A simple model for the QE of CsI coated MCPs – M. Juda

The QE of CsI coated MCPs is a function of how easily the electrons generated by the absorption of the x-ray photon can escape from the CsI photocathode. There are two populations of electrons: the primary electrons (initial photoelectron and Auger electrons) and secondary electrons (generated by interactions of the primary population within the photocathode). We'll assume that once the electrons leave the photocathode they are amplified in the MCP and detected. Thus the QE of the detector should be 1-P_{zero}, where P_{zero} is the probability that no electrons are produced when a photon interacts with the photocathode.

Useful constants & conversions:

$angstrom := 10^{-8}\cdot cm$ $\quad eV := 1.602177\cdot 10^{-12}\cdot erg$ $\quad keV := 10^{3}\cdot eV$ $\quad \mu g := 10^{-6}\cdot gm$

$c := 2.99792458\cdot 10^{10}\cdot cm\cdot sec^{-1}$ $\quad h := 6.6260755\cdot 10^{-27}\cdot erg\cdot sec$ $\quad Eto\lambda(e) := \frac{h\cdot c}{e}$ $\quad \mu m := 10^{-6}\cdot m$

Interaction of photons with the photocathode are governed by the photoelectric absorption cross section. The cross section can be calculated from the forward scattering factors tabulated by Henke et al. (1993).

$A_{Cs} := 132.905$ Cs atomic weight

$A_{I} := 126.9044$ I atomic weight

$cs_f_data := READPRN(cs)$

$i_f_data := READPRN(i)$

$m := 0 .. length\left(cs_f_data^{\langle 0\rangle}\right) - 1$

$n := 0 .. length\left(i_f_data^{\langle 0\rangle}\right) - 1$

$E_{Cs_m} := \left(cs_f_data^{\langle 0\rangle}\right)_m\cdot eV$

$E_{I_n} := \left(i_f_data^{\langle 0\rangle}\right)_n\cdot eV$

$f1_{Cs_m} := \left(cs_f_data^{\langle 1\rangle}\right)_m$

$f1_{I_n} := \left(i_f_data^{\langle 1\rangle}\right)_n$

$f2_{Cs_m} := \left(cs_f_data^{\langle 2\rangle}\right)_m$

$f2_{I_n} := \left(i_f_data^{\langle 2\rangle}\right)_n$

f_x and μ_ρ_x are the imaginary part of the scattering factor and mass absorption cross section.

$f_{cs}(E) := linterp\left(E_{Cs}, f2_{Cs}, E\right)$

$f_{I}(E) := linterp\left(E_{I}, f2_{I}, E\right)$

$\mu_\rho_{cs}(E) := 4.2079\cdot 10^{7}\cdot\frac{f_{cs}(E)}{A_{Cs}}\cdot\frac{eV}{E}\cdot cm^{2}\cdot gm^{-1}$

$\mu_\rho_{I}(E) := 4.2079\cdot 10^{7}\cdot\frac{f_{I}(E)}{A_{I}}\cdot\frac{eV}{E}\cdot cm^{2}\cdot gm^{-1}$

$\mu\rho_{CsI}(E) := \frac{A_{Cs}\cdot\mu_\rho_{cs}(E) + A_{I}\cdot\mu_\rho_{I}(E)}{A_{Cs} + A_{I}}$ mass absorption cross section for CsI

I described a model for the secondary electron yield in an earlier memo (HRC MCP Photocathode Yield, October 27, 1994). Briefly, since it has been observed experimentally that the energy distribution of the secondary electrons is independent of photon energy, the secondary electron yield is determined by the mean energy deposited within one electron escape depth of the surface of the photocathode divided by the mean energy of the secondary electrons.

So for a CsI photocathode with a density of ρ_{CsI}, a mean range of secondary electrons of λ_s, a mean secondary energy of E_s illuminated at normal incidence, the yield of secondary electrons is given by:

