

A Liquid Helium Polarimeter of Unique Design

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INTRODUCTION

Much of the present effort in low energy nuclear physics is directed towards an investigation of spin dependent effects in nuclear interactions and for such an investigation either the incident beam or the target polarisation must be accurately known. The instrument described in this chapter was designed for the precise measurement of neutron beam polarisation in the energy range 2 to 20 MeV. The essential requirements of such a device and the way in which these requirements have influenced the final design are described.

When a beam of neutrons of polarisation P_1 is scattered from a target, more neutrons may be scattered at an angle θ to one side of the original beam direction than at a similar angle to the other. If $L(\theta)$ and $R(\theta)$ are the numbers scattered to the left and right of the beam respectively, then the asymmetry of the scattering is defined as:

$$\epsilon(\theta) = \frac{L(\theta) - R(\theta)}{L(\theta) + R(\theta)}$$

The factor relating this asymmetry to the initial beam polarisation is known as the analysing power of the scatterer, $P_A(\theta)$, and is given by:

$$\epsilon(\theta) = P_A(\theta)P_1$$

$\epsilon(\theta)$ is the experimentally measured quantity, so if it is required to determine P_1 accurately

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$P_A(\theta)$ 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, θ . A further condition is that the scatterer chosen should have a reasonable cross-section for scattering at the angles of highest polarisation so that a statistically accurate measurement of the polarisation may readily be obtained. The nucleus which satisfies these requirements best is the helium-4 nucleus which has no nuclear excited states below 20 MeV.¹

DESIGN CONSIDERATIONS

Light is emitted from helium when a charged particle is slowed down or stopped in it. Such a charged particle could be a helium nucleus recoiling from collision with an incident neutron. Thus, if the scattered neutron and the recoiling helium nucleus can both be detected one has an efficient method of reducing the background present in neutron experiments. Also if the energy of the recoil can be measured accurately, the background can be further reduced by setting a pulse height window on the recoil spectrum.

The difficulties encountered in obtaining good resolution are due to two factors. The first is that helium scintillates in the far ultraviolet region of the electromagnetic spectrum² and these wavelengths are outside the range of conventional photomultipliers. The second problem is that the scintillation light must be transmitted from the liquid helium to the cathode of a photomultiplier which is operating around room temperature. The way in which these problems have been overcome will be described.

The liquid phase of helium was chosen in preference to the gaseous phase for two reasons. The first is the higher density of helium nuclei in the liquid leads to higher counting rates and hence better statistics on the final result. The second reason is that for neutron experiments at energies around 10 MeV in which time-of-flight techniques are employed to measure energies, the rise times of the pulses used in the timing must be rapid, i.e. about 10^{-9} s. Scintillation pulses from liquid helium are known to meet these requirements, whereas those from gaseous helium, even under high pressure, are inferior, particularly as regards decay time. The disadvantage of a liquid helium target is that it needs to be filled regularly,* unlike a gas target which may be run indefinitely without attention. Several high pressure gas targets have already been constructed.³

FINAL DESIGN

The liquid helium is contained in a 3" diameter copper bowl, 1/16" thick, at one end of a quartz light pipe. This light pipe transmits the scintillation light to a 56 A.V.P. photomultiplier whose cathode is at room temperature. To convert the scintillation light to a wavelength suitable for detection by the photomultiplier a layer of wavelength shifter is deposited on top of a diffuse reflecting paint which covers the inside of the bowl. It has been found that DPS† is superior to POPOP** as a wavelength shifter in this wavelength region giving an increase in pulse height of about 1.3. The optimum thickness of the layer is $100 \mu\text{g}/\text{cm}^2$.

The diffuse reflecting paint is, of course, essential if good resolution is required, otherwise the size of the signal from the photomultiplier for equal scintillations in the

*With liquid helium self-filling systems now available commercially, this disadvantage is effectively removed.

†*p-p'* diphenylstilbene.

***p*-bis[2-(5-phenyloxazolyl)]*p*-benzene.

bowl will depend on position. Another consideration affecting this coat of reflecting paint is the rise time of the light pulse which stimulates the cathode of the photomultiplier. As has been pointed out, this should be as short as possible to reduce the background in the neutron scattering experiment. If the reflectivity of the bowl was 100%, light could be reflected many times before entering the light pipe and then being transmitted to the photomultiplier and this would adversely affect the rise-time of the pulse. Thus a compromise has to be reached between high reflectivity with good resolution and low reflectivity with good timing characteristics. The reflector paint, N.E.560, has been found to be suitable for this purpose.

Because of the large temperature difference between the scintillating medium and the photocathode it is necessary to transmit the light with high efficiency through a medium which will stand the high temperature gradient. Previous designs have used a quartz⁴ or sapphire window in the scintillating volume and placed the photomultiplier a short distance away in the insulating vacuum. It was felt however, that improved transmission would be obtained if the photomultiplier was directly coupled through a light pipe to the scintillating volume, thus reducing light losses at additional optical interfaces. The light guide chosen for this purpose is quartz. Not only has quartz a very high transmission, but its cut-off wavelength is well down in the ultraviolet region. In order that the photocathode should remain near room temperature, the light guide is 15" long with its end well above the top plate of the cryostat which acts as a heat sink. The other end of the light pipe is coated with 50 $\mu\text{g}/\text{cm}^2$ of the wavelength shifter DPS and immersed in the helium as shown in Fig. 1. Its diameter is 2".

