Experimental observations of dispersing plasmons

1. q=0 energy of the plasmon by EELS

2. plasmon dispersion by EELS

3. shift of the plasmon energy and dispersion under high pressure (increased electron density) by IXS

Electron energy loss spectroscopy (EELS)

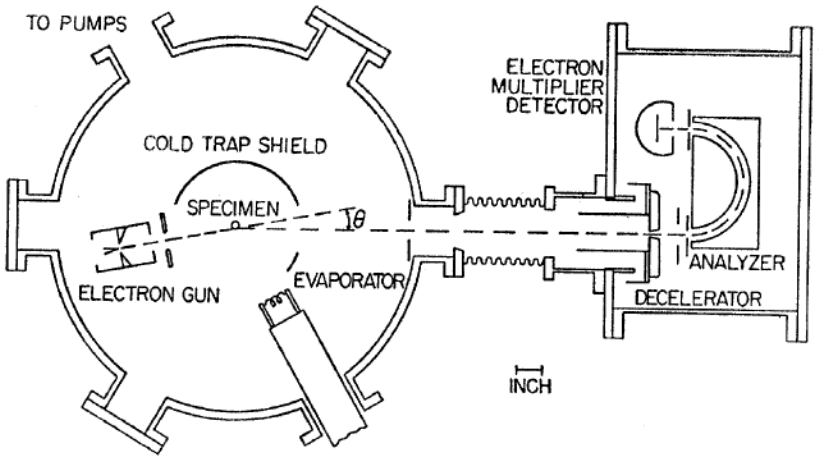

FIG. 1. Schematic outline of the apparatus.

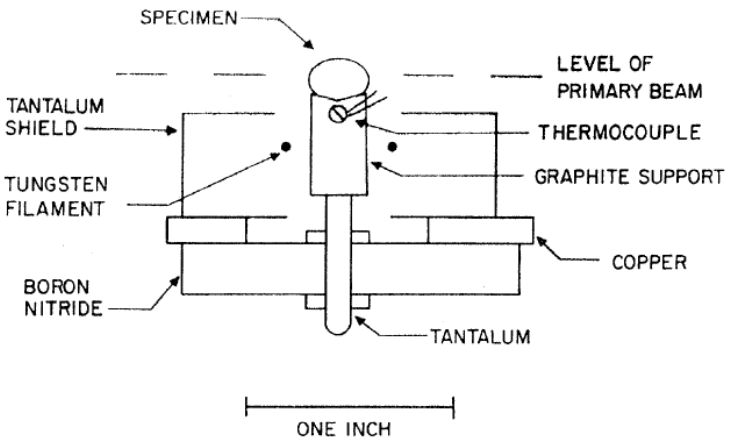

FIG. 2. Section through the specimen holder.

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Characteristic Energy Losses of 8-keV Electrons in Liquid Al, Bi, In, Ga, Hg, and Au*

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Characteristic loss spectra have been obtained in a reflection scattering geometry for liquid Al, Bi, In, Ga, Hg, and Au and, in the case of Al, Bi, and Au, for the same specimens in the solid phase. Peaks due to surface and volume plasmon excitation dominated the loss spectra for all elements except Au. The relative intensity of these peaks varied rapidly with scattering angle for the Al, Bi, In, and Ga specimens, but there was little angular variation when Al, Bi, or Au was evaporated onto a frozen substrate of the same element. The Al plasmon losses varied with temperature and changed at the melting point as would be expected from the known density variation. Changes in the Bi plasmon energy losses on melting and changes in other structure on melting have been interpreted in terms of band-structure changes. The peaks in the gold loss spectra appeared to become broader and less distinct on melting, from which it was concluded that the Au excited states had shorter lifetimes with increased disorder. In general, however, the liquid- and solid-state spectra of the same element were similar, thereby showing that for these materials there was not a large change in the electronic structure on melting.