$\rho_{CsI} := 4.51 \cdot gm \cdot cm^{-3}$ bulk density of CsI

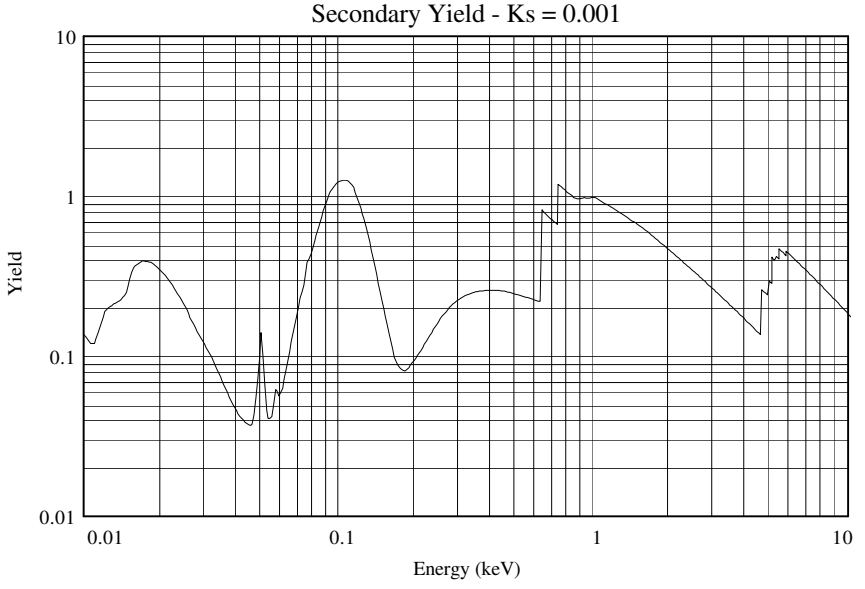
$\lambda_s := 250 \cdot angstrom$ range of secondary electrons in CsI (Henke, Knauer, & Premaratne 1981)

$E_s := 1 \cdot eV$ value guessed from plot in Henke, Knauer, & Premaratne (1981)

$\phi := 84.0 \cdot deg$ Angle with respect to normal incidence to the photocathode

$$yield_{secondary}(E, K_s) := \frac{E \cdot \mu\rho_{CsI}(E) \cdot \rho_{CsI} \cdot \lambda_s}{E_s \cdot \cos(\phi)} \cdot K_s$$

The constant of proportionality K_s could be dependent on the deposition and should be adjusted to match the actual secondary electron yield.

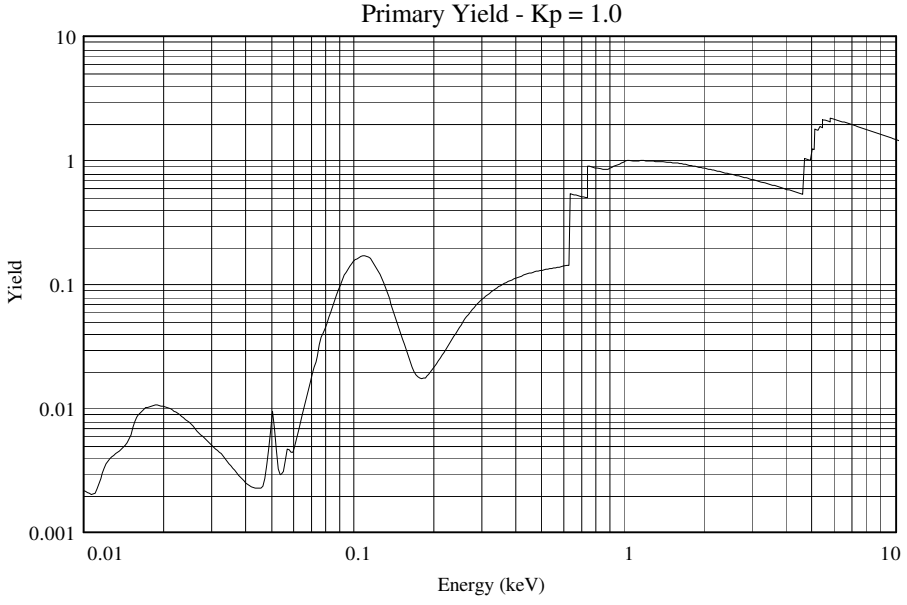


The primary electron yield can be described following arguments similar to those for determining the yield of secondary electrons (Henke, Knauer, and Premaratne 1981). The energies of the primary electrons should be proportional to the photon energy. However the range of primary electrons will be a function of their energy (and hence, via the previous statement, the photon energy). The range of the primary electrons is most likely given by the practical range using an extrapolation of the Bethe-Bloch continuous-slowing-sown-approximation:

$R_0 := 250 \cdot angstrom$ I created a dummy range normalization of 250 angstroms at 1 keV
Note that only the product of R_0 and K_p matters.

