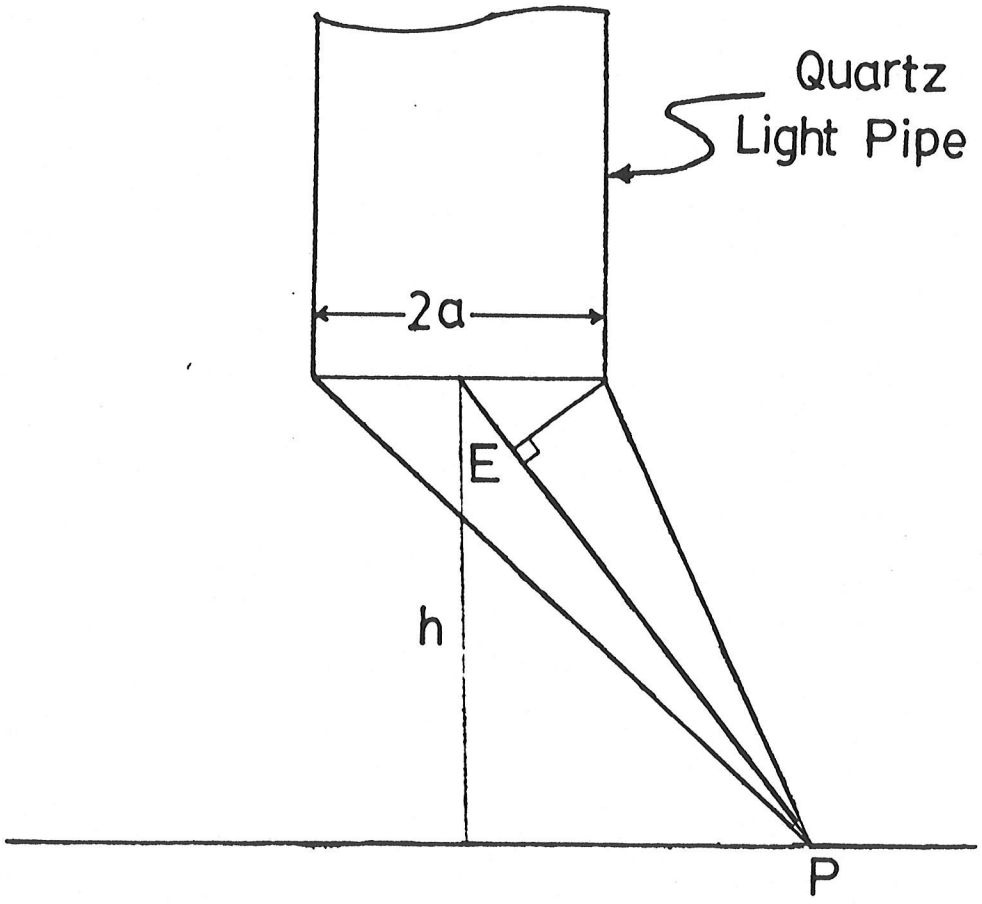


Fig. 2-3 An angle subtended by point on isoangular volume at end of quartz light-pipe. (See notation for Eq. 2-1)

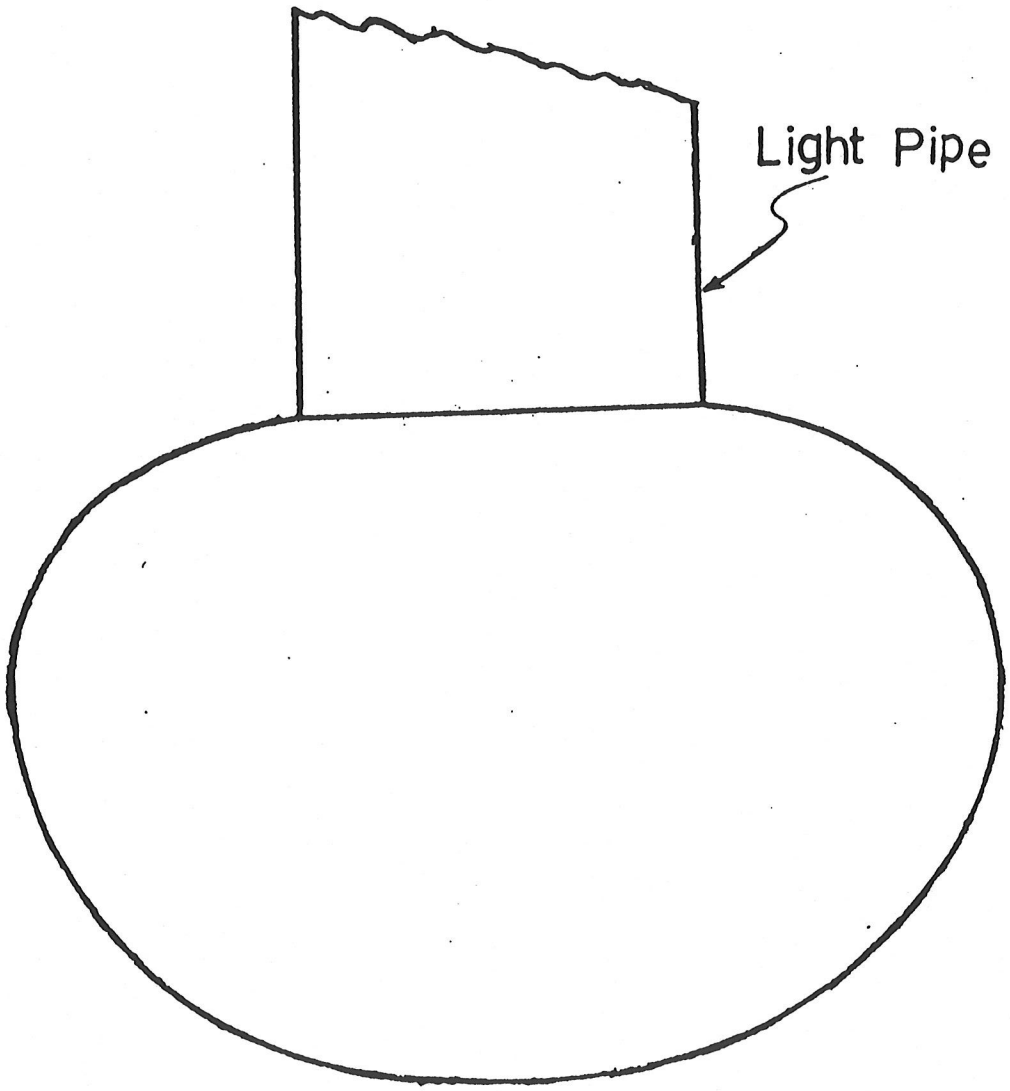


Fig. 2-4 Isoangular shape of scintillation volume.

(4) a fast fluorescence decay time, to avoid an undue increase in the time response of the instrument.