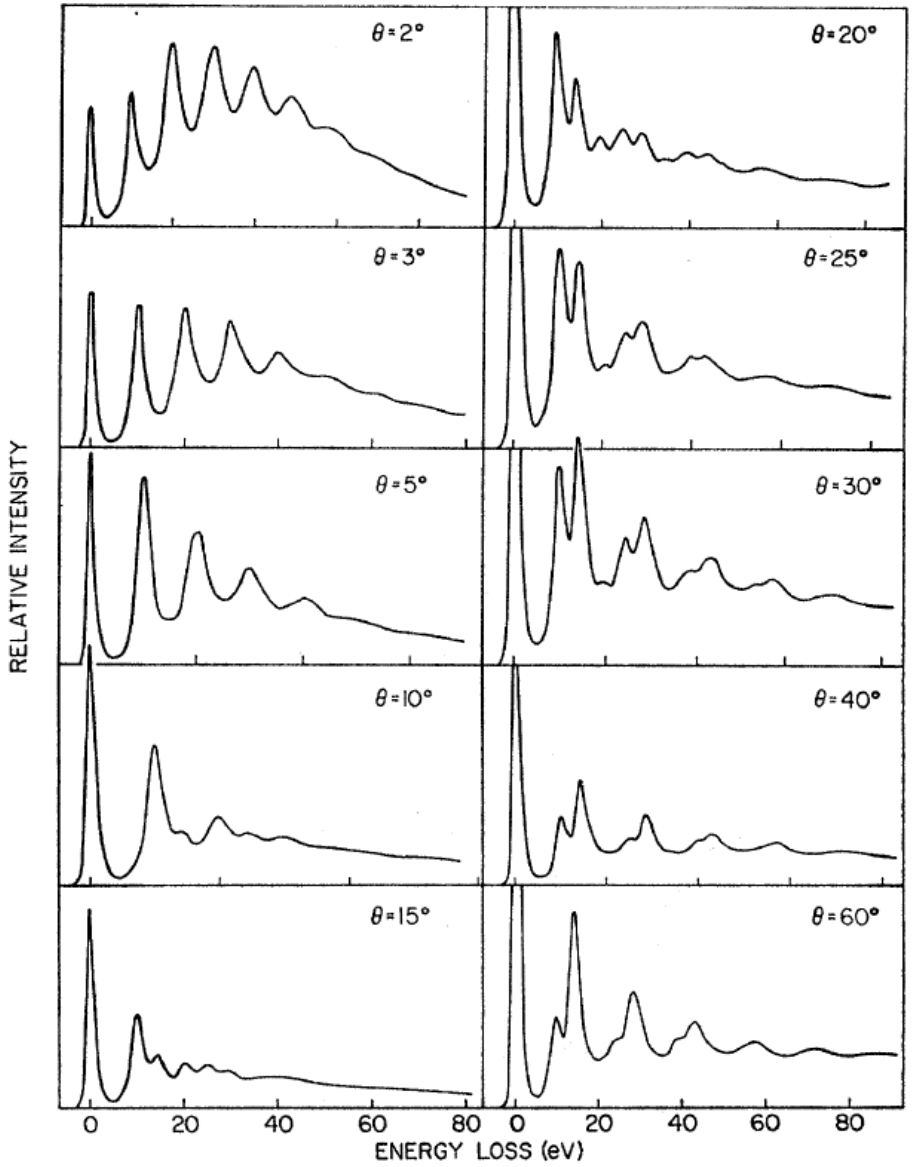

FIG. 3. Characteristic loss spectra of liquid Al for the total scattering angles θ indicated. These spectra have been traced from the original records and no direct comparison can be made between the different intensity scales; note also the different energy loss scales.

