QE (Quantum Efficiency) curves are transfer curves, describing for a given amount of light at a given wavelength received by a pixel, how much of an output response to expect. QE curves can be expressed in Relative units where the y-axis has been normalized such that the highest peak value is 1.00 or 100%. QE curves can also be expressed in Absolute units of Amps per Watts.

If you have a QE curve expressed in A/W but need to have units expressed as uJ/ m²/DN. How do you make the conversion? We will show two methods.

**METHOD 1**

The unit of A/W is equivalent to C/J (the seconds divide out of the numerator and denominator).

\[ A = \text{Amp} = \frac{C}{S} = \text{coulomb/seconds} \]
\[ W = \text{Watt} = \frac{J}{S} = \text{joules/seconds} \]

\[ \frac{A}{W} = \frac{\left(\frac{C}{S}\right)}{\left(\frac{J}{S}\right)} = \frac{C}{J} \]

Next, convert C/J into counts/J, assuming that the pixel full well (45,000 e-) corresponds to full scale (4095 counts for 12-bit A/D converter), and using the charge of an electron.

Next, multiply by the pixel area (20 um)(20 um) and then invert to obtain the sensitivity of the sensor. Using this method, and using approximately what the sensitivity is at 766 nm on the QE chart for the SA1.1 (about .17 A/W) we get 0.0259 uJ/ m²/DN.

**METHOD 2**

This alternate method is described in CCD Arrays, Cameras & Displays, Gerald C. Holst, pg 99, eq 4-10. Responsivity (approximated for a given wavelength)

\[ \text{If wavelength units needs to be microns – wavelength/1.24} \]
\[ A = \text{pixel area} \]
\[ 2n \times \text{wavelength} \times A \times \text{QE represented in units of DN/J/cm}^2 \]
\[ \text{e-fw} \times 1.24 \]
\[ = (4096/45,000) \times (766/1.24) \times (400/10) \times 0.17 = 382.4 \text{ DN/uJ/cm}^2 \]
Note: area needed to be converted to cm

Since the inverse of the responsivity is the sensitivity to the light stimulus

Sensitivity @ 766 nm = 1/382.4 DN/µJ/cm² = 0.002615 µJ/cm² /DN = 0.02615 µJ/m² /DN

compared to Method 1 of 0.0259 µJ/m²/DN

charge of (1) electron is approximately -1.602×10⁻¹⁹ C

full well = 45,000 e-

DN4096 = 45,000/4096 = 10.986328125 e-/ DN

Pixel Area = 20µ x 20µ = 400µ

Therefore, DN has a charge of:

10.986328125 e-/ DN x 1.602×10⁻¹⁹ C/e- = 17.60 x 10⁻¹⁹ C/DN

And (1) count of a DN4096 = 7.209 x 10⁻¹⁵ C/4096 = 1.760009765625 x 10⁻¹⁹ C/DN

C convert to counts = 4096/7.209 x 10⁻¹⁵ = 5.68 e⁻¹³

@ 766 nm the responsivity is 0.17 A/W = 0.17 C/J = 0.17 x 5.68 e⁻¹³ = 0.9656 e⁻¹³

ADDITIONAL NOTES

Responsivity is the ratio of the optical detector (pixel) output photocurrent (or voltage) in amperes (or volts) to the incident optical power in watts.

Where n is the QE

R ~ [0.766/(1.23985)] x 0.2752 ~ 0.170

A photodiode’s capability to convert light energy to electrical energy, is expressed as a percentage, called the Quantum Efficiency, (Q.E.). The sensitivity of a photodiode may also be expressed in absolute units of amps of photodiode current per watt of incident illumination. The QE is related to the photodiode’s responsivity by this equation:

R[A/W] is the responsivity. In our case at 766 nm & if R[A/W] is 0.17.

QE = (1.24 x 105 x 0.17)/766 = 27.52%

Note: Fill Factor is already considered in a QE measurement since the effective pixel area exposed includes the FF.

www.visionsystech.com
Sensitivity is the ratio of the pixel output change (voltage or current) obtained after an exposure time to the amount of light change that has a specific wavelength.

Converting Units:

charge of (1) electron is approximately $-1.602 \times 10^{-19}$ C

$1V = 1$ joule/coulomb

The responsivity of can be expressed as DN/(nJ/cm²). The unit DN stands for Digital Number, which is the digital pixel value and (nJ/cm²) is the level of illumination coupled with the exposure time in the camera. Another common unit used for camera response is lux-sec. Illumination can be expressed in lux or candelas. However, to state correctly the responsivity of a camera, the incident light on the sensor has to be related to exposure time, hence lux-sec. To compare different units you must convert one system of units to the other. The conversion for 1 lux-sec = 0.159 nJ/cm². The radiometric expression of $\frac{DN}{(nJ/cm^2)}$ indicates, for a known exposure of 1 nJ/cm², the camera will output pixel data of $\times$ DN (digital numbers).

Who is needing it?
Anyone needing to compare one manufactures camera to another or when you want to know the pixel output in DN (digital numbers) based on a given input illumination level.

Further Information on Converting QE Units:
CCD Arrays, Cameras & Displays,
Gerald C. Holst, pg 99, eq 4-10