Tetraphenylbutadiene (TPB) in polystrene (Eggler and Huddleston, 1956), sodium salicylate (Forte, 1956, T. Takahashi et al, 1966), P-quaterphenyl (Sayres and Wu, 1957) and diphenylstilbene (Northrop et al, 1958) are among the materials used for this purpose.

The converter can be deposited in a thin layer on the walls of the scintillation volume or on the end of the light-guide, either by evaporation from solution or by vacuum evaporation.

2.4 SUMMARY

Plate 1 is a general view of the polarimeter. The polarimeter can be completely dismantled to investigate suspect joints which may arise. The diffusion pump is bolted onto the bottom of the stainless steel cylinder (the outer case of the polarimeter) shown in the photograph. The roughing pump is also shown in that plate.

The top flange is shown in greater detail in Plate 2. The tubes entering the cryostat are for filling and boil-off. Those tubes pass through channels in the nitrogen reservoir. At the centre of the flange is seen the photomultiplier tube which is optically coupled to the top end of the quartz light-pipe. The light-pipe is supported at the lower end in a cradle which is bolted onto the helium reservoir. Also, the scintillation volume is bolted onto the helium reservoir and an indium wire provides a helium-vacuum seal.

The helium reservoir and the scintillation volume are surrounded by a double-wall copper heat radiation shield which is attached to the lower end of the nitrogen reservoir.

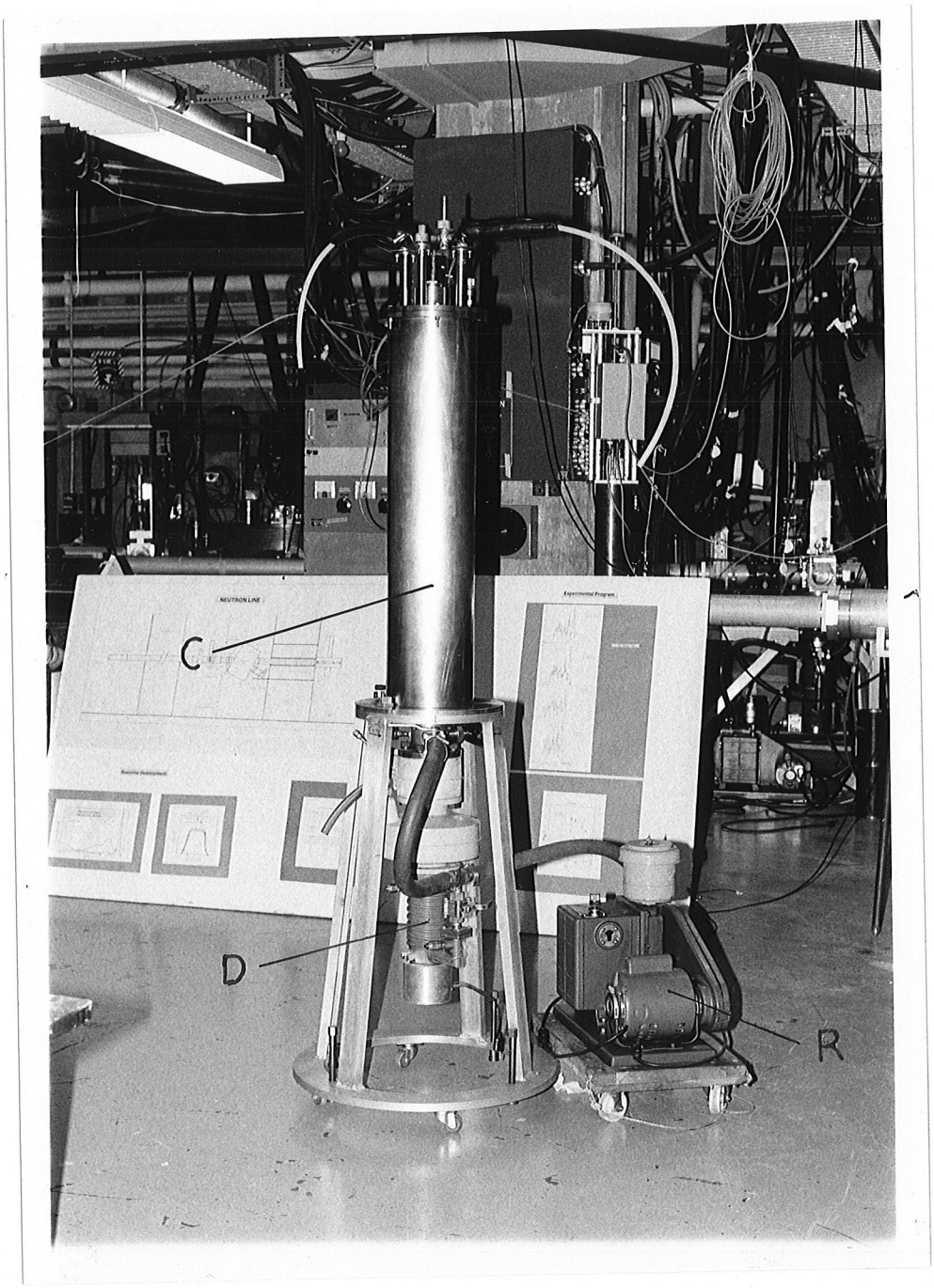


Plate 1 A general view of the liquid polarimeter.

C: the outer case of the polarimeter.

D: the diffusion pump.

R: the roughing pump.

