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CLM-P151

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THE COUNTING EFFICIENCY FOR β PARTICLES OF ZnS(Ag) AND GLASS SCINTILLATORS AND THE ADSORPTION OF TRITUM ON THE SCINTILLATORS AND ON STAINLESS STEEL

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1967

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CLM - P 151

THE COUNTING EFFICIENCY FOR β PARTICLES OF ZnS(Ag) AND GLASS SCINTILLATORS AND THE ADSORPTION OF TRITIUM ON THE SCINTILLATORS AND ON STAINLESS STEEL

by

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(Submitted in abbreviated form for publication in Plasma Physics)

A B S T R A C T

The counting efficiencies of two types of ZnS(Ag) and glass scintillator probes for β particles from tritium has been measured using standard sources. Depending on the detailed construction the values lie between 1% and 50%. The counting efficiency for monoenergetic electrons was found to be a linear function of electron energy in the range 2-20 keV.

The build up of tritium adsorption on the phosphors, and on a stainless steel vacuum vessel, after various periods of exposure has also been measured.

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September, 1967 (MEJ)

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1. INTRODUCTION

S.R. Rodionov[1] has described a method for investigating the single particle confinement properties of open ended magnetic traps such as are used in fusion research. The principle of the method is to generate β particles on the field lines from tritium gas which fills the trap, and to determine the equilibrium β population. The method can be extended to topologically toroidal geometries provided compact probes can be developed to detect the β particles in the interior of the trap, within the ultra high vacuum system, and in the presence of a magnetic field. The most suitable probe is a scintillation counter incorporating a light guide so that the photomultiplier and its magnetic shielding can be placed outside the vacuum system and away from the magnetic field. The extent of tritium adsorption on scintillating surfaces is of crucial importance since the count rate due to adsorption will set a limit to the sensitivity for detecting electrons generated in the trap. Adsorption of tritium on the vacuum vessel will contribute to the general background level.

2. CONSTRUCTION OF THE PROBES

2.1 Powder Scintillator

These probes were constructed by painting a thin layer of a transparent epoxy resin on to one end of a length of quartz rod polished on all surfaces, sprinkling ZnS(Ag) powder screened through a very fine copper mesh on to the epoxy resin, and curing at 200°C for one hour.

2.2 Glass Scintillator

These probes were constructed from a piece of N.E.901 glass scintillator (Nuclear Enterprises Ltd.) one cm diameter and 0·3 cm thick polished on one face, and frosted on the other, and a length of quartz rod polished on all surfaces. The frosted surface of the scintillator, and one end of the polished quartz rod were joined with a thin layer of the same epoxy resin.

In both type of probe the 20 cm long quartz light guide passed through a quartz to metal vacuum seal, and was optically coupled to an E.M.I. S type photomultiplier. At the gain and discriminator settings selected the count rate due to the dark current of these tubes was typically 100 cps.

2.3 Scintillator with Fibre Optic Light Guide

Some measurements were also made on a more complicated ZnS(Ag) probe with 45 cm of 0·8 cm diameter quartz light guide with an elastomer 'O' ring vacuum seal, coupled outside the vacuum system to 45 cm of 1 cm diameter fibre optic light guide.

3. PROBE COUNTING EFFICIENCY FOR TRITIUM β PARTICLES

3.1 From Standard Tritiated Polymer Sources

Both types of probe were calibrated with poly (methyl-T) methacrylate sheet coated with 1500 Å of aluminium to exclude the serious effects of self scintillation in the source. The calculated number of tritium decay β's emitted from the polymer source was

corrected for absorption in the aluminium by measuring the count rate from identical sources coated with different thicknesses of aluminium. A correction for pinholes in the aluminium was made by taking a background count rate with 1 mm of glass between the source and the scintillator.

The polymer sheet used for this calibration was supplied by the Radio Chemical Centre, Amersham. The specific activity was determined by them by liquid scintillation counting of the bulk material, assuming that the β emission originates from an 0·9 micron surface layer. The overall accuracy of the determination is estimated as ± 7%. The efficiencies of glass probes determined in this way varied from probe to probe in the range 12% - 17% and of ZnS(Ag) probes in the range 7% - 50%. The counting efficiency of the fibre optic probe was 1%.

To establish that the probes could be baked as required for use in the ultra high vacuum system one of the ZnS(Ag) powder probes was cycled fourteen times to 200°C. It's efficiency measured at intervals during the heat cycling was found to decrease progressively, finally reaching an equilibrium sensitivity 90% of its initial value.

