Detectors in Instrumentation

Photomultiplier Tubes

• photochathode (K) converts photons into electrons
• dynodes amplify the electrons

\[ \text{voltage divider chain} \]

\[ \begin{align*}
\text{Cathode} & \quad \downarrow \\
\text{Dynodes} & \quad \downarrow \\
\text{anode} & \quad \downarrow \\
\text{hv} & \quad \downarrow \\
\text{quantum efficiency} & \quad \downarrow
\end{align*} \]

quantum efficiency

• quantum efficiency - number of photoelectrons emitted per incident photon
  – 100% - electron
  – all photoemissive devices have < 100%
  – typical PMT 25% (1 in 4 photons releases electron)
• photon hits metallic surface
  – no electrons emitted below certain frequency - characteristic of material
  – kinetic energy of electrons independent of light intensity
  – kinetic energy increases with \( v \)
  – electrons emitted instantaneously (<nanosecond)

RCA - Photomultiplier manual, (1970) Fig. 92, pg 183
Work function

Energy of a photon
\[ E_p = \frac{hc}{\lambda} = h\nu \]

note that \[ E_p = \frac{1239.5}{\lambda} \text{ eV} \] (\( \lambda \) in nm)

maximum kinetic energy of liberated electron \[ K_{\text{max}} = h\nu - \phi \]
\( \phi \) is the work function

minimum energy with which electron bound to metal

photons of visible light 400 - 700 nm have 3.1 to 1.8 eV

<table>
<thead>
<tr>
<th>Metal</th>
<th>( \phi ) (eV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Na</td>
<td>2.46</td>
</tr>
<tr>
<td>Al</td>
<td>4.08</td>
</tr>
<tr>
<td>Cu</td>
<td>4.70</td>
</tr>
<tr>
<td>Zn</td>
<td>4.31</td>
</tr>
<tr>
<td>Ag</td>
<td>4.73</td>
</tr>
<tr>
<td>Pt</td>
<td>6.35</td>
</tr>
<tr>
<td>Pb</td>
<td>4.14</td>
</tr>
<tr>
<td>Fe</td>
<td>4.50</td>
</tr>
</tbody>
</table>

Table from Physics for Scientists and Engineers, Serway, 1982 (Table 40.1)

quantum mechanical explanation

- photon gives all its energy to electron
- photons with \( h\nu < \phi \) don’t release electron
- easily ionized elements used for photocathodes
- number of photons (intensity) irrelevant

PMT spectral response

- different photocathodes different response
- quantum efficiency ~ 25 - 30% max

- typical cathode materials:
  - K<sub>2</sub>CsSb (bialkali)
  - Cs<sub>3</sub>Sb
  - Ag-O-Cs
  - (Cs)Na<sub>3</sub>KSb (trialkali)

sensitivity mA/watt

30% QE

wavelength (nm)

PMT brochure - EM 1976
inside front cover
PMT dynode configurations

- box and grid
- circular focused
- linear focused
- Venetian blind

**typical side on PMT**

- side window
- circular focused tube (e.g., RCA 1P28)
- 1000 volts max
- typical operating 600 V
- 9 dynodes
- gain $10^6$
- rise time 2ns
- cathode size 8 x 24 mm

PMT dynode configurations

- Choice of configuration depends on:
  - tube diameter requirement
  - pulse response time
  - Venetian blind - largest input area
  - linear focused - fastest response time
  - current capability
  - gain/voltage slope
Gain vs number of dynodes

![Graph showing gain vs number of dynodes](image)

SbCs dynodes

voltage applied cathode to anode

**Temperature and dark count**

- no light
- dark count (dark current)
- units - counts per second
- varies with area of photocathode

![Graph showing temperature and dark count](image)

T degrees centigrade

**Array detectors**

![Diagram of array detectors](image)
one pixel - the potential well

- \(+ve\) potential to gate
  - creates depletion region to store electrons
- light creates electrons

charge transfer

- multiple gates
  - potential wells moved by switching voltages
- charge from any source moved to serial register for readout

CCD readout

- image created
- rows shifted in parallel
- once in serial register pixels shifted individually towards output node
- next row shifted into register after clearing 1st
Total luminescence instrument

![Diagram of luminescence instrument](image)

**Fig. 15-8** Dispersion on the detector

![Diagram of dispersion on detector](image)

Dispersion on the detector

Quantum efficiency of detectors

![Diagram of quantum efficiency](image)

**Fig. 6** Quantum efficiency of detectors

- UV response of CCD is poor and needs back-thinned version
SNR for various detectors

100% QE, zero dark noise, zero read noise

PMT better at short integration times
Charge devices better at long integration times

Fig. 8, Sweedler et al., Anal. Chem. (1988) 60, 282A

light sources

- tungsten filament:
- hydrogen or deuterium lamp
- mercury lamp:

Some light source spectra

Both these sources give deep uv radiation
High pressure Xenon-arc has strong uv output.
More light source spectra

Tungsten used primarily in the visible

Mercury lamps give strong uv at 253 nm not shown here

RCA - Photomultiplier manual, (1979), pg 120/121