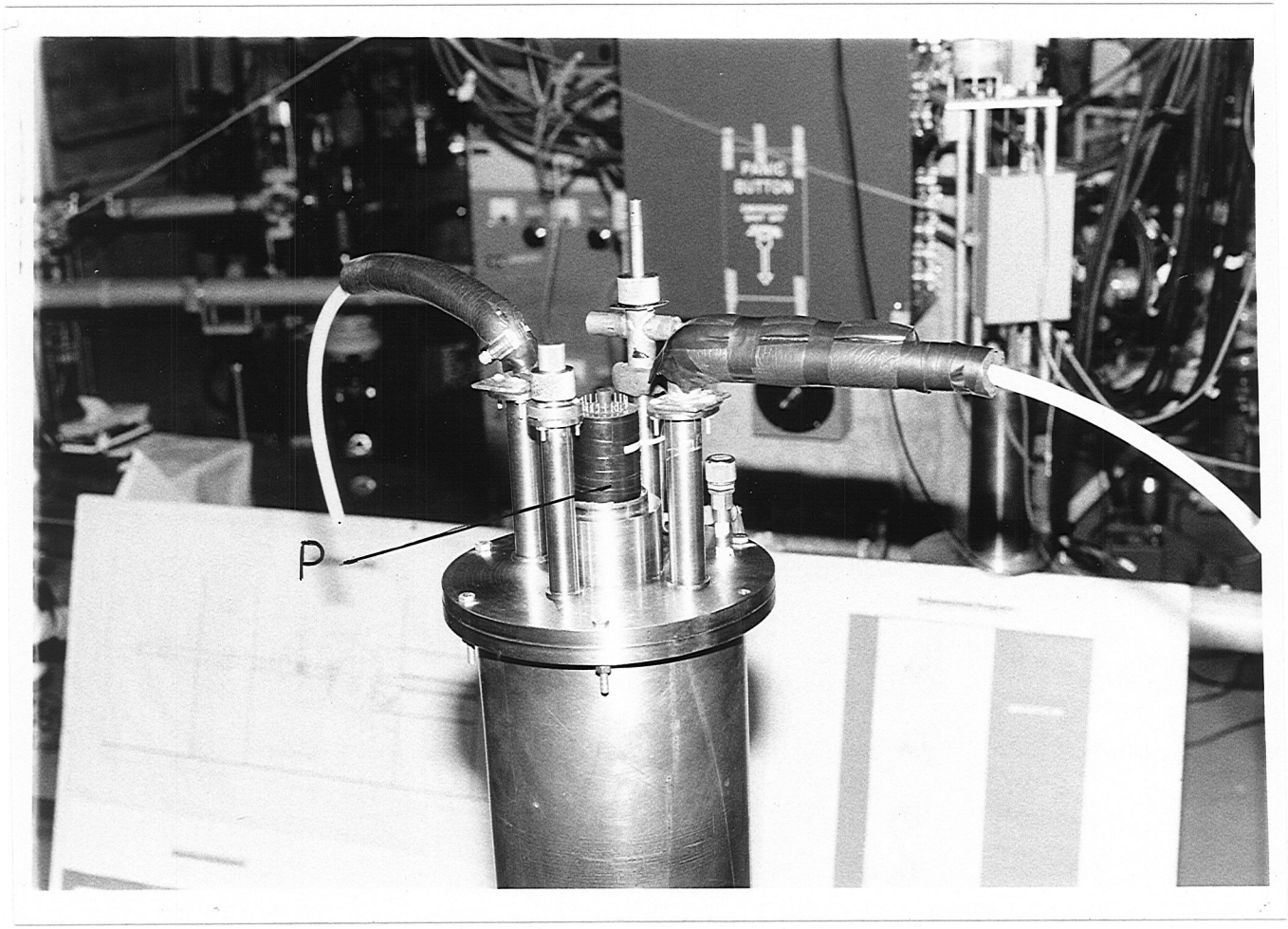


Plate 2 The top flange of the polarimeter.

P: the photomultiplier tube.

CHAPTER 3

TESTING THE POLARIMETER WITH AN α-SOURCE

3.1 INTRODUCTION

A small monoenergetic alpha source is a very useful tool for investigating the energy resolution and overall performance of the polarimeter. The alpha particles simulate the monoenergetic recoil helium nuclei which would result if neutrons were scattered through a specific angle. A series of pulse height spectra taken with the alpha source at different locations in the scintillation volume will reveal both the energy resolution of the system and the extent to which pulse height depends on the location of the scintillation.

We used a ^{210}Po (5.3 Mev) α-source which is available as a nickel needle (381 nm diameter) with the active material electrodeposited at one end. (See Fig. 3-1)

In this chapter, the pulse height spectra from both liquid argon and liquid helium are shown.

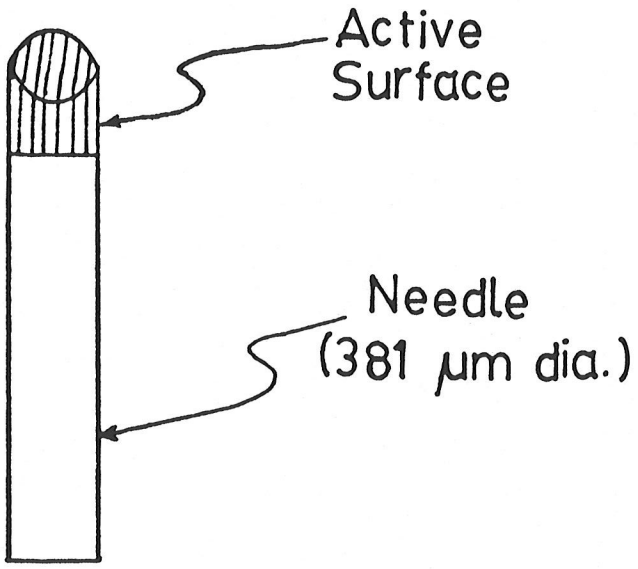


Fig. 3-1 $^{210}P_o$ (5.3 Mev)α-source is available as a nickel needle (381 μm diameter) with active material electrodeposited at one end.

3.2 EXPERIMENTAL

In order to observe the scintillation light, as mentioned earlier (sec. 2.3.1), a film of wavelength shifter (100 ug/cm^2 DPS) has been deposited on the inside of the scintillation volume and 30 ug/cm^2 DPS on the end of the light-pipe. Titanium dioxide, which is used as a reflector paint, is applied to the sides of the scintillation volume to improve the light collecting properties of the cryostat.

The scintillations which are produced in the scintillation volume are conveyed to a XP 2230 H Philips photomultiplier at the top of the polarimeter by a quartz light-pipe (76.2 cm long). Silicone rubber potting compound (RTV-602) provides a good optical contact between the quartz light-pipe and the photomultiplier.

Fig. 3-2 shows the block diagram of the electronics used in testing the polarimeter. As mentioned earlier (sec. 1-3), the detected scintillations are presented as a burst of charge collected at the photomultiplier anode. The function of the preamplifier is therefore to integrate the total charge of the pulse and convert it to a voltage signal, retaining the proportionality to the energy deposited.

The fundamental function of the main amplifier is to amplify the signals from the preamplifier and condition the signal for sorting and recording according to the pulse height.

A VAX computer with a CAMAC interface and MBD-11 branch driver form a data acquisition and analysis system. The CAMAC-ADC+ (Analog-to-

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+ The CAMAC-ADC used is Model 3511 operating in peak detect mode.

