Energetic particles and their detection in situ (particle detectors)
Part III

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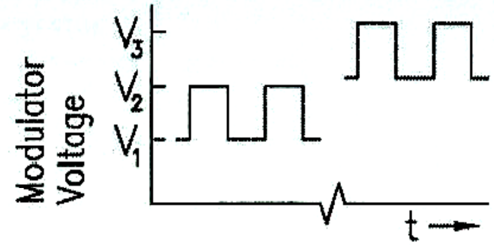
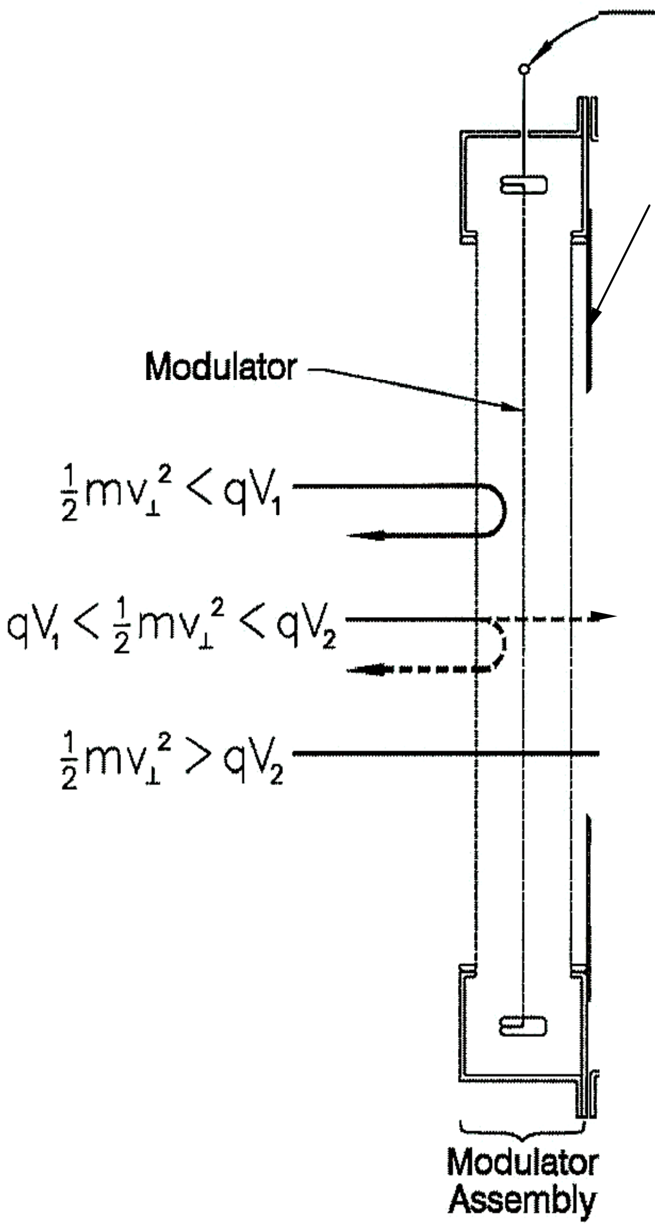
Energy Analyzers

- To measure (select) the energy of low energy (≤ ~100 keV/charge) charged particles electrostatic and magnetic *energy analyzers* are used in space instruments
- Magnetic analyzers are bulky and heavy compared to electrostatic analyzers, and require magnetic shielding to prevent interference with magnetic field measurements on the same spacecraft.
- Electrostatic analyzers often use high voltages that require special care to prevent discharge
- Incorporating UV suppression is essential since most detector systems (SSDs, CEMs, MCPs) placed behind energy analyzers are sensitive to UV
- Three types of electrostatic analyzers are discussed
  - *Retarding Potential Analyzer* (RPA) for low energies (few eV to ~ few keV/e)
  - *Spherical* and *Cylindrical Section Analyzers* (ESA) for medium energies (~ 0.1 to ~20 keV/e
  - *Small-Angle Deflection Analyzers* (SADA) for high energies (up to a few MeV/e)
- Many different configuration of analyzers are used, but they all operate by using various electric field configurations to allow only particles in a selected energy/charge (ε) window($\varepsilon_1 < \varepsilon < \varepsilon_2$) to pass through the system

Retarding Potential Analyzer





- The RPA consists of three highly transparent metal grids, an aperture stop (to define the acceptance geometry) and support structure
- It is a simple device with a large acceptance area and geometrical factor
- Its disadvantage are
  - upper energy range is limited to ~6 to 8 keV/e
  - UV suppression is very difficult
- The energy of incoming ions is determined by applying to the central metal grid a time-varying, dc-biased square wave potential that varies from V_1 to $V_1 + \Delta V$ (V and ΔV can be changed)
- Ions with 'perpendicular' energies, $mv^2_\perp < 2qV_1$, are rejected, those with $mv^2_\perp > 2q(V_1 + \Delta V)$ are accepted and ions with energies in between are either accept or reject depending on whether the modulating voltage is in its high or low step

Spherical and *Cylindrical Section Analyzers* (ESA)