3.2 From Tritium Gas

To obtain experience in counting tritium decay β particles in ultra high vacuum conditions the probe efficiency was also determined by counting the particles from a known cylindrical volume of tritium gas at pressures between 10^{-6} and 10^{-4} torr. The count rate was linearly proportional to gas pressure in this range. [See Fig.1]

The vacuum vessel was constructed of EN58 stainless steel, and all seals were of gold wire. It was pumped with an 80 litre/sec ion pump, and fitted with a quadrupole mass spectrometer. The base pressure after baking was $< 10^{-9}$ torr.

Tritium gas released from pyrophoric uranium was admitted to the vacuum system by diffusion through a hot nickel tube. The partial pressure of tritium in the vacuum system measured by the mass spectrometer was between 70 and 95% of the total pressure depending on the cleanliness of the vacuum system prior to the admission of tritium.

The probe efficiencies determined in this way agreed with the polymer determination to within a factor 2. This agreement is satisfactory in view of the uncertainty with which the pressure calibration of the mass spectrometer was known.

4. VARIATION OF PROBE EFFICIENCY WITH ELECTRON ENERGY

The principle employed was to accelerate electrons from a filament through a known potential (v_1) on to the phosphor (see Fig.2). (In order to exclude light from the filament and to improve the energy resolution the electron beam was passed through an electrostatic filter.) The count rate of electrons incident upon the scintillator with the post analyser accelerator grid grounded was recorded. A voltage was applied to the post analyser accelerator grid such that the numerical sum of the voltages applied to the electron gun, and grid was equal to 20 kV, and the count rate of electrons incident upon the scintillator again recorded. The ratio of the former count rate to the latter gave the efficiency of the scintillator, at a specific electron energy, relative to the efficiency at 20 kV.

This procedure was repeated at 1 kV intervals over the range 2-20 kV, and the results are shown in Fig.3. A similar variation of efficiency with energy was found for the simple probes with high efficiency as for the fibre optic probe with low efficiency.

5. ADSORPTION OF TRITIUM ON STAINLESS STEEL VACUUM VESSEL, AND ON SCINTILLATOR SURFACES

5.1 Equilibrium Conditions

In these experiments the probe was exposed to tritium for periods long enough for it to attain equilibrium with its surroundings, i.e. for at least two days before starting observations.

Adsorption is expressed as a fraction of a monolayer on the walls, and probe, assuming the number of atoms cm^{-2} in a monolayer to be $2{\cdot}8 \times 10^{14}$ for ZnS(Ag) and 6×10^{14} for stainless steel. The first section of Table I contains measurements of adsorption that had built up on the vacuum vessel, which had been exposed to tritium at low pressures (10^{-6} - 10^{-4} torr) for 400 hours over a period of 18 months. The second section contains measurements of adsorption that had built up on a new stainless steel cylindrical liner and probe which had been exposed to tritium in the same pressure range for 30 hours over a period of 18 days. Adsorption effects on the walls and probe were distinguished by admitting nitrogen to one atmosphere pressure so that β's originating at the walls could no longer reach the probe.

TABLE I

Adsorption of Tritium on Stainless Steel

Condition	Observed β's/sec Incident on Probe		Deduced fraction of a Monolayer of Tritium	
			On Probe	On Stainless Steel
	Vacuum	1 ats. N_2		
Vacuum Vessel	$3{\cdot}2 \times 10^{5}$	$2{\cdot}27 \times 10^{4}$	$4{\cdot}7 \times 10^{-2}$	75×10^{-2}
New Liner	$3{\cdot}17 \times 10^{4}$	$1{\cdot}21 \times 10^{4}$	$2{\cdot}13 \times 10^{-2}$	$4{\cdot}9 \times 10^{-2}$

Baking the vacuum vessel to $400^{o}C$ for four hours produced no significant change in adsorption, but heating the new cylindrical liner in situ to $70^{o}C$ reduced the adsorption on it by a factor of four.

5.2 Transient Contamination of the Probe

In addition to the adsorption of tritium on a probe produced by exposure to tritium for prolonged periods of time there is an initial adsorption which builds up whenever a probe is exposed to a system which has previously contained tritium, i.e. to previously

contaminated surfaces. Measurements of this effect, and also the extent of contamination of a ZnS(Ag) probe on exposure to tritium gas at 10^{-7} and 10^{-6} torr are presented in Table II. Similar results were obtained using glass scintillators.