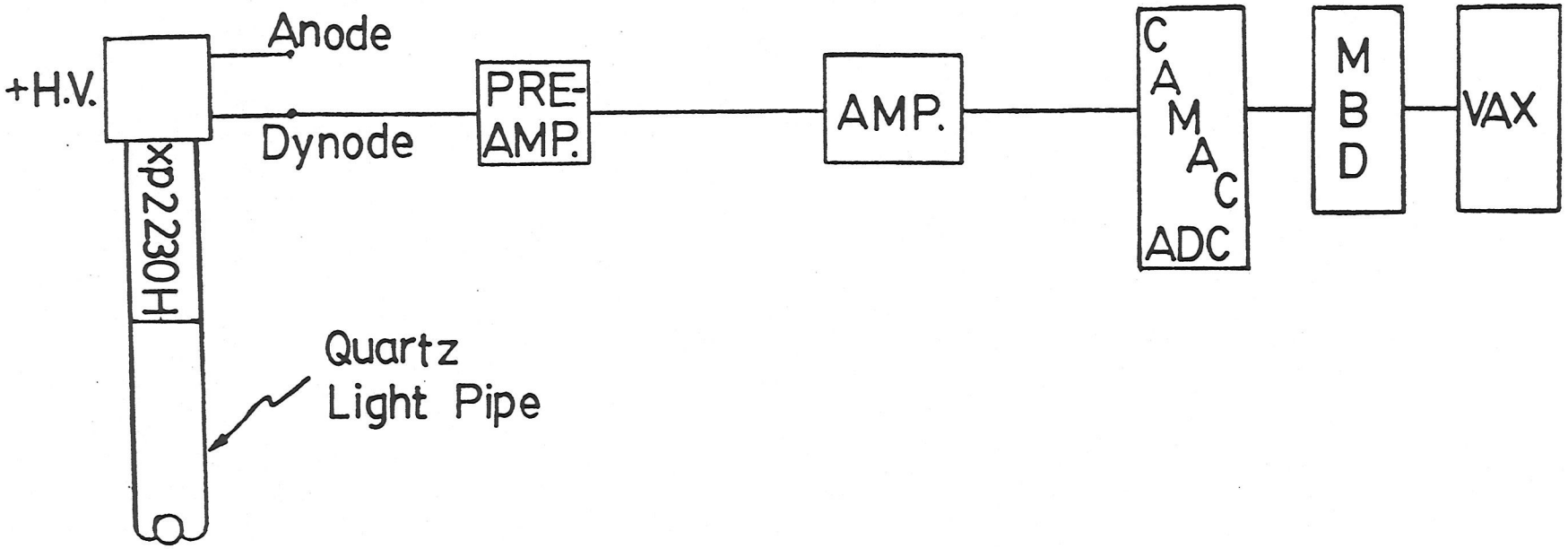

Fig. 3-2 Electronics used in testing with ^{210}Po α-source.

Digital Converter) accepts analog pulses of 50 mv to 8v pulse height. With the conversion gain of the ADC set to 1024, the full scale (50mv-8v) is divided into 1024 discrete segments (channels). Pulse heights that are close to 50mv will register in the lower channels just above channel zero, and pulse heights that are close to eight volts will register in the upper channels near channel 1023. All pulse heights between these limits will register in their corresponding channels. Pulse heights that extend above eight volts are disregarded. The MBD program handles CAMAC operations and data transfers to and from the VAX computer. Fig. 3-3 shows a simplified block diagram of the U. of M. Cyclotron Laboratory VAX computer configuration. More details on the XSYS data acquisition system used can be found in papers of Robertson et al. (1981), King et al. (1981) and Holzsweig et al. (1981).

3.2.1 Scintillations from argon

As a preliminary test, the polarimeter was tested using argon gas (at about 1 atm) as a scintillating target. A typical pulse height spectrum for scintillations from the α-source is shown in Fig. 3-4, where the channel number is proportional to the intensity of the scintillations induced in the argon gas, which, in turn, is proportional to the energy deposited in the scintillator due to the stopping of the alpha particles (see Eqs. 1-11, 1-12). The centroid of the peak, at channel 157, corresponds to the energy of the ^{210}Po alpha source (5.3 Mev). The pulse height resolution (full width at half maximum - FWHM) is about 22%.

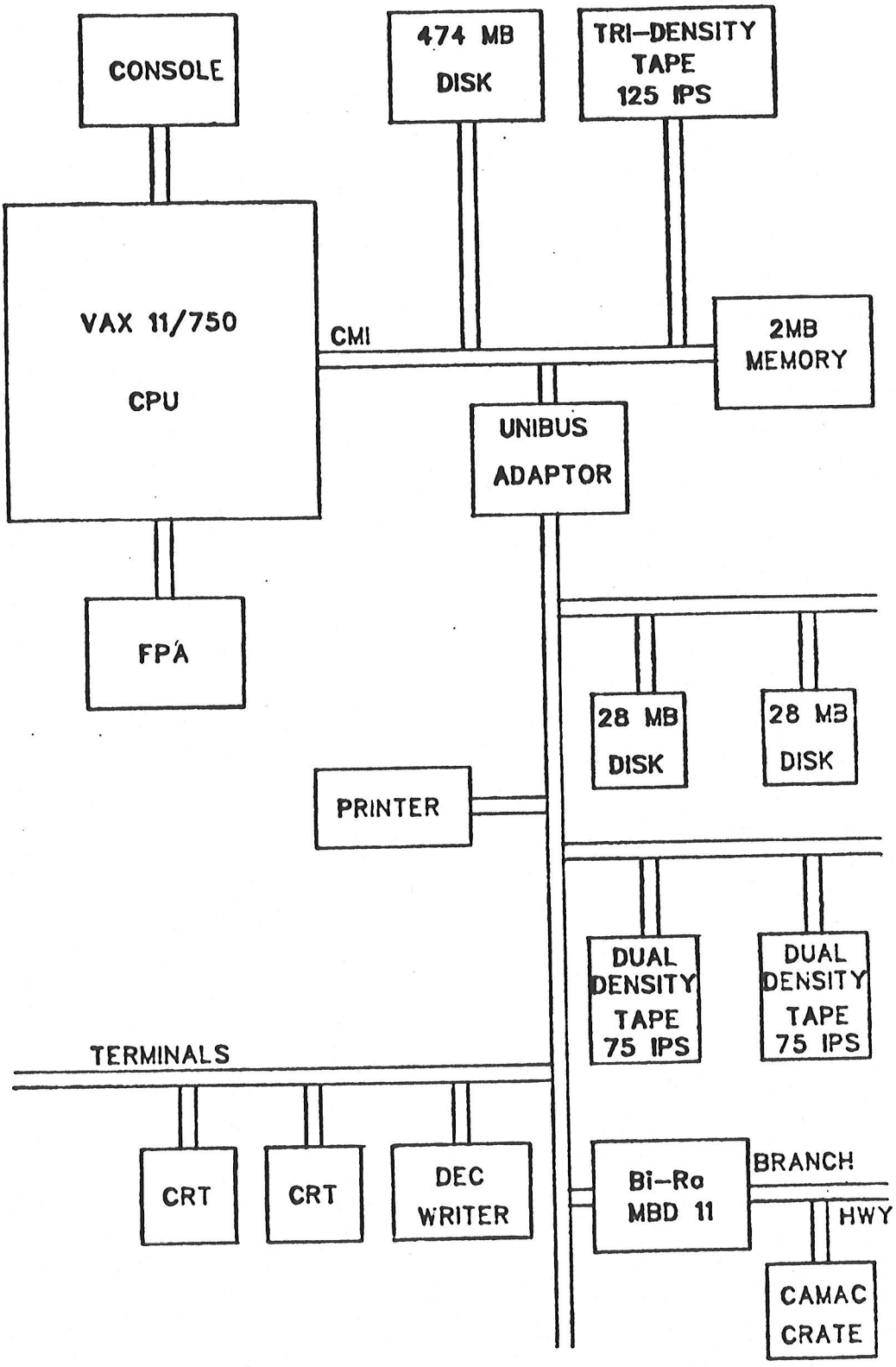

Fig. 3-3 A simplified block diagram of VAX computer configuration.