$\lambda_p(E) := R_0 \cdot \left(\frac{E}{keV}\right)^{1.9}$ [Should have a $E^{1.9}$ dependence]

$$yield_{primary}(E, K_p) := \frac{\mu\rho_{CsI}(E) \cdot \rho_{CsI} \cdot \lambda_p(E)}{\cos(\phi)} \cdot K_p$$



The total electron yield is just the sum of the primary and secondary yields:

$$yield(E, K_p, K_s) := yield_{primary}(E, K_p) + yield_{secondary}(E, K_s)$$

Only the fraction of the MCP area that are the pores can actually detect photons. so this provides the maximum possible QE. The MCP pores are arranged in a hexagonal pattern.

GEOC MCPs: $D_{pore} := 10\cdot\mu m$ $Pitch_{pore} := 12.5\cdot\mu m$ $f_{pore} := \frac{\pi\cdot\left(\frac{D_{pore}}{2}\right)^2}{\left(\frac{\sqrt{3}}{2}\right)\cdot Pitch_{pore}^{2}}$

$f_{pore} = 0.58$

I use Poisson statistics with the mean given by the yield to determine the probability of producing at least one electron (actually use 1.0 minus the probability of getting zero electrons). The QE of a pore of the MCP will just be the probability of yielding at least one electron.

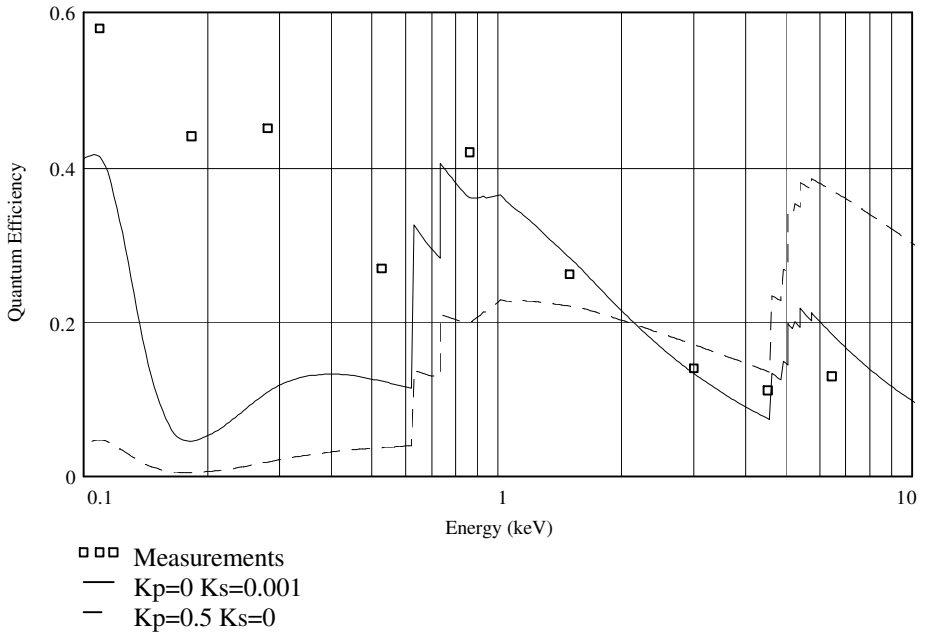
$QE_{model}(E, K_p, K_s) := \left(1 - ppois\left(0, yield\left(E, K_p, K_s\right)\right)\right)\cdot f_{pore}$

(Note: the probability of getting zero electrons assuming Poisson statistics could also be written as exp(-yield).)

The QE of CsI coated MCPs have been measured in the laboratory at a few energies; we can use these for comparison with the model to refine the model parameters.

$qe_data := READPRN(mcp_qe)$

$E_{meas} := qe_data^{\langle 0\rangle}\cdot keV$ $QE_{meas} := qe_data^{\langle 1\rangle}$ $i := 0 .. length\left(E_{meas}\right) - 1$



It is quite evident that there is no linear combination of primary and secondary yields from this model that will result in a good fit to the measured data. The QE at low energy is much higher than expected based on the mass absorption cross section of CsI.

We can take a slightly different approach and try to empirically derive a function of energy that can be used with the mass absorption cross section to generate the photocathode yield. Starting with the measured QE vs energy and assuming Poisson statistics, we can work backward to get a yield and then remove the dependence on the mass absorption cross section.

