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EXTRACTION OF ELECTRONS FROM A LIQUID PHOTOCATHODE
INTO A LOW-PRESSURE WIRE CHAMBER

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For many years there has been an interest in the detection of UV photons in wire chambers. This allows the construction of large-area instruments with good spatial accuracy, able to operate in strong magnetic fields. This field was started by Séguinot and Ypsilantis [1], who suggested the addition of a gas with a low photoionization potential I_g to a wire chamber with an optical window. With the first successful use of triethylamine (TEA) (threshold at 165 nm) in an imaging multistep avalanche chamber by Charpak et al. [2], and the introduction of tetrakis(dimethylamine)ethylene (TMAE) (threshold at 231 nm) as a photon detection gas by this author [3], Cherenkov ring imaging gained interest and is at present used for particle identification [4]. To date no gas has been found with a lower I_g than TMAE, which has been somewhat hampered by its low vapour pressure [5].

In the search for gases with low I_g , it has been noted that the photo-current of a molecule E_{th} in a solution is lower than its value of I_g . The relationship of E_{th} to I_g is given by

$$E_{th} = I_g + S + S^+ + E(e) ,$$

where S is the solvation energy of the molecule and S^+ that of the cation, and $E(e)$ is the energy of the photoejected electron. Table 1 lists the measured values of four of the tetraaminoethylenes (of which TMAE is a member) and their E_{th} measured in tetramethylsilane (TMS) [6]. These very low values of E_{th} led us to search for a means of detecting photoelectrons liberated in TMAE serving at its own solvent.

Thus we have built a liquid photocathode, shown schematically in Fig. 1. The instrument consists of a water-cooled copper plate for condensing the TMAE, and a low-pressure wire chamber (as reviewed by Breskin [7]). We chose this design since it was felt that the photocathode would not work in gas at 1 atm, and these counters have proved efficient for single-electron counting. The optical window is 4 mm thick quartz. The cold plate is coated with a thin layer of aluminium to provide some reflection. The anode plane is made of 10 μ m gold-plated tungsten wires with a 1 mm spacing, and guard wires to prevent sparking.

The second cathode is a wire mesh, with a cathode-to-anode spacing of 3 mm. The TMAE entered the instrument through eight ports, two on each side to ensure even deposition. All eight ports were heated to prevent the cold plate from cooling the entire instrument.

In the operation of this prototype, the instrument was kept at an elevated temperature ($\sim 45^\circ\text{C}$), and the photocathode was cooled with tap water at 18°C . After several days of evacuation, the instrument was exposed to a reservoir of liquid TMAE at a temperature of 25°C . Since there was no provision made for monitoring the thickness of the photocathode, the TMAE was deposited until the surface of the cold plate appeared wet, which took several hours. The reservoir was then closed and 3 Torr of isobutane were added as a counting gas. From the formula for the pressure of TMAE [5],

$$P(\text{Torr}) = 0.577 \exp \left[6454 \left(\frac{1}{300} - \frac{1}{T} \right) \right]$$

(where T is the absolute temperature), the pressure of the gaseous TMAE in the instrument was 0.3 Torr.

To measure the spectral response of the liquid photocathode, two transmission filters*) and a pulsed xenon flash-tube**) with a cut-off at about 250 nm were used. The transmission of the filters is given in Table 2. Many tests were performed with various cathode thicknesses and anode voltages. In all measurements, the light transmitted by filter 03 FIR 035 was detected by the instrument. The results with filter 03 FIR 019 were inconsistent from one measurement to the other, with an apparent tendency towards detection at the highest voltage the anode would hold. This voltage was usually about 490 V with an estimated gain of 10^4 . This gain is far below the value of 10^6 - 10^7 quoted by Breskin [7], and is due to counter defects that limited the anode voltage. It was also noted that at times the instrument had a greater sensitivity to light in the room. From these

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filter measurements we conclude that the threshold for detection of UV light is about 290 nm (4.3 eV).

Several pure, but not spectroscopic grade, BaF_2 crystals were also used as UV light sources. This scintillator has two emission continua, peaked at 225 nm and 310 nm with light yields of 2 photons/keV and 6.5 photons/keV, respectively [8]. Figure 2 shows the superposition of the pulse-height spectra of ^{137}Cs (662 keV) on a 9 cm $\phi \times 2$ cm thick crystal, and ^{241}Am (59.6 keV) on a 2 cm $\phi \times 0.5$ cm thick crystal. Since the 662 keV photons interact primarily through Compton scattering, the average energy loss in this crystal is less than half this value. Because of the high index of refraction of BaF_2 (and thus its small critical angle), the lack of reflectors, and geometric considerations, no more than 10% of the light in the 225 nm continuum reaches the photocathode. The detection efficiency for ^{241}Am was $\geq 10\%$ and, correcting for the finite thickness of the crystal, the detection efficiency for ^{137}Cs was $\geq 45\%$. From this we can estimate that the quantum efficiency at 225 nm is on the order of 1% or better. It has been shown that, at least in the case of removing electrons from liquid xenon into xenon gas, there is a dramatic dependence of efficiency on electric field strength [9]. In future designs that allow considerably higher fields on the cathode, higher efficiency and a lower energy threshold can be hoped for.

One can imagine many applications for the liquid photocathode coupled to BaF_2 , such as imaging γ -ray detectors for medicine, positron-emission tomography, and use with a coded aperture plate for γ -ray astronomy [10]. In particle physics, it may offer high energy and spatial resolution calorimeters (a 1 GeV electron will produce 2×10^6 photons in the 225 nm continuum of BaF_2), while greatly increasing the number of radiators available for Cherenkov ring imaging. Since light of 250 nm will pass through 1 m of water [11], there may be applications for this device in proton decay experiments.

There is a great deal of work left to do. The efficiency of the TMAE liquid photocathode must be determined as a function of thickness, electric field strength, counter gas pressure, and photon wavelength. We intend to investigate

the use of a semitransparent photocathode, deposited directly on the BaF_2 or the quartz windows, which is necessary for high spatial resolution γ -ray imaging. We have measured the melting point of TMAE to be about -2.5°C ; thus it is easy to solidify and may be an interesting photocathode. There are also many other materials with low values of I_g which were not considered before because of their low vapour pressure but which may now be of interest as a liquid. We feel that the work reported here may open up a new field of large, high spatial resolution, UV photon and γ -ray imaging detectors.

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Table 1

Measured values of I_g and E_{th} (in TMS)
for several of the tetraaminoethylenes [6]

Compound	I_g		E_{th}	
	nm	eV	nm	eV
TMAE	231	5.36	350	3.54
TMBI	229	5.41	340	3.65
TMAB	221	5.60	324	3.83
TMPD	200	6.20	281	4.40

Table 2

Transmission of UV filters

Filter No.	Peak		10% of peak transmission			
	nm	eV	nm	eV	nm	eV
03 FIR 035	282	4.4	294	4.2	273	4.5
03 FIU 019	300	4.1	315	3.9	290	4.3

Figure captions

Fig. 1 : Schematic of the liquid photocathode and wire chamber.

Fig. 2 : Pulse height spectra of ^{137}Cs (white) and ^{241}Am γ -rays (black) made with BaF_2 as the scintillator.

LIQUID PHOTOCATHODE

Fig. 1

Fig. 2