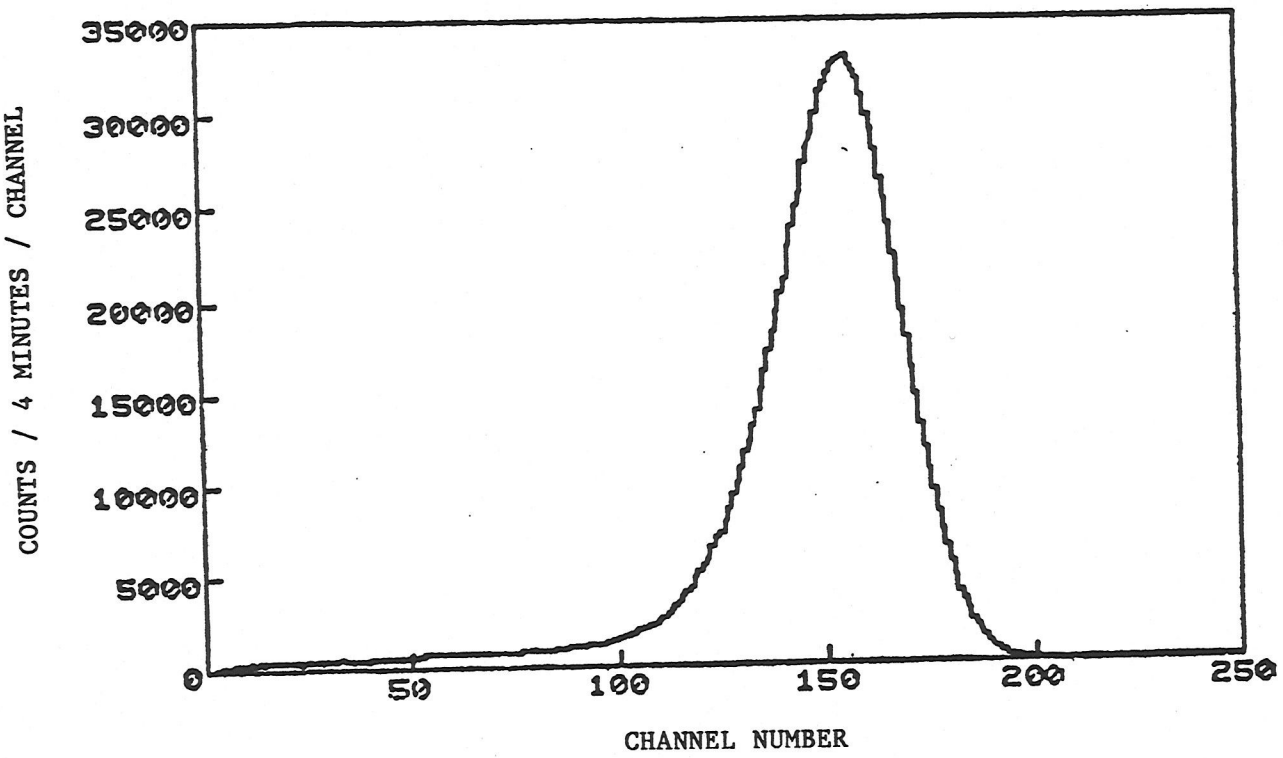

Fig. 3-4 A typical pulse height spectrum for scintillations in argon gas by the ^{210}Po α-source at the centre of the scintillation volume.

The polarimeter has also been tested using liquid argon as the scintillator. Ramsay (1980) gave a "recipe" for producing liquid argon simply and economically. Argon is condensed by passing it through two metres of one-half inch outer diameter copper tubing arranged in a coil and immersed in liquid nitrogen (Fig. 3-5). A flow rate of two litres of gas per second (NTP) (estimated from rate of pressure drop in the argon cylinder) is found to be adequate to prevent freeze-up but not so high as to result in feed through of uncondensed gas. The liquid argon flows directly into the scintillation volume of the polarimeter. A complete filling with liquid argon takes about 20 minutes using this method.

Because of the undesirable effect of the presence of impurities in the gas on the production of the scintillations, it was necessary to do the following:

(1) evacuate the whole system (pipes, condensing coil, scintillation volume) before filling.

(2) hold the system at a roughing pressure of less than 2 Pascals for 3-4 hours.

(3) vent to argon gas before filling.

This method has been very successful. Fig. 3-6 shows a pulse height spectrum of scintillations induced in liquid argon by the α-source at the centre of the scintillation volume. The resolution (FWHM) is 20%.

The polarimeter as described could be operated for about 30 hours between fillings.

Comparing Fig. 3-4 with Fig. 3-6, we can see that the pulse height in the case of liquid argon is greater than that of argon gas.