TABLE II

Adsorption of Tritium on Scintillating Surfaces

Condition	Observed β's/sec Incident on the Probe		Deduced fraction of a Monolayer of Tritium	
			On Probe	On Stainless Steel
	Vacuum	1 ats. N_2		
Background count rate of system at atmosphere	-	$2{\cdot}7 \times 10^{4}$	$4{\cdot}6 \times 10^{-2}$	-
Adsorption after exposure to contaminated Vacuum Vessel for 2 days	$5{\cdot}8 \times 10^{4}$	$2{\cdot}6 \times 10^{4}$	$4{\cdot}6 \times 10^{-2}$	8×10^{-2}
ZnS(Ag) Probe exposed to Tritium for 4½ hours at 10^{-7} torr	$7{\cdot}5 \times 10^{4}$	$3{\cdot}6 \times 10^{4}$	$6{\cdot}2 \times 10^{-2}$	$9{\cdot}4 \times 10^{-2}$
ZnS(Ag) Probe exposed to Tritium for 4½ hours at 10^{-6} torr	$2{\cdot}0 \times 10^{5}$	$1{\cdot}2 \times 10^{5}$	$2{\cdot}1 \times 10^{-1}$	$2{\cdot}3 \times 10^{-1}$
Probe tip baked	-	$7{\cdot}7 \times 10^{4}$	$1{\cdot}4 \times 10^{-1}$	-

In addition to measuring the equilibrium adsorption level that is established on a probe after prolonged exposure it is important to know the increase in adsorption that occurs when the probe is suddenly exposed to tritium gas for brief periods of time. Fig.4 shows the additional adsorption which takes place when a probe is exposed to various pressures of tritium for two minutes only.

6. CONCLUSIONS

The efficiencies of various probes have been measured by counting β particles emitted from tritiated polymer sheet, and from a known volume of tritium gas. ZnS(Ag), and glass scintillator probes were found to have efficiencies between 7 and 50%. A more complicated fibre optic probe had an efficiency of 1%.

Glass scintillators show a counting efficiency over a fixed discriminator bias which is a linear function of electron energy in the range 2 to 20 keV. The ZnS(Ag) scintillators show a similar variation of efficiency but with some fall off at energies below 10 keV.

Prolonged exposure of EN58 stainless steel surfaces to tritium gas at low pressures ($10^{-6} \rightarrow 10^{-4}$ torr) over a long period of time results in the build up of 0·75 of a monolayer

of tritium on the surface, which is not significantly reduced by baking in vacuum for 4 hours at 400°C. Contamination on newly exposed surfaces is less, and can be reduced by baking for a short time at 70°C.

A clean scintillation probe exposed to the contaminated vacuum vessel becomes covered with ~ 0·05 of a monolayer of tritium in a few hours. This level is increased by about a factor of five on exposure to tritium gas at 10^{-6} torr for several hours; some of this additional adsorption can be removed by baking the probe tip.

Further exposure of the probe to tritium in the pressure range $10^{-6} \rightarrow 10^{-4}$ torr for 2 minutes increased the adsorption progressively by 10^{-4} to 10^{-3} of a monolayer the increase varying linearly with pressure.

7. ACKNOWLEDGEMENTS

The author is indebted to Dr. A. Gibson for his constant interest and advice, and to Mr. T. Godfrey for his technical assistance.