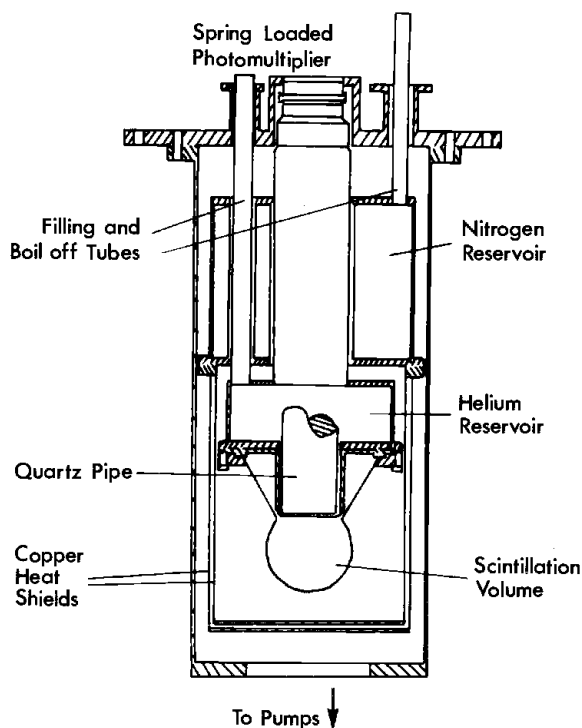


Fig. 1: The polarimeter design.

As the refractive index of helium is 1.026, any light entering the pipe from the helium end is totally internally reflected in the pipe and must leave by the other end if the walls of the light pipe are clean and not in contact with anything. A seal however, has to be made to prevent the escape of helium gas and this takes the form of a thin 'O' ring near the top of the pipe. This total internal reflection condition is also lost when the light pipe is coated at one end with a wavelength shifter, as in this case. Silvering the walls could reduce the light losses but would also increase the variation in transit times up the pipe, hence spoiling both rise and fall times of the detected pulses. It has not been found necessary in the present case to use this technique although it would probably increase the total charge collected at the anode of the photomultiplier.

The light guide is optically coupled to the spring loaded photomultiplier with Dow-Corning C-2-0057 optical coupling grease. A photomultiplier with a quartz window is soon to be used in place of the 56 A.V.P. and it is expected that this will further improve the resolution of the instrument.

The bowl containing the helium is sealed to the helium reservoir with an indium ring. This allows the reflector paint and wavelength shifter to be renewed as necessary. The helium system is supported in the insulating vacuum by three filling and boil-off tubes and is totally surrounded by a copper radiation shield cooled with liquid nitrogen.

The resolution of the instrument has been investigated using α -particles from a polonium-210 source electrodeposited on a silver wire, and helium nuclei recoiling from collision with a neutron (Fig. 2). The results of these tests are consistent with a resolution of 12% for $E_{\alpha} = 9$ MeV inclusive of position effects in the scintillating volume and statistical effects at the cathode of the photomultiplier.

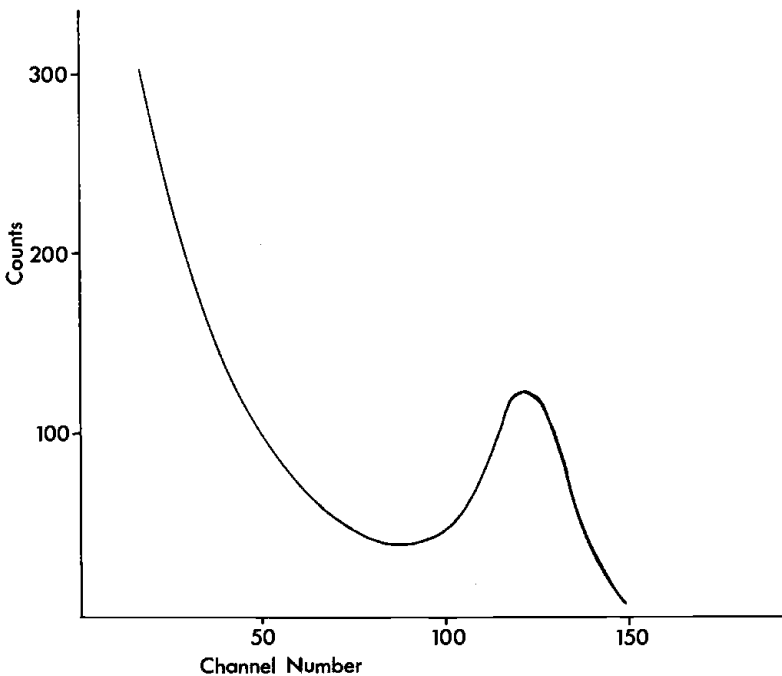


Fig. 2: α -recoil spectrum.

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DISCUSSION

J. B. Birks: Does the emission spectrum of liquid helium correspond to that of the excimer (excited dimer) or of the dimer cation (He_2^+)? What is the scintillation decay time?

P. B. Dunscombe: The emission spectrum in the u.v. is largely due to the radiative dissociation of the excited dimer. The He_2^+ ion is formed in the liquid (binding energy about 2 eV). The decay time of the scintillation from liquid helium is of the order of 10 ns.