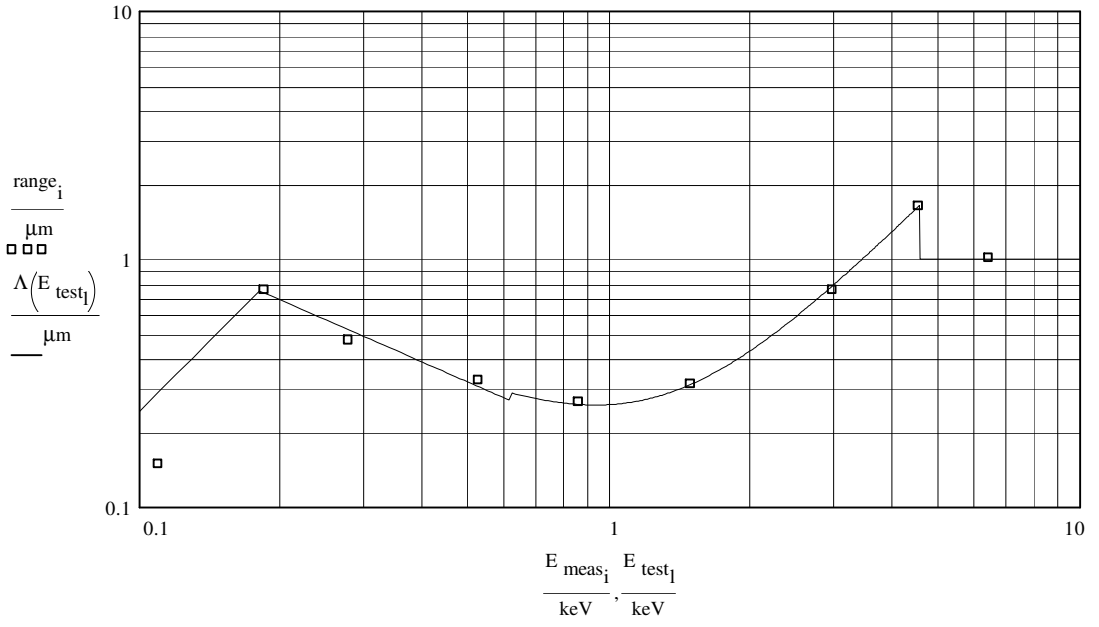
$$range_i := \frac{-\ln\left(1 - \frac{QE_{meas_i}}{f_{pore}}\right)}{\mu\rho_{CsI}\left(E_{meas_i}\right)\cdot\rho_{CsI}}$$

Except for the Be-K and Fe-K points, the data result in a reasonably smooth curve. Just guessing at a rough crude shape for this curve we can get a second model for the yield of the photocathode and the QE.

We can try to create a piece-wise ad-hoc model for the effective "range" as a function of energy that goes through the derived values (we won't force the poorly determined Be point).

$$\Lambda(E) := \begin{cases} \left(\frac{E}{keV}\right)^{-0.83}\cdot 0.18\cdot\mu m & \text{if } 0.18\cdot keV < E < 0.620\cdot keV \\ \left(\frac{E}{keV}\right)^{1.9}\cdot 0.09\cdot\mu m + \left(\frac{E}{keV}\right)^{-0.83}\cdot 0.17\cdot\mu m & \text{if } 0.620\cdot keV \le E \le 4.557\cdot keV \\ (1\cdot\mu m) & \text{if } E > 4.557\cdot keV \\ \left[0.747\cdot\mu m\cdot\left(\frac{E}{0.18\cdot keV}\right)^{1.9}\right] & \text{if } E \le 0.18\cdot keV \end{cases}$$