- Charged particles are deflected by the electric field between the inner and outer concentric spherical (or cylindrical) section electrodes

- Only particles having the right energy per charge ε and arrival directions will pass through the entrance aperture and ESA to be detected without first hitting one of the electrodes

- The mean energy per charge $\mathcal{E}$ of the particle arriving at the detector is

□ $\mathcal{E} \approx 0.5(V_{out}\text{-}V_{in})/\ln(R_{out}/R_{in}) \approx$

□ $0.5\Delta V/(\Delta R/\langle R\rangle)$

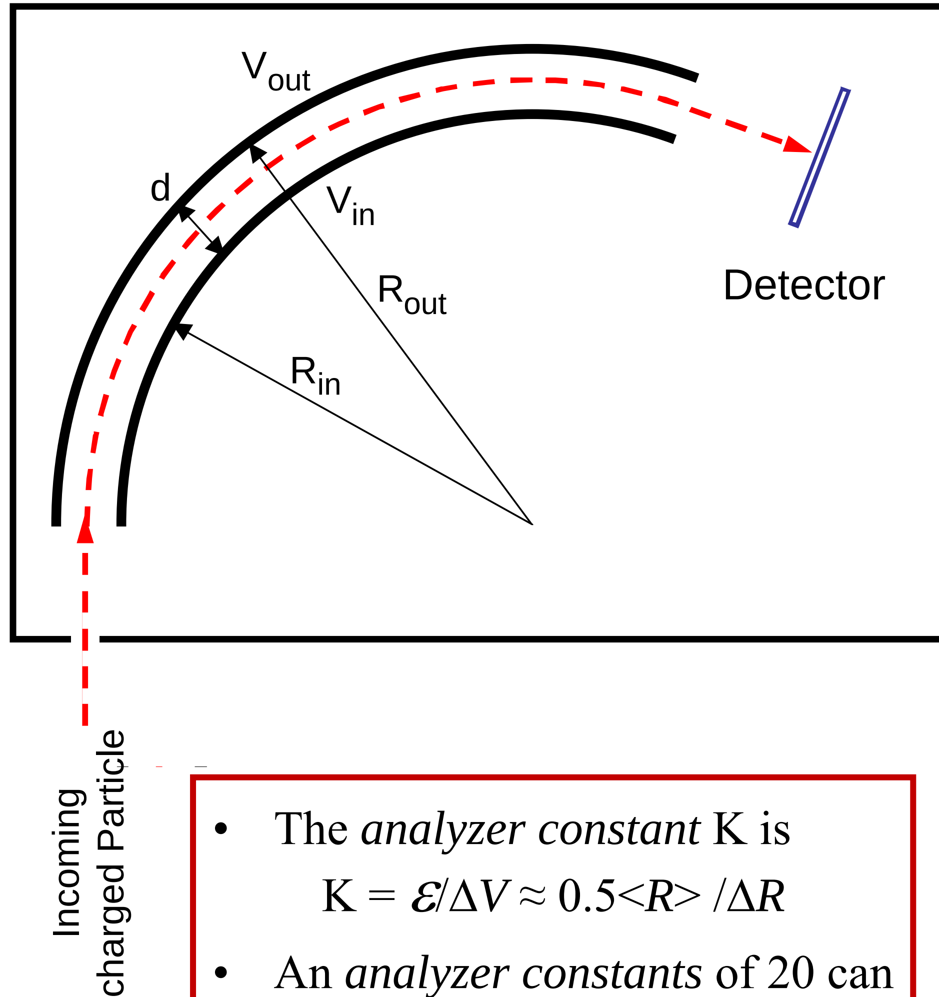
□ $\Delta R = R_{out} - R_{in}$ and $\langle R\rangle = (R_{out} + R_{in})/2$