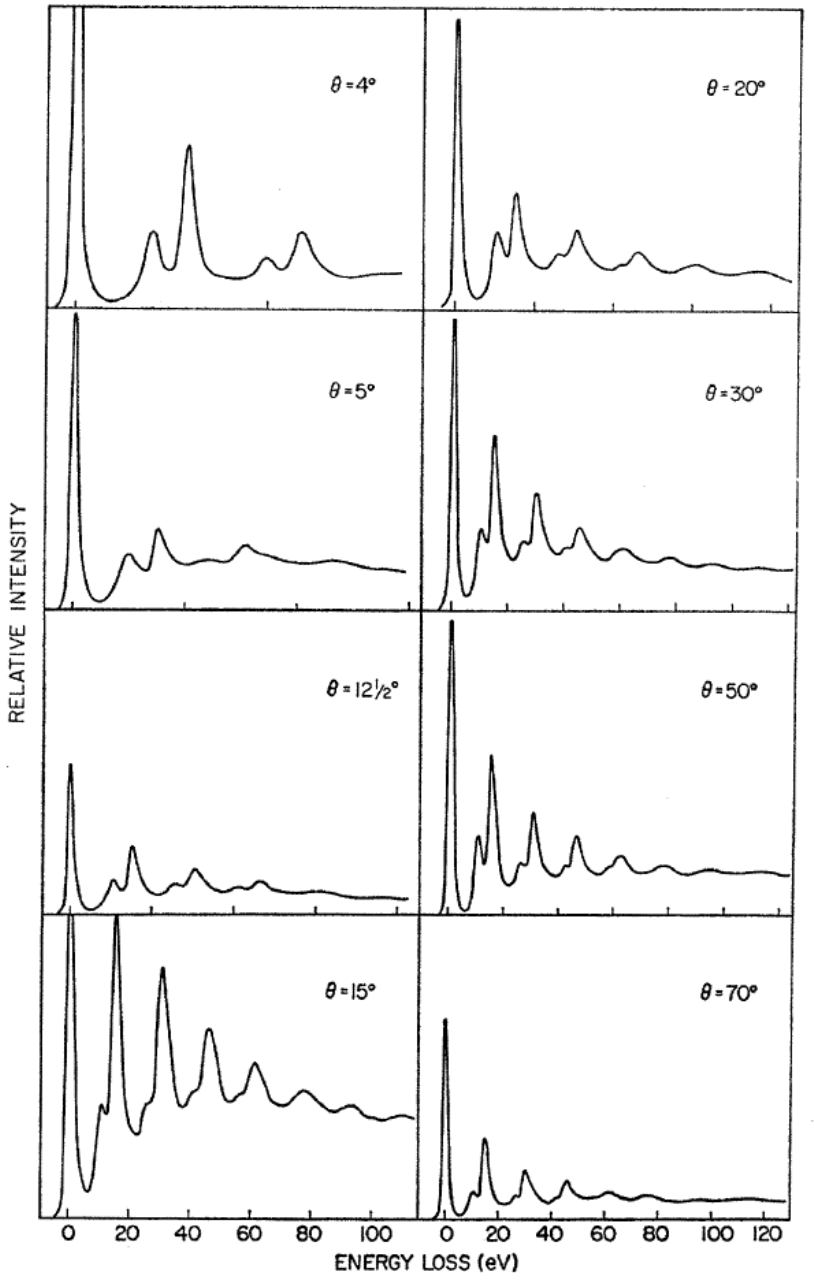

FIG. 5. Characteristic loss spectra recorded when Al was evaporated onto a frozen Al substrate for the scattering angles indicated. Note the different energy-loss scales.

Plasmon dispersion and electron-hole continuum

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Valence-electron excitations in the alkali metals

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To study the dynamical response of the valence-electron gas in nearly-free-electron metals, we carried out an electron-energy-loss investigation on Na, K, Rb, and Cs. On polycrystalline samples we measured the volume plasmon dispersion, which showed strong deviations not only from the random-phase approximation, but deviations as well from the predictions of the current theories for Fermi liquids, including short-range exchange and correlation. In addition, anomalous dispersion of the plasmon half-width was found. Both results may be traced back to exchange and correlation effects not properly treated by the current Fermi-liquid theories. Furthermore, we observed the excitation of intraband transitions in Na and Rb, the dispersion of which yields the effective band mass for unoccupied states. The results for Na are at variance with recently published enhancement of the band mass for the occupied states. To elucidate the influence of band structure, measurements were also performed on a single-crystalline Na film and we observed the so-called zone-boundary collective state in Na.