$$l := 0 .. 1000 \qquad E_{test_l} := (0.01 + l\cdot 0.01)\cdot keV$$

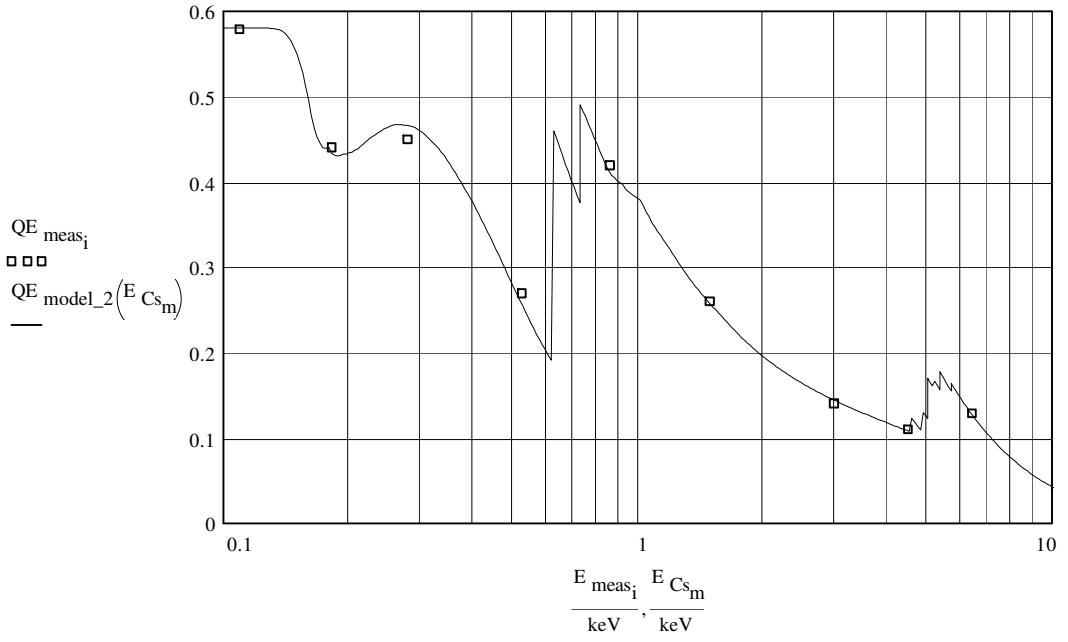


The yield and QE can be calculated in a similar fashion as before:

$$\text{yield}_2(E) := \Lambda(E)\cdot \rho_{CsI}\cdot \mu\rho_{CsI}(E)$$

$$QE_{model_2}(E) := \left(1 - \text{ppois}\left(0, \text{yield}_2(E)\right)\right)\cdot f_{pore}$$

Below is a figure that compares the QE derived from measurements for this model.



Write out a table with this model for the QE of CsI coated MCPs

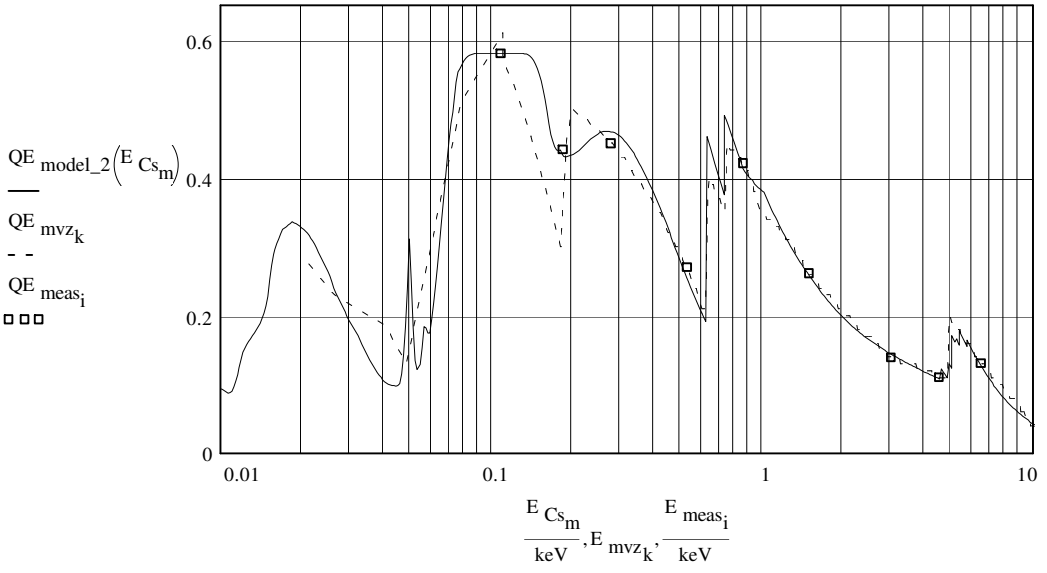
$$\text{column1} := \frac{E_{Cs}}{eV} \qquad \text{column2}_m := QE_{model_2}\left(E_{Cs_m}\right)$$

$$\text{WRITEPRN}(\text{qeoutput}) := \text{augment}(\text{column1}, \text{column2})$$

Martin Zombeck has provided the ASC with a QE curve derived from lab measurements - we can compare this with the model curve derived here.

$MQE := READPRN(mvzhrcqe)$

$E_{mvz} := MQE^{\langle 0 \rangle}$ $QE_{mvz} := MQE^{\langle 1 \rangle}$ $k := 0 .. length(E_{mvz}) - 1$



Apart from the 0.1 – 0.3 keV range the overall shape of the two curves are not very different.