- The energy per charge resolution is

$$\Delta\mathcal{E}/\mathcal{E} \approx \Delta R/\langle R\rangle$$

- The acceptance angle α is also

$$\alpha \approx \Delta R/\langle R\rangle$$



- The *analyzer constant* K is

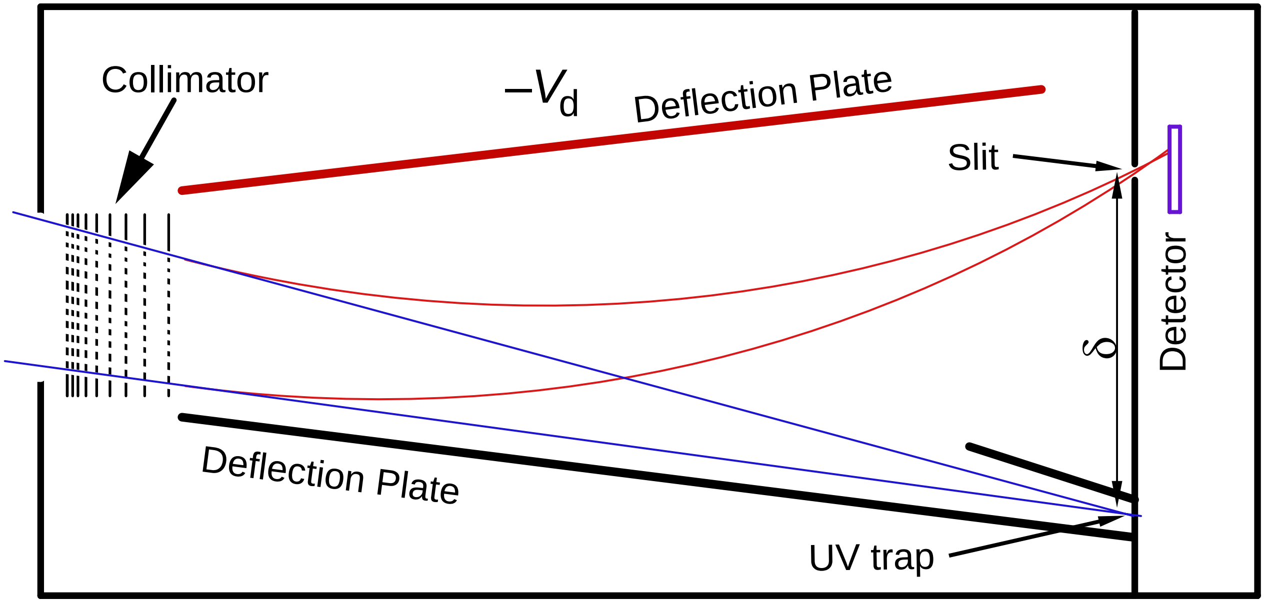
$$K = \mathcal{E}/\Delta V \approx 0.5\langle R\rangle/\Delta R$$

- An *analyzer constants* of 20 can be achieved with $\langle R\rangle = 20$ cm and a gap between the plates $\Delta R = 0.5$ cm

Small Angle Deflection Analyzer (SADA)

- Charged particles pass through a *multi-slit collimator* (which defines their incoming directions) and are then deflected by the electric field between the upper and lower deflection plates
- Only particles having the right energy per charge $\mathcal{E}$ will pass through the narrow slit and are detected (alternatively, a position-sensitive detector could be used to *measure* $\mathcal{E}$)
- The mean energy per charge $\mathcal{E}$ of the particle arriving at the detector is

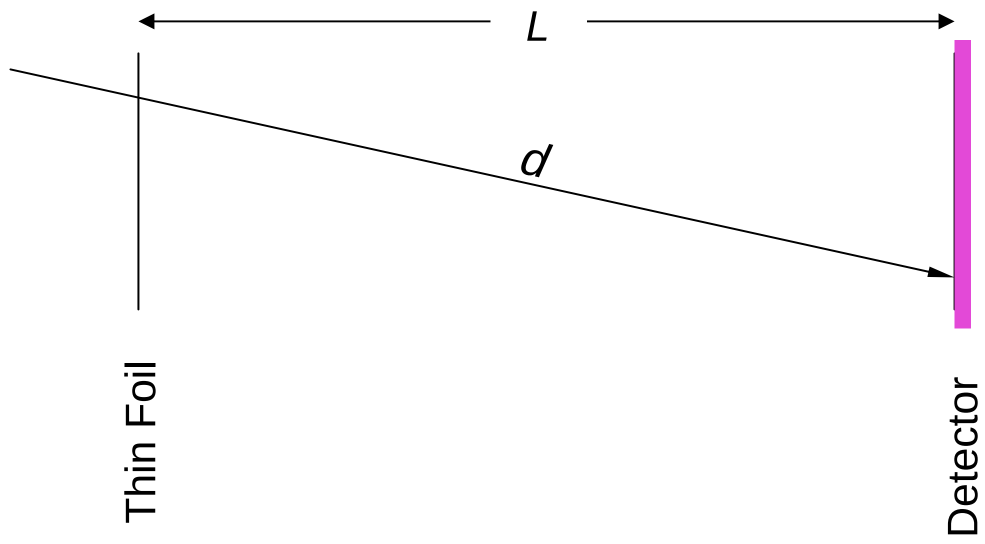
  $\mathcal{E} \approx (V_{up}-V_{lo})L^2/(4h\delta)$ where L and h are average length and separation of deflection plates
- The energy resolution is $\Delta\mathcal{E}/\mathcal{E} \approx \Delta\delta/\delta$ where $\Delta\delta$ is the slit width
- The *analyzer constant* $K = L^2/(4h\delta)$ and the *acceptance angle* $\alpha \approx h/(2L)$



The main advantage of a SADA is that particles up to several MeV/charge can be deflected since K can be large and large deflection voltages can be supported

UV trapping is effective

Time-of-flight (TOF) – Energy detector



- Measure time-of-flight, τ, between foil and detector separated by L (typically ~ 10 cm)
- Measure energy E of particles in the detector

Particle mass $m = 2E \bullet (\tau/d)^2$

mass resolution $(\Delta m/m)^2 = (\Delta E/E)^2 + (2\Delta\tau/\tau)^2 + (2\Delta d/d)^2$

typical resolutions $\Delta E = 35$ keV; $\Delta\tau = 150$ ps