8. REFERENCE

1. RODIONOV, S.N. J. Nucl. E. (C) 1 1960, 247.

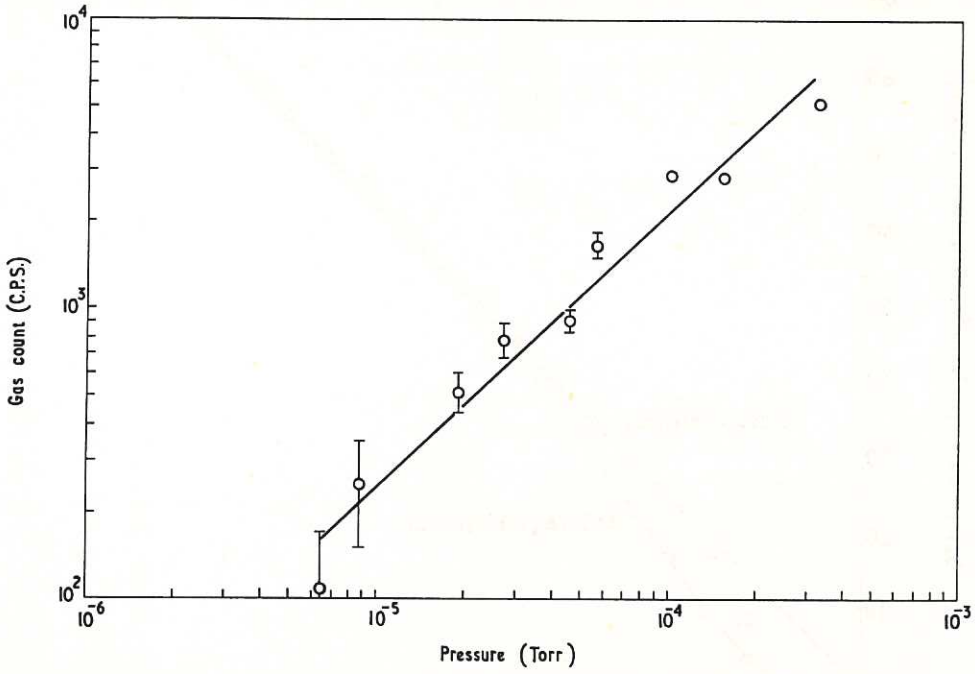
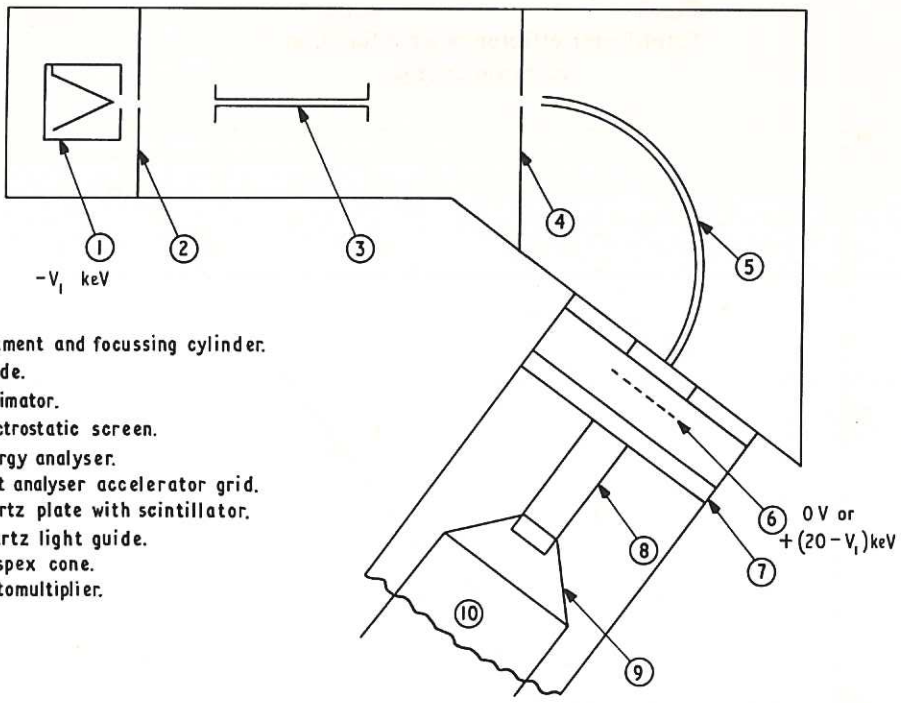


Fig. 1 (CLM-P 151)
Count rate from tritium gas as a function of tritium pressure



Key:
1. Filament and focussing cylinder.
2. Anode.
3. Collimator.
4. Electrostatic screen.
5. Energy analyser.
6. Post analyser accelerator grid.
7. Quartz plate with scintillator.
8. Quartz light guide.
9. Perspex cone.
10. Photomultiplier.

