List of particle species that can be detected by Micro-Channel Plates and similar secondary electron multipliers.

A Micro-Channel Plate (MCP) can detected certain particle species with decent quantum efficiency (QE). Commonly MCP are used to detect charged particles at low to intermediate energies and to register **photons from VUV to X-ray** energies. “Detection” means that a significant charge cloud is created in a channel (pore).

Generally, a particle (or photon) can liberate an electron from channel surface atoms into the continuum if it carries sufficient momentum or if it can transfer sufficient potential energy. Therefore, fast-enough **neutral atoms** can also be detected by MCP and even **exited atoms** like He* (even when “slow”). At least about 10 eV of energy transfer is required to release an electron from the channel wall to start the avalanche. This number also determines the cut-off energy for photon detection which translates to a photon wave-length of about 200 nm (although there can be non-linear effects at extreme photon fluxes enhancing this cut-off wavelength).

Not in all cases when ionization of a channel wall atom is possible, the electron will eventually be released to the continuum: the surface energy barrier has to be overcome and the electron must have the right emission direction. Also, the electron should be born close to surface because it may lose too much energy on its way out due to scattering and will be absorbed in the bulk. These effects reduce the QE at for VUV photons to about 10%. At EUV energies QE cannot improve much: although the primary electron energy increases, the ionization takes place deeper in the bulk on average and the electrons thus can hardly make it to the continuum. For the same reason the QE dies out at gamma ray energies as the MCP becomes virtually transparent. Surface coatings, e.g. with CsI or KBr, can increase the QE but are unstable when exposed to ambient air much.

Electrons and other charged particles (also fast neutrals) can achieve higher QE because they produce primary electrons more efficiently by Coulomb interaction, possibly more than one primary electron can be liberated on impact. For the fraction of those hitting the channel wall surface the QE can be close to 100%. A limiting factor for the maximum QE of MCP is the open area ratio (OAR) of the first MCP, i.e. the ratio of area covered by open channels and the total active area. If a particle or photon does not hit inside a channel on the photo-emissive surface but on the “grid”, chances for avalanche creation in a neighbouring channel is small. Therefore, MCP with larger OAR than the standard value (around 60%) will typically show a higher QE[i] (only for particles producing many primary electrons the improvement is negligible).

The QE for **electrons** reaches this OAR-limited maximum QE of almost 60% for an impact energy range between 100eV and 1000eV. The QE remains considerably high (40-50%) down to few 10 eV and up to few 10 keV.

The QE for **ions** or **neutral atoms/molecules** depends on the ratio of impact energy to the square root of mass over a wide range of energy and mass. If the energy is measured in keV and the mass in Dalton (= atomic mass unit) the OAR-limited maximum QE of about 60% is achieved for $E/\sqrt{m} > 1$. As this value drops the QE diminishes, passing 10% at about $E/\sqrt{m} = 0.1$. Example: a He atom (charged or neutral) with 2 keV kinetic energy has $E/\sqrt{m} = 1$ and therefore the maximum QE. For Argon or CO_2 at same energy QE is reduced to about 40%.

As long as a particle is charged it is possible to increase its kinetic energy at impact on the MCP by biasing the MCP stack's front side to a favourable potential, e.g. +200 V for electrons or to a few kV for ions (positive or negative, depending on ion charge). Thus it is possible to even detect charged particles born with **near zero kinetic energy** (slow **bio-molecules** with high Daltons may need potentials beyond 10 keV on MCP front which is difficult to handle).

For **medium to high energy ions/neutrals** (beyond few 10 keV) QE may approach 100% due to multi-fold ionization events on impact. At the same time the mean pulse height (charge cloud) for a detected particle will increase.

It is to mention that atoms irradiating the MCP surface with "favourable" energy (high QE) produce considerably more wear-out by spurious sputtering effects compared to electron or photon impact. This leads to deterioration of QE (premature aging) and gain loss which is a considerable problem especially if irradiation is inhomogeneous which will lead to a non-uniform response eventually.

MCP are consumables and there QE and gain changes with exposure.

It is also important to remember that **QE** is a **function of incidence angle**. If the incidence direction of a particle or photon is aligned with the channel axis, the QE drops to zero. For a relative angle between 8^o and 20^o the QE is maximal with a rather steep drop-off at smaller relative angle and a smooth decrease towards larger angles. This means that particle and photons that are impinging normal to the surface will have maximum QE for typical pore tilt angles.

Highly transparent **meshes** biased slightly more negative can increase the quantum efficiency in driving back-scattered from the MCP face towards the pores but they may also block off impinging particles/photons and thus deteriorate this positive effect. Moreover, **meshes can affect the spatial resolution** (micro-lensing) and even the temporal precision. This has also to be considered if a mesh serves a potential shield for a field-free zone against penetration from the high MCP front side potential.

To determine the **effective QE** of a detection system, not only the presence of meshes and possible aging effects, e.g. from long-term use must be taken into account but also whether all initiated charge avalanches are registered by the read-out anode and follow-up electronics.

If timing electronics is properly set and the MCP is operated decently in saturated mode with sufficient gain, every charge count avalanches will lead to a "count". Counts will be lost if the **electronic threshold level** is set too high so that "small" avalanches are not registered. Even in case of proper settings, **aging effects** on the MCP (possibly only local) may lead to lost counts.

In some cases an increased electronic threshold may set on purpose, sacrificing counts for achieving a better **signal-to-noise ratio** (= resolution) or to discriminate against **dark counts** or other background with low pulse heights or **electronic noise**.

In practise it is common to cut out up to 20% of low-gain counts by setting the electronic threshold level a bit high. The use of a RoentDek **CFDx** circuit which measures the pulse height for each count is very beneficial in this respect because it allows registering all signals and to reject certain pulse heights by software later.

Besides the “classical” particles or photons as mentioned above people have used RoentDek MCP detectors also for “exotic” particles, among those:
- Thermal and “cold” neutrons (with Boron-doped MCP)
- Positrons, anti-protons, positronium (and myons)
- Anything that was converted to photons above, e.g. fast neutrons, gammas (via scintillator screen imaged by a RoentDek RS-PMT)

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[i] So-called funnelled MCP may increase the QE for some particles/energy ranges to near 90% which is especially of importance for multi-coincidence experiments. Please contact RoentDek if you have demand for this recently (re-)developed technique.