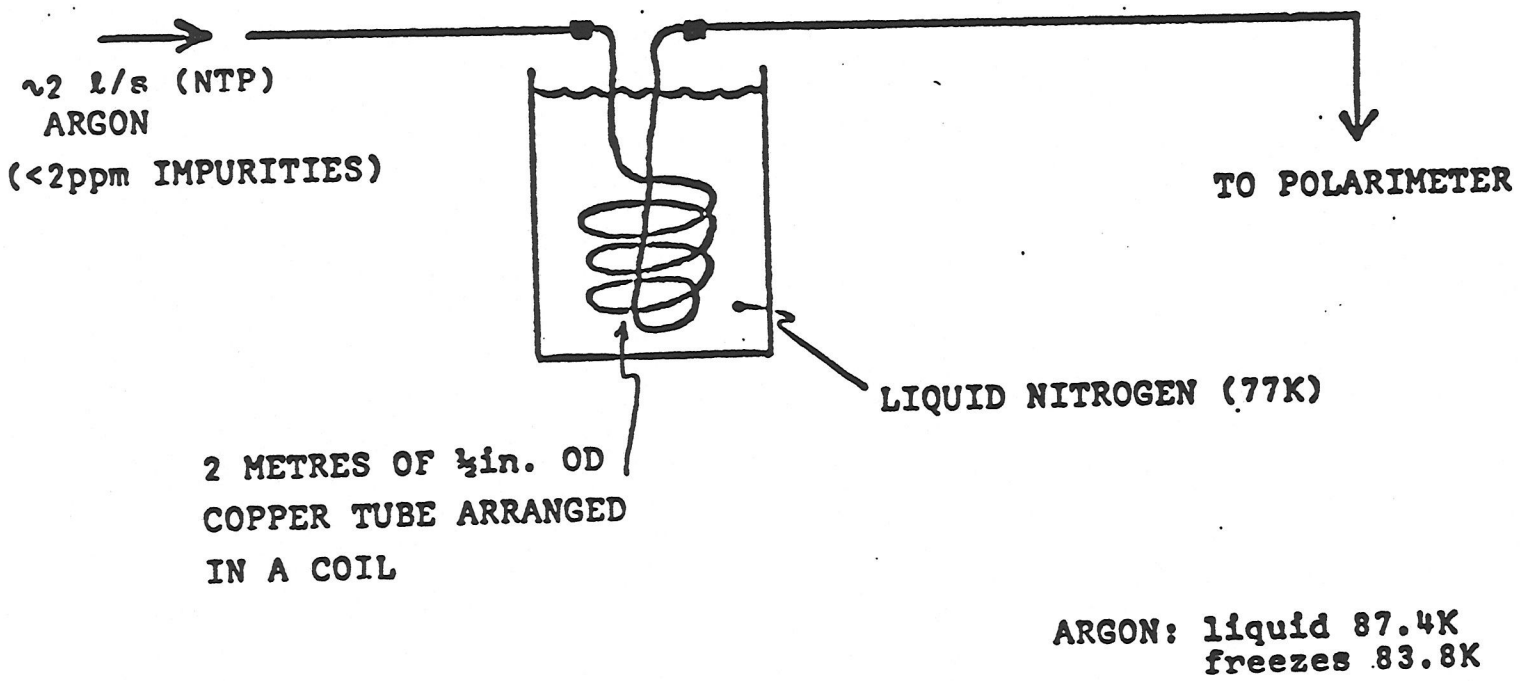

Fig. 3-5 Method of preparing liquid argon. The flow rate indicated is low enough to ensure that no uncondensed argon is fed through, but not so low that the condensing coil freezes up.

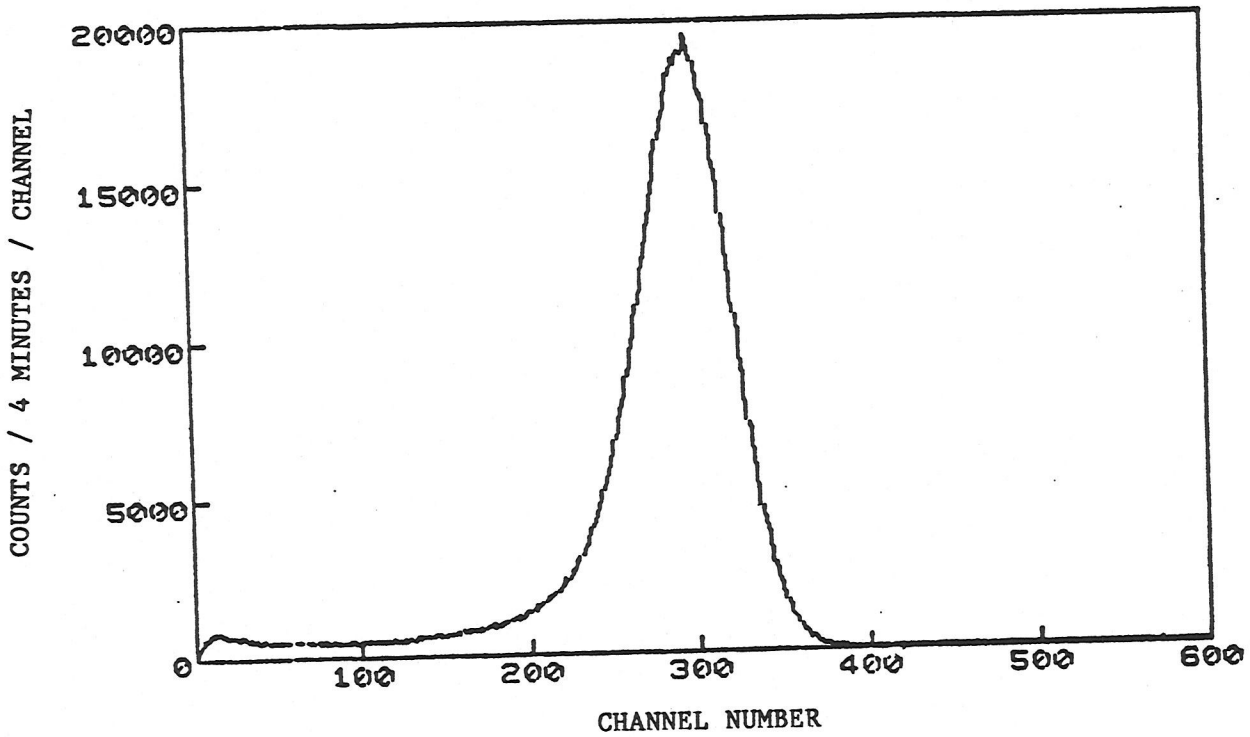

Fig. 3-6 A pulse height spectrum of scintillations induced in liquid argon by the α-source at the centre of the scintillation volume.

In order to explain this, it is first useful to define the range of heavy charged particles (e.g. α-particles). Heavy charged particles travel almost in straight lines, losing energy discontinuously, but because of the very large number of collisions they undergo, the process can be regarded as continuous. A heavy charged particle of a given initial energy E_o has therefore a well defined straight path of length R in the stopping medium. The range R is given by:

$$R = \int_{Eo}^{0} \frac{dE}{dE/dx} \qquad 3\text{-}1$$

Where $(-dE/dx)$ is the rate of energy loss per unit path length and the integration is over the net energy loss from an initial energy E_o to an end energy of zero. The rate of energy loss per unit path length is high in heavy media. Hence, the range of the alpha particles in liquid argon (50 um) is much less than that in argon gas ($\sim$ the radius of the scintillation volume). Therefore, in the case of argon gas, many of the alpha particles stop in the walls of the scintillation volume resulting in a decrease of the energy deposited in the argon gas. That leads to a loss of the pulse height. On the other hand, in the case of liquid argon, the alpha particles completely stop in the liquid argon resulting in an increase in the energy gained by the liquid argon. Therefore, a large pulse height can be obtained.

3.2.2 Scintillations from liquid helium:

Owing to its low latent heat of vaporization (2.6 joules cm^{-3}), liquid helium is only available in superinsulated storage vessels. A vacuum-jacket transfer tube is therefore used to transfer liquid helium

from the storage vessel into the polarimeter. The transfer tube consists of two concentric steel tubes bent in the form of an inverted 'U', the inner tube held in the centre by means of spacers, and the ends of the annular space sealed. The annular space is evacuated to 10^{-4}-10^{-6} torr to provide thermal insulation. Fig. 3-7 shows one end of a transfer line. A complete filling with liquid helium takes about one hour.

A pulse height spectrum of scintillations induced in liquid helium by an α-source at the centre of the scintillation volume is shown in Fig. 3-8. The α-source was moved to different positions in the scintillation volume and pulse height spectra were taken at these positions. The peak centroid is plotted as a function of the α-source distance from the lower end of the light-pipe in Fig. 3-9. It is seen that the pulse height response of the isoangular volume is nearly independent of the α-source position, as we would expect. Also, a representative curve of resolution versus the α-source position is shown in Fig. 3-10. We can see that the energy resolution (FWHM) of the polarimeter is approximately 13.0%, with an estimated error of 0.3%. The polarimeter could be operated for about three hours between fillings. This period could be increased if the helium transfer line is left inside the polarimeter after filling.