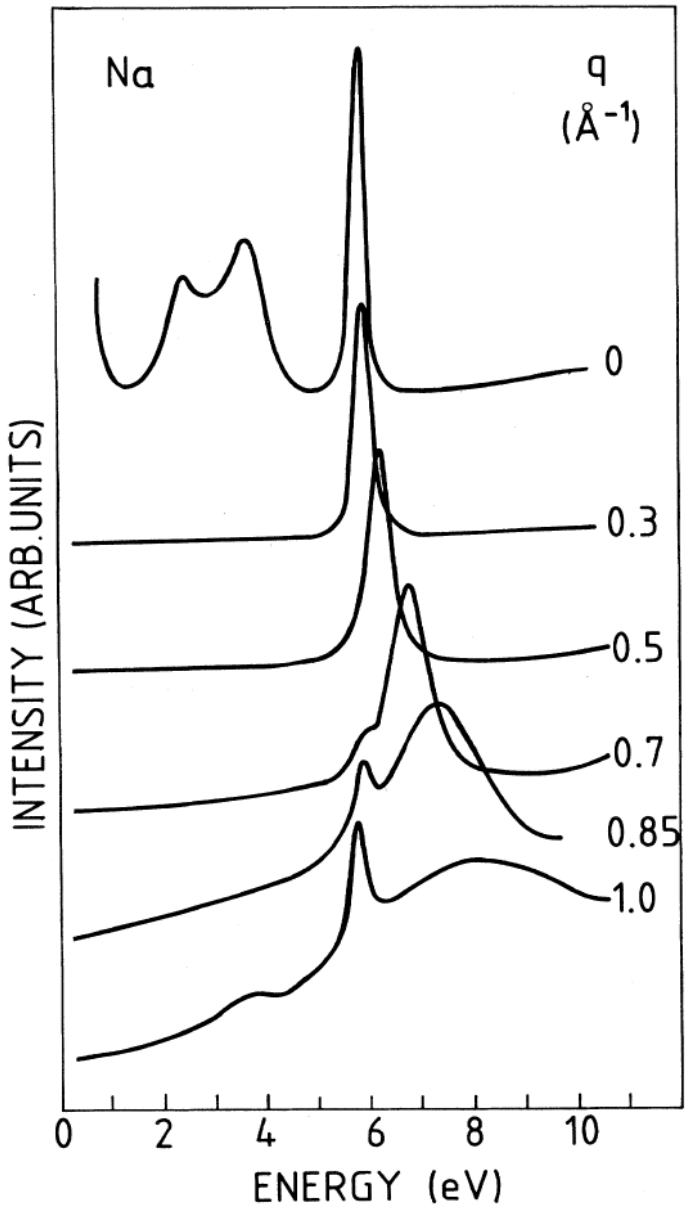
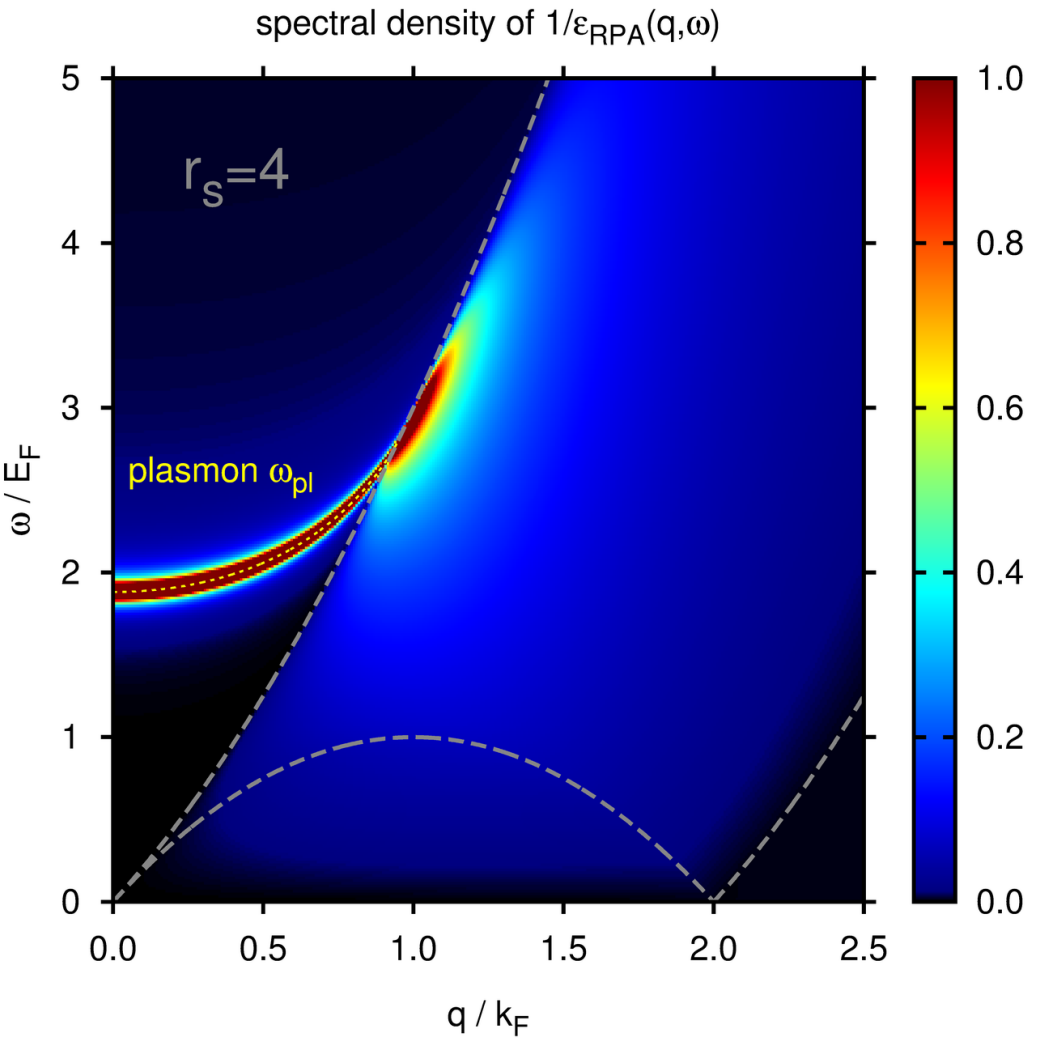


