Table 4.3.4.2. *Plasmon energies measured (and calculated) for a few simple metals; most data have been extracted from Raether (1980)*

Monovalent			Divalent			Trivalent			Tetravalent		
$\hbar\omega_p$ (eV)			$\hbar\omega_p$ (eV)			$\hbar\omega_p$ (eV)			$\hbar\omega_p$ (eV)		
	Meas.	Calc.		Meas.	Calc.		Meas.	Calc.		Meas.	Calc.
Li	7.1	(8.0)	Be	18.7	(18.4)	B	22.7	(?)	C	34.0	(31)
Na	5.7	(5.9)	Mg	10.4	(10.9)	Al	14.95	(15.8)	Si	16.5	(16.6)
K	3.7	(4.3)	Ca	8.8	(8.0)	Ga	13.8	(14.5)	Ge	16.0	(15.6)
Rb	3.4	(3.9)	Sr	8.0	(7.0)	In	11.4	(12.5)	Sn	13.7	(14.3)
Cs	2.9	(3.4)	Ba	7.2	(6.7)	Sc	14.0	(12.9)	Pb	(13)	(13.5)

solution, reproduced in Fig. 4.3.4.11, is due to Castaing & Henry (1962). It consists of a double magnetic prism and a concave electrostatic mirror biased at the potential of the microscope cathode. The system possesses two pairs of stigmatic points that may coincide with a diffraction plane and an image plane of the electron-microscope column. One of these sets of points is achromatic and can be used for image filtering. The other is strongly chromatic and is used for spectrum analysis. Zanchi, Sevely & Jouffrey (1977) and Rose & Plies (1974) have proposed replacing this system, which requires an extra source of high voltage for the mirror, by a purely magnetic equivalent device. Several solutions, known as the α and ω filters, with three or four magnets, have thus been built, both on very high voltage microscopes (Zanchi, Perez & Sevely, 1975) and on more conventional ones (Krahl & Herrmann, 1980), the latest version now being available from one EM manufacturer (Zeiss EM S12).

4.3.4.2.3. *Detection systems*

The final important component in EELS is the detector that measures the electron flux in the dispersion plane of the spectrometer and transfers it through a suitable interface to the data storage device for further computer processing. Until about 1990, all systems were operated in a sequential acquisition mode. The dispersed beam was scanned in front of a narrow slit located in the spectrometer dispersion plane. Electrons were then generally recorded by a combination of scintillator and photomultiplier capable of single electron counting.

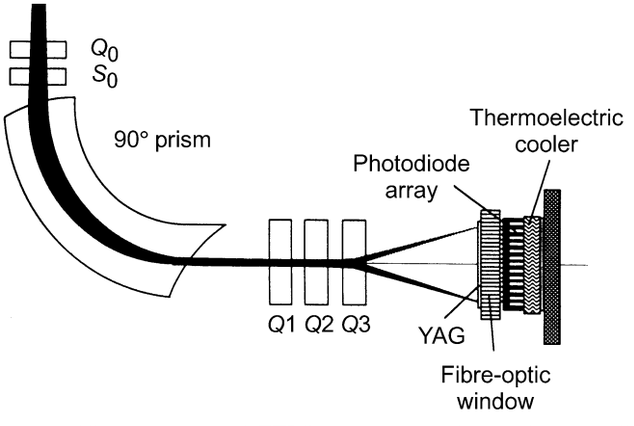

Fig. 4.3.4.12. A commercial EELS spectrometer designed for parallel detection on a photodiode array. The family of quadrupoles controls the dispersion on the detector level [courtesy of Krivanek *et al.* (1987))].

This process is, however, highly inefficient: while the counts are measured in one channel, all information concerning the other channels is lost. These requirements for improved detection efficiency have led to the consideration of possible solutions for parallel detection of the EELS spectrum. They use a multiarray of detectors, the position, the size and the number of which have to be adapted to the spectral distribution delivered by the spectrometer. In most cases with magnetic type devices, auxiliary electron optics has to be introduced between the spectrometer and the detector so that the dispersion matches the size of the individual detection cells. Different systems have been proposed and tested for recording media, the most widely used solutions at present being the photodiode and the charge-coupled diode arrays described by Shuman & Kruit (1985), Krivanek, Ahn & Keeney (1987), Strauss, Naday, Sherman & Zaluzec (1987), Egerton & Crozier (1987), Berger & McMullan (1989), *etc.* Fig. 4.3.4.12 shows a device, now commercially available from Gatan, that is made of a convenient combination of these different components. This progress in detection has led to significant improvements in many areas of EELS: enhanced detection limits, reduced beam damage in sensitive materials, data of improved quality in terms of both SNR and resolution, and access to time-resolved spectroscopy at the ms time scale (chronospectra). Several of these important consequences are illustrated in the following sections.

4.3.4.3. *Excitation spectrum of valence electrons*

Most inelastic interaction of fast incident electrons is with outer atomic shells in atoms, or in solids with valence electrons (referred to as conduction electrons in metals). These involve excitations in the 0–50 eV range, but, in a few cases, interband transitions from low-binding-energy shells may also contribute.

4.3.4.3.1. *Volume plasmons*

The basic concept introduced by the many-body theory in the interacting free electron gas is the volume plasmon. In a condensed material, the assembly of loosely bound electrons behaves as a plasma in which collective oscillations can be induced by a fast external charged particle. These eigenmodes, known as *volume plasmons*, are longitudinal charge-density fluctuations around the average bulk density in the plasma $n \simeq 10^{28}$ e^-/m^3). Their eigen frequency is given, in the free electron gas, as

$$\omega_p = \left(\frac{n e^2}{m\varepsilon_0}\right)^{1/2}. \qquad (4.3.4.8)$$

The corresponding $\hbar\omega_p$ energy, measured in an energy-loss spectrum (see the famous example of the plasmon in aluminium

 references