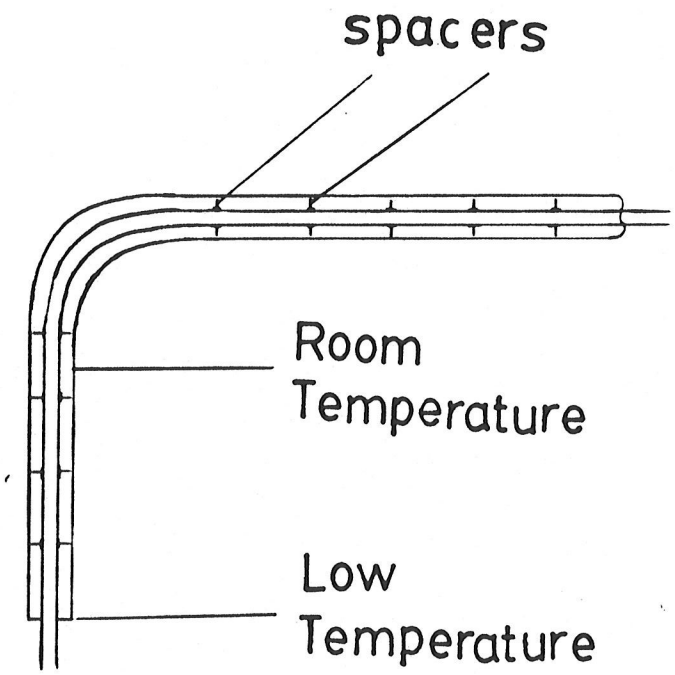

Fig. 3-7 Diagrammatic representation of part of a cryogenic transfer line.

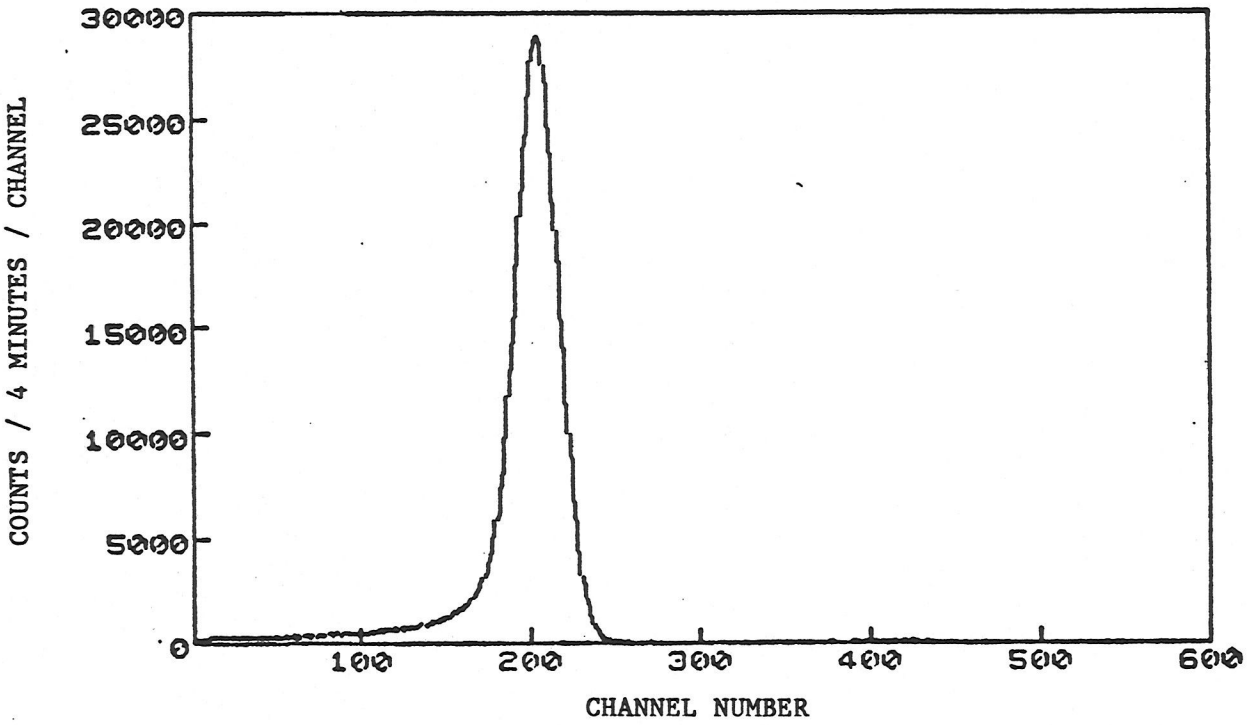

Fig. 3-8 A pulse height spectrum of scintillations induced in liquid helium by the α-source at the centre of the scintillation volume.