FIG. 1. Experimental energy-loss spectra of Na for different momentum transfers, demonstrating surface plasmons, the volume plasmon dispersion, and the onset of double scattering contribution at high q ($q > 0.7$ Å^{-1}).

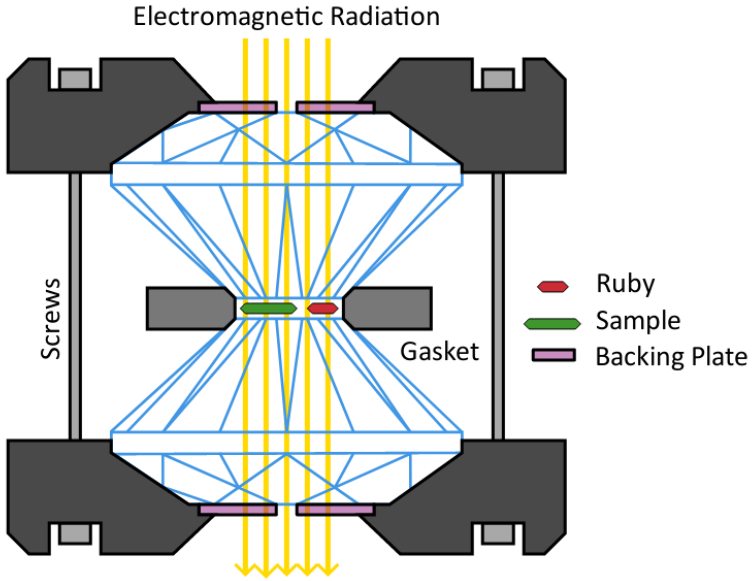


sodium

mass density	0.968 g cm^{-3}
molar density	22.99 g mol^{-1}

r_s=4.0 k_F=0.91 Å^{-1} E_F=3.1 eV

Inelastic X-ray scattering (IXS)



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Plasmons in Sodium under Pressure: Increasing Departure from Nearly Free-Electron Behavior

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We have measured plasmon energies in Na under high pressure up to 43 GPa using inelastic x-ray scattering (IXS). The momentum-resolved results show clear deviations, growing with increasing pressure, from the predictions for a nearly free-electron metal. Plasmon energy calculations based on first-principles electronic band structures and a quasiclassical plasmon model allow us to identify a pressure-induced increase in the electron-ion interaction and associated changes in the electronic band structure as the origin of these deviations, rather than effects of exchange and correlation. Additional IXS results obtained for K and Rb are addressed briefly.