Fig. 2 (CLM-P 151)
Schematic diagram of the electrostatic energy analyser

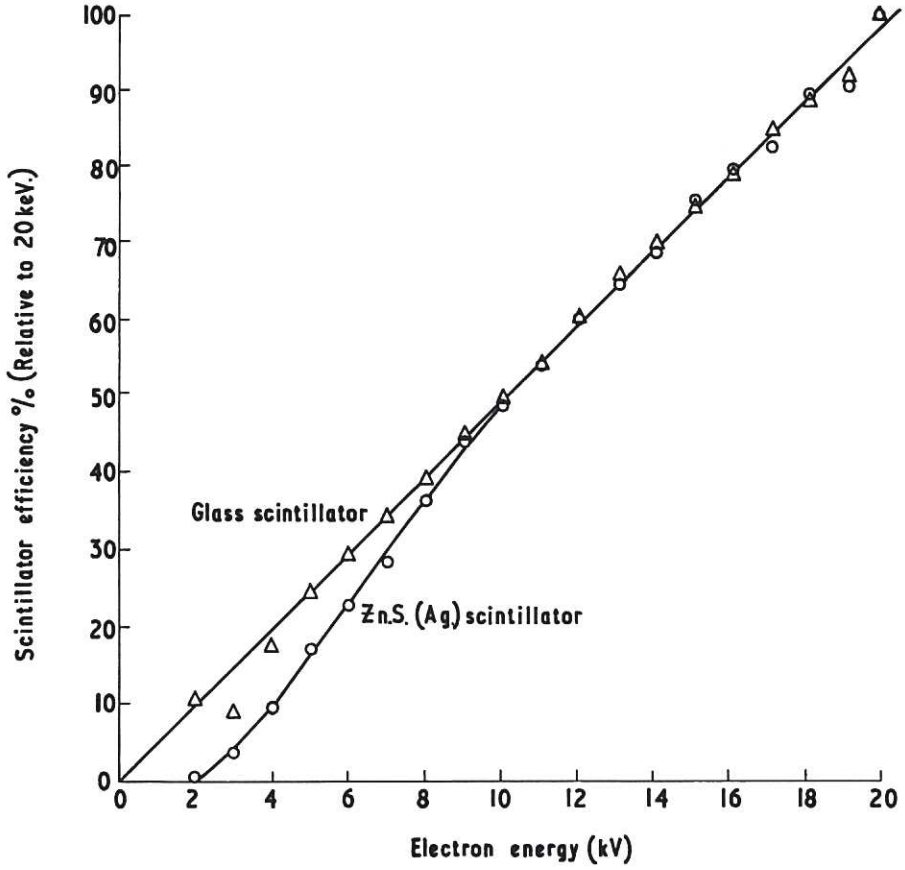


Fig. 3 (CLM-P 151)
Scintillator efficiency as a function of electron energy

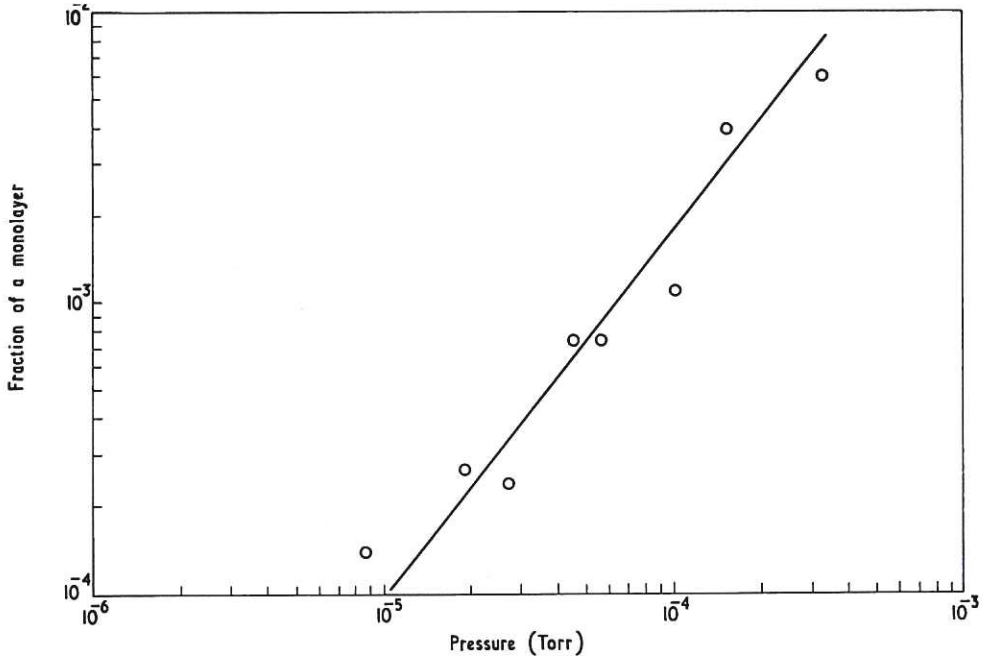


Fig. 4 (CLM-P 151)
The fraction of a monolayer increase of tritium adsorbed on a probe as a result of brief exposure to various pressures of tritium