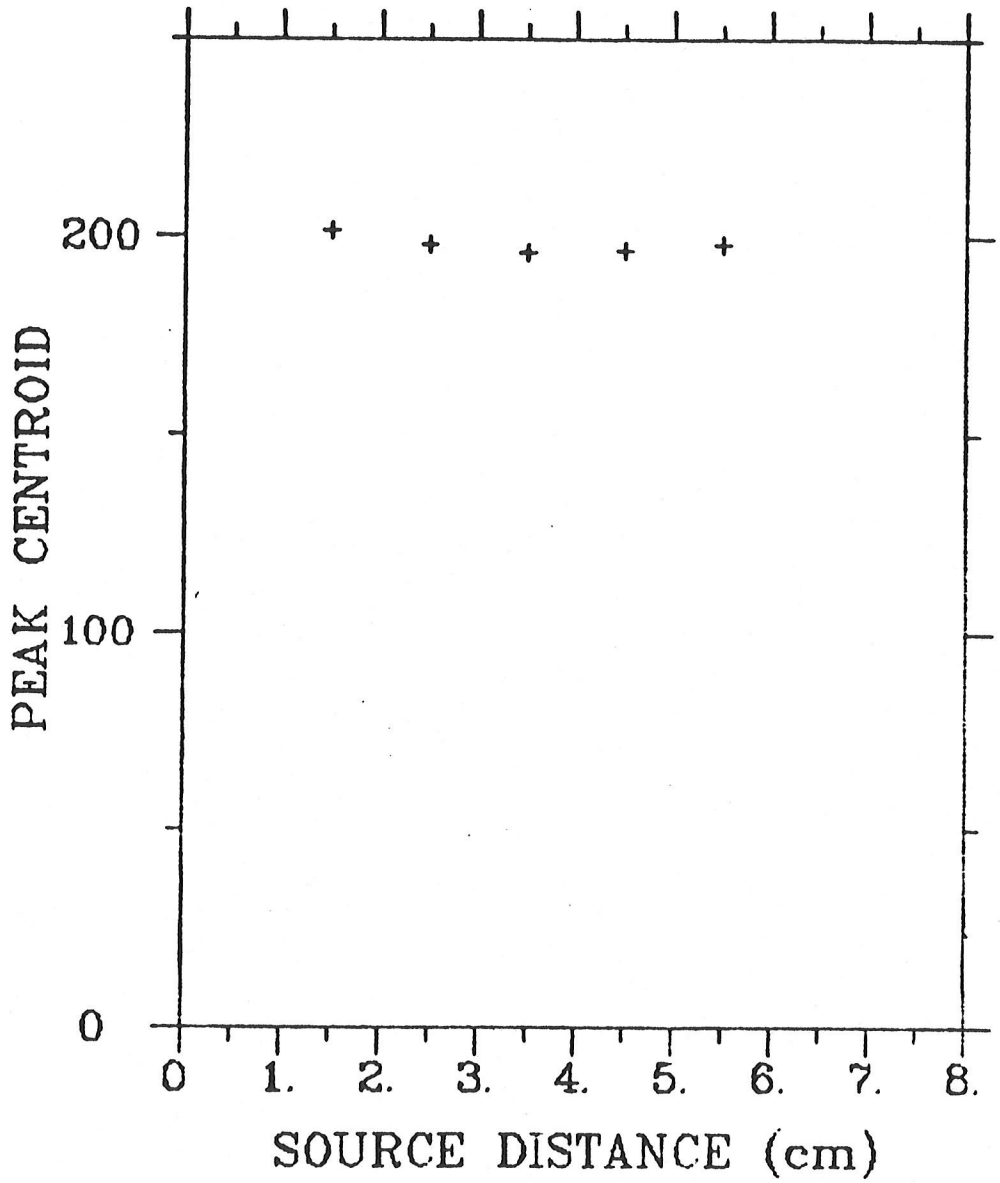

Fig. 3-9 The peak centroid is plotted as a function of α-source position. The source is on axis of the scintillation volume, with distance measured from the lower end of the light-pipe.

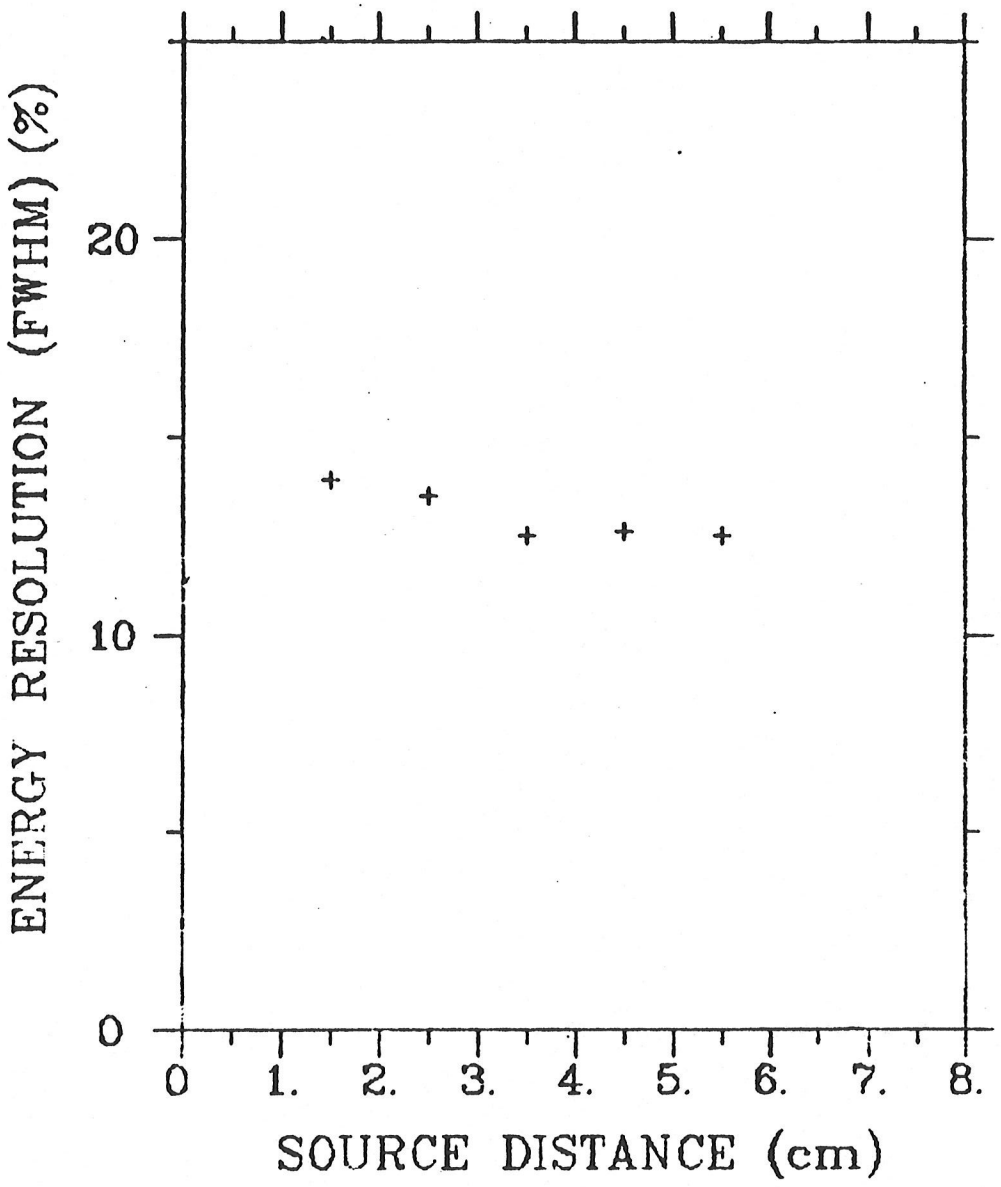

Fig. 3-10 The resolution is plotted as a function of α-source position. The source is on axis of the scintillation volume, with distance measured from the lower end of the light-pipe.

CONCLUSION

A new liquid helium polarimeter has been built and tested.

The goals of the project, namely to reduce the boil-off rate of liquid helium and improve the energy resolution, have been achieved (The energy resolution of the old polarimeter (Birchall et al., 1969) was 25%.).

The advantages of the isoangular volume have been demonstrated in the case of liquid helium. Unfortunately, it has proved impossible to demonstrate similar performance in the case of liquid argon because of the existence of impurities in the argon gas used to prepare the liquid argon.

FUTURE WORK

It is recommended that, to improve the reflectivity of the iso-angular volume, an opaque and very white coating be obtained by spraying a saturated solution of sodium salicylate in methyl alcohol on the iso-angular volume walls that have first been silvered. The coating is dried by heating to over 100°C. This sodium salicylate layer is used, both as an ultraviolet converter, and a light diffuser. Constancy of the polarimeter operation should in this way be attained for a couple of months.

It can be said that the liquid helium neutron polarimeter as described herein has an important use as a neutron detector of high efficiency and good resolution. A polarimeter of this type is useful for studies of neutron polarization in (p,n) reactions.

Also, measurements of the cross-section and angular distributions for the scattering of fast neutrons from high purity liquid argon can be carried out. Moreover, the analysing power of the argon can be measured and compared to that of liquid helium. If argon proves suitable as a polarization analyser, it would be cheaper and more convenient than liquid helium.

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