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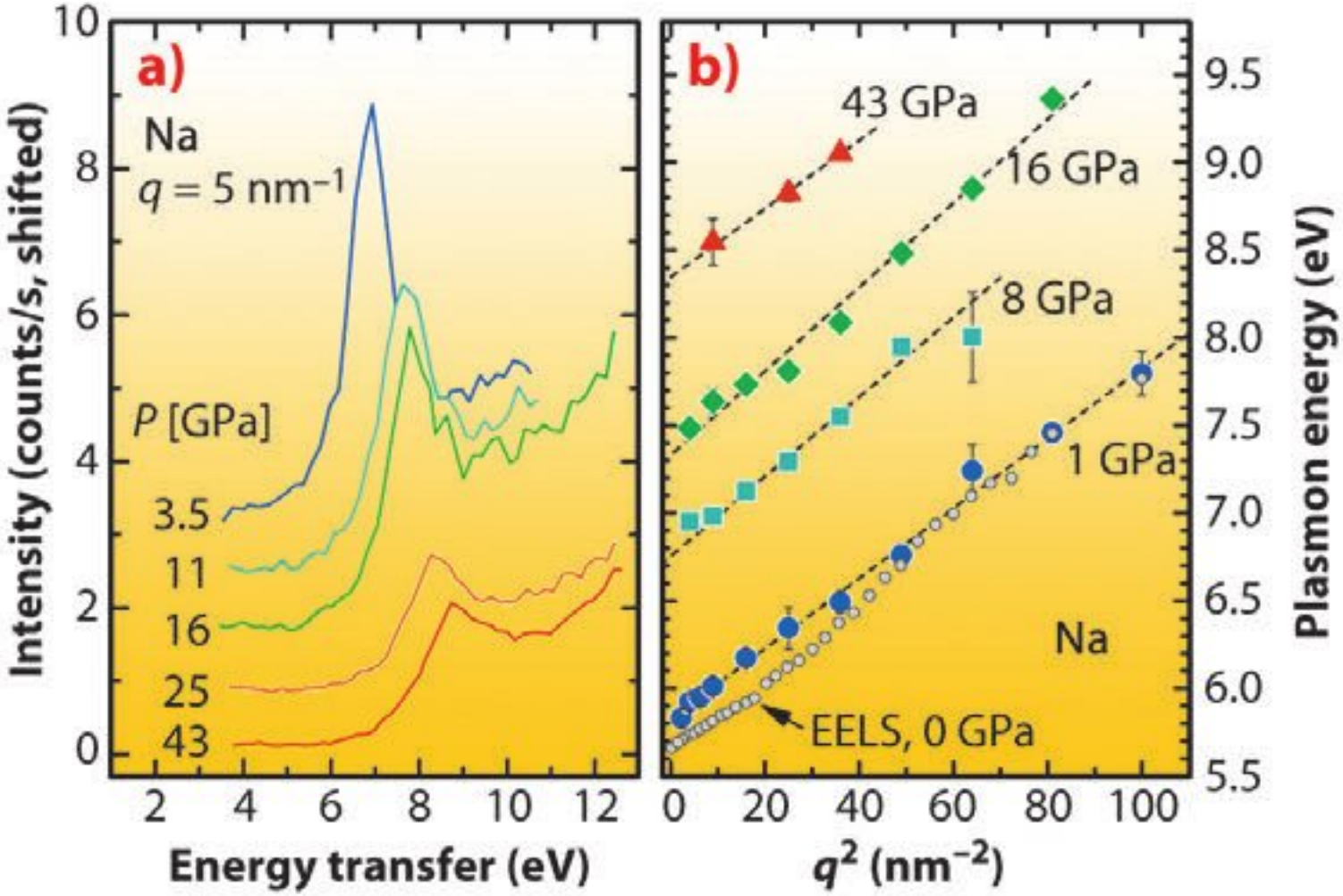

FIG. 1. IXS spectra of polycrystalline sodium pressurized in a diamond anvil cell. (a) Energy transfer spectra for a momentum transfer of $q = 5$ nm^{-1} and pressures of 3.5–43 GPa. (b) Energy transfer spectra of Na at 16 GPa and momentum transfers of 2–9 nm^{-1}. Vertical offsets are added for clarity.

FIG. 3. (a) Plasmon dispersions $E(q^2)$ of polycrystalline Na as a function of pressure. Ambient-pressure electron-energy-loss spectroscopy results by vom Felde *et al.* [10] are indicated by small open symbols. (b) Plasmon linewidth of Na versus pressure.

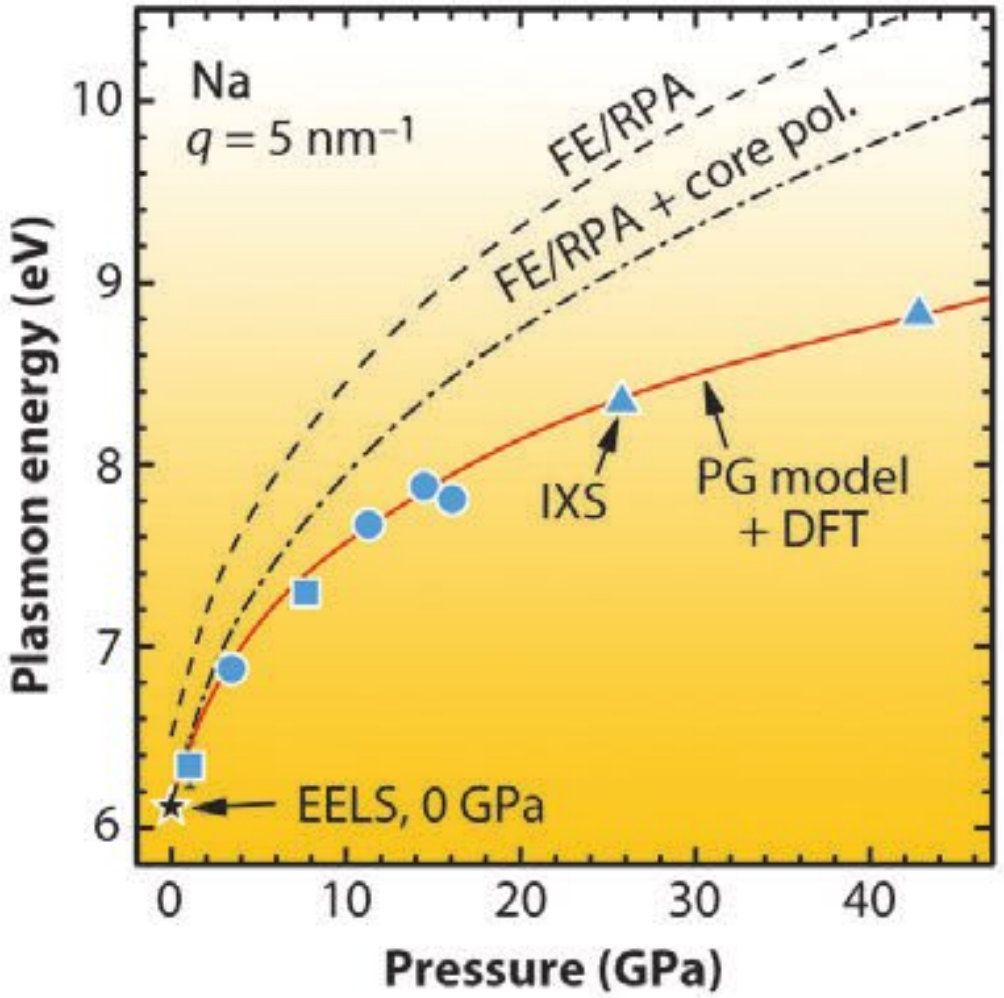

FIG. 4. Experimental pressure dependence of the directionally averaged plasmon energy in Na at $q = 5\ \mathrm{nm}^{-1}$ (large symbols) and results of the free-electron (FE) gas model, FE model with core polarization, and the PG model (solid line). The star indicates the ambient-